PAPER NO.609

FLOOD MANAGEMENT OF DEG NULLAH BY PART DIVERSION INTO BASANTER NULLAH

BY
Liaquat Rabbani
Dr. Muhammad Latif

FLOOD MANAGEMENT OF DEG NALLLAH BY PART DIVERSION INTO BASANTAR NALLAH

Liaquat Rabbani and Dr.Muhammad Latif

ABSTRACT

Economic growth in vast areas of district Sialkot, Narowal, Gujranwala and Sheikhupura has suffered serious set back due to hazardous floods in Deg Nallah. Thousands of acres of Paddy crop is damaged, industries on Sheikhupura Road are flooded, and Roads and other infrastructure are shattered making life miserable for lakhs of people almost every year. The problem can be solved through effective management of Deg Nallah floods. In this paper, the author has proposed management of Deg Nallah floods by diverting a part of flow in Basantar Nallah for disposal into River Ravi. The study covers hydrological aspects of estimating floods in Deg Nallah, designing of a diversion structure across Deg Nallah an physical verification of the structure at a physical model at Hydraulic Research Station, Nandipur. BY this diversion along with other works flood problem of Deg Nallah can be eliminated effectively.

A low crest weir structure was designed to divert 42% of Deg Nallah discharge into Basantar Nallah. Size and location of the structure was optimized through a number of tests at the model. Placement of the structure in the Nallah, crest level and widths of diversion and main weirs were reduced by 18% of the original length of the structure and cost.

INTRODUCTION

Deg Nallah originated from Indian held Kashmir, where it has two branches called Devak River and Basantar River which combine to form Deg Nallah before entertaining into Pakistan territory near Lehri check post about 14 km north-east of Zafarwal town (Fig.1). Here it takes southwesterly route and crosses Zafarwal-Chawinda road, Pasrur-Narowal road and railway line near Qila Soba Singh. Therefore, it crosses Marala-Ravi (M.R.) link canal and Bambanwala-Ravi-Bedian-Dialpur (BRBD) Canal and Muridke Distributary. Further down stream it crosses Pakistan Railways Lahore-Peshawar main line, G.T. Road, Motorway M-2, Lahore-Faisalabad section of Pakistan railways and Lahore-Sheikhupura road and terminates at Deg Diversion channel to Join River Ravi 18 km downstream of Shahdara town. Total area of flood plain is about 2,590 ha. Commanded area of some important distributaries and minors lie in the flood plain of the Deg Nallah. The estimated farmer population directly affected by Deg Nallah flood is about 0.5 million. However, due to disruption of railroad systems and other infrastructure, the effect of Deg Nallah floods are my much large population in the adjoining areas.

Deg Nallah in its initial reach in Pakistan is a straight braided channel with wide and shallow cross section and steep slope. Bankful capacity of the Nallah in this reach is small and over spills and spreads over large areas. Due to steeper cross land slop, the spilled water does not return back to the main stream and takes a more favourable route to river Ravi towards Narowal and Baddomalhi towns flooding a number of villages and vast tracts of cropped lands on the way. There are a number of structures on the Nallah, which act as bottlenecks and hamper free flow due to limited capacities or malfunctioning causing pounding and aggravating flood conditions.

The first major obstruction to Deg Nallah flow is the Super passage over M.R. Link canal. Safe capacity of this structure is 481 m^3/sec only whereas flood of the order of 3,398 m^3/sec is estimated to have entered Pakistan from across the border. Flood discharge higher than the super passage capacity gets stranded and inundates vast areas. After the M. R. Link, Deg Nallah crosses BRBD Canal. There is a super passage at this location which carries the Nallah over the canal. This structure is another serious obstruction to the flow. Due to insufficient discharge capacity and malfunctioning of these structures, flow is obstructed resulting in rise in water level and spillage. From BRBD Canal to G.T. Road there are a number of road bridges over Deg Nallah. Bays of these bridges have been blocked or choked by public enroachments. Industries along Deg Nallah banks extend up to Sheikhupura and beyond. Flooding of industries by Deg Nallah cause damage to machinery, raw material and finished goods.

In the past the Punjab Irrigation Department carried out some studies but no workable and economically viable solution to the problem could be found. Flood management of Deg Nallah is a pressing problem, which must be solved as soon as possible.

Deg Nallah floods have been of serious concern for the Irrigation Department Punjab since long. Studies have been and are being carried out at various levels for finding a socially acceptable and economically viable solution to the problem. Considering the importance of this problem it is proposed to manage the Deg Nallah flood by diverting part of it into another natural stream called Basantar Nallah for disposal into River Ravi near Narowal city.

FLOOD MANAGEMENT

Floods in natural streams have been occurring since centuries since centuries but went unnoticed because people lived on higher lands or at safe distances from river waters. Increase in population and need for extra land compelled the human to enroach upon lands, which are passage of water during floods. Intensity of population and other investment in the form of infrastructure, industrialization, private investment, irrigation extension in these is constantly on the increase and consequently losses due to floods increasing rapidly.

Punjab is the land of five major rivers and a number of tributary streams. Deg Nallah is a tributary or river Ravi that floods vast areas in the Province. Flood protection works for the Deg Nallah is becoming intensive and expensive and the government is allocating more and more funds into flood protection scheme. Need for effective management of Deg Nallah floods has become necessary for conservation of provincial resources.

FLOOD MANAGEMENT OPTIONS

There are three options of flood management:

1. Construction of check/storage dams in the upper catchment.
2. Restoring the natural route of flood water to their original condition
3. Diversion to other areas

Each one of the above methods is briefly discussed below:

1. Construction of check/storage dams in the upper catchment.

Floods can be effectively managed by constructing check/storage dams on major tributaries or rivers/streams in the upper catchment areas. These dams create barrier for water and provide time lag among various contributing branches to prevent synchronization of peaks in the main stream. Due to staggering effect high flood peaks are eliminated. This method of flood management controls erosion and provides additional water in the form of surface storage and also contributes to the ground water reservoir. This method is preferable over all others if site conditions permit.

Upper catchment of Deg Nallah is situated in Indian Held Kashmir, therefore, option of constructing check dams is not possible.

2. Restoring Channels to original condition

Restoring from the path of floodwater and clearing encroachments and all obstructions from the path of floodwater can eliminate damages due to floods. However, in most of the cases due to high density of construction and other installations in the flood areas this option of flood management becomes difficult to implement for social and economical reasons. Deg Nallah and its flood path is facing a situation where lot of residential, industrial, agricultural and infrastructural development has taken place. Restoration of the path to its original conditions in not possible. Therefore, this option of flood management of Deg Nallah is also not practicable.

3. Diversion to other areas

When conditions do not permit implementation of option 1 and 2 above diversion of part of flood the other areas provides an effective flood management option.

Deg Nallah is an ideal case of flood management through part diversion to other areas and is opted for implementation.

FLOOD MANAGEMENT OF DEG NALLAH THROUGH PART DIVERSION INTO BASANTAR NALLAH

Comprehensive management of flood problem of Deg Nallah is proposed through a number of diversions into other natural streams. The first part diversion is proposed into Basantar Nallah by constructing a diversion structure on Deg Nallah near village Deole of Tehsil Zafafwal and diverting part of flood into Basantar Nallah through a connecting channel 6.5 km long between Deg Nallah and Basantar Nallah. The approved scheme includes the construction of another diversion structure across Basantar Nallah to divert the excessive flow into Budhi Nallah through a link channel and channelization of Budhi Nallah which ultimately outfall in Ravi in Pakistan.

Second part diversion of Deg Nallah is proposed into Nikki Deg near Qila Soba Singh and the third into Sem Nallah near Muridke. But presentation in this paper is limited to the first part diversion into Basantar Nallah.

Flow diagram of Deg Nallah Flood Management is shown in Figure 2.

Basantar Nallah is another tributary of river Ravi. It has its catchment area adjacent to Deg Nallah on the left .Main stream of Basantar has a steeper slope and joins river Ravi seven km south of narowal city about 95 km upstream of Deg Nallah outfall into River Ravi. The diversion structure on Deg Nallah near village Deole is designed as a proportionate divide structure to divert the flood in the ratio of 45% and 58% into Basantar Nallah and Deg Nallah in the entire reach downstream will be eliminated.

For verification of the design and prototype performance, a physical scale model of the diversion structure was constructed at the HRS, Nandipur.

HYDROLOGY OF DEG NALLAH

Total catchment area of Deg Nallah and its tributaries is 1887 sq. miles.

Detailed hydrological evaluation was carried out for estimation of flood peak against which protection is to be provided. Upper catchment of Deg Nallah lies in Indian held Kashmir, therefore, no rainfall or discharge data of the upper catchment is available. In Pakistan there is no gauging facility on Deg Nallah until Qila Soba Singh 20km inside the border. Most of the flood discharge over spills before reaching Qila Soba Singh as such measurements at Qila Soba Singh does not represent actual discharge entering Pakistan. Rainfall records of upper catchment are not available, therefore, rainfall data of Sialkot city, being nearest, was used.

RAINFALL DATA

Meteorological observatory of the Pakistan Met. Department at Sialkot is the nearest to the upper catchment of Deg Nallah. Data of one-day maximum rainfall in a month in Sialkot for 46 years (1952-1997) was collected and given in Table 3.

FREQUENCY ANALYSIS

Frequency analysis was carried out to develop frequency curve on the Gumble distribution. Results of the frequency analysis and the frequency curve are shown in Figure 4. Twenty four (24) hours maximum rainfall at Sialkot for various return periods is observed from the frequency curve and is given in Table 4.

TABLE 4

Considering the arial distribution of rainfall pattern in the region of Deg Nallah Catchment, it is observed that upper catchment of Deg Nallah receives heavier rains than Sialkot. Therefore, the rainfall estimated for various return periods from the frequency analysis of Sialkot data was increased by 15% for upper catchment to work out 24-hour maximum rainfall for Deg Nallah upper catchment given in Table 4 in the last column.

DESIGN RETURN PERIOD

Selection of the design return period for a flood management scheme is a very important factor, which directly affects the cost of the scheme. This also is the indicator of level of protection, therefore, need to be fixed considering damages and other implications likely to be faced from flood inundation. Selection of higher design return period means higher discharges for design lesser probability of damages and higher cost of the scheme.

Keeping in view, social economical and other factors of the flood affected area of Deg Nallah 10 year has been taken as the design period for Deg Nallah flood management scheme. The diversion structure is designed to withstand 100-year flood without damages.

ESTIMATION OF DESIGN FLOOD

From the results of frequency analysis of the rainfall data of Sialkot 10 year return period 24 hour max. rainfall with an increase of 15%, for the upper catchment of Deg Nallah is 25.7 cm (10.12 inches).

This rainfall is considered for estimation of design flood from the curve number (CN) method using CN 86 for the upper catchment area. Estimated design floods for various return periods are given in table 5.

TABLE 5

HYDRAULIC DESIGN OF DIVERSION STRUCTURE

The flood diversion structure on Deg Nallah was designed as a proportionate divide structure to divert 793 m3/sec (28,000 cusec) discharge in Deg Nallah, into Basantar Nallah. Average Nallah bed level at the structure location is EL 281.64 m (924 ft). To allow for the continuity of flow in the Nallah downstream of the structure crest level of the weir across Deg Nallah was kept at EL. 281.64 m (924 ft.). Crest of weir across the diversion channel was places at EL 282.25 m (926 ft), to ensure diversion during higher discharges only.

According to Lacey, regime width of the control structure should be

2.67.SQRT(67,000)

The Nallah is shallow, wide (width 1676 m) and steep slope (slope 1/640) at the structure location. If 210.6 m wide weir was constructed it would cause severe constriction to flow creating problem due to back water upstream and deep scour downstream from flow concentration. Both the problems are not desirable. Backwater of heading up will cause submergence of villages on the Nallah banks. Expensive energy dissipation structure shall be required for controlling the downstream scour. To avoid these problems wide structure was designed which shall neither cause backwater nor flow concentration. To start with 1082 m wide structure was proposed for testing at the model. Width of structure and other dimensions/levels were adjusted and verified by the physical model.

MODEL STUDIES

Model study of a flood diversion scheme constitutes several activities starting with data collection to construction and operation of the morel.

Experimentation yields results, which are interpreted using latest "state-of-the-art" Model activities for the Deg Nallah diversion structure carried out at HRS, Nandipur, Nallah diversion structure was constructed at tray No. 5.

OBJECTIVES OF THE MODEL

The objective is to evolve and verify the design of the diversion structure on Deg Nallah, which would divide the flow of Deg Nallah in the ratio of 42% and 58% into Basantar Nallah and Deg Nallah respectively.

The author proposed original design of structure. Thorough investigation of the diversion structure site near village Deole made by the model experts in order to clearly perceive the existing natural conditions. The design was discussed in detail at the expert level by the author and the model experts. Mr. Bashir Sheikh, PRO IRI Lahore and Mr. Ghulam Qadir, SRO IRI Nandipur who prepared the model on supply of data and designs by the author. Plans of testing programme were finalized at the model after joint discussion between the author, IRI.

DATA REQUIREMENT FOR MODEL

Following data/site information were supplied to HRS Nandipur for model preparation.

1. Discharge in Deg Nallah against various return periods estimated from frequency analyses was as follows:

Sr. No	Return Period (Years)	Discharge m^3/sec. (Cusecs)	Remarks
1	10	1897 (67,000)	Design Flood
2	25	2577 (91,000)	-
3	50	3087 (109,000)	-
4	100	3597 (127,000)	-

1. Detailed contour plan of the structure location covering 4 km upstream and 2-km downstream reach of Nallah on 1:6000 scale and 66 cm (2 feet contour interval).
2. Nallah cross sections at 152.4 m intervals for 4 km u/s and 4.5 km d/s of the diversion structure axis.
3. Nallah bed materials from the structure site.
4. Detailed layout drawing of the diversion structure and its ancillary works.
5. Cross section and slope of the connecting diversion channel between Deg Nallah and Basantar Nallah.
6. Approximate water levels during various flood events inquired from local residents in different years.

SCALE SELECTION FOR MODEL

Tray No. 5 used for the model is 310 feet long and 100 feet wide (Figure 4). Leaving some space up-stream for approach flow and on down-stream for level control, 240 feet length of the tray was available for the 6km reach (figure 5) of Deg Nallah to be replicated at the model.

The horizontal scale of model was selected on the basis of available length as follows:

Length....

The vertical scale corresponding to the above horizontal scale is calculated by Manning, Lacey and I.R.I. as below:

Manning formula..

For the models where channels are modulated in sand the distortion is generally limited to about five, as slope of banks become steep and unstable for distortion larger than five and result in lesser scour.

The Froudian scale ratios between the model and prototype are given in Table 6.

Table 6 : scale ratios between model and prototype

Parameters		Dimension	Scale Ratio	Absolute Magnitude	
				Prototype	Model
Length and Width		L_r	1:75	100ft	1.333 ft
Depth		Y_r	.1:25	10	0.5 ft
Velocity		$Y_r^{1/2}$	1:5	10'/sec	2'/sec
Discharge		$L_r * Y_r^{3/2}$	1:9375	10,000 cusec	1.066 cusecs
Time		$L_r / Y_r^{1/2}$	1:15	1 minute	4 seconds
Area	Horiz.	L^2_r	1:5625	10,000 ft2	1.777 ft2
	Vert.	$L_r . Y_r$	1:1875	10,000 ft2	5.333 ft2

MODEL STUDY PROGRAMME

Model study programme at HRS Nandipur commenced in October 1998 and concluded in February 1999. A series of tests were conducted at the model starting with the base test for calibration of the model followed by the actual testing for finalizing the configuration of the diversion structure. Results of various tests are discussed here under:

EXPERIMENTATION

TEST 1 – CALIBRATION TEST

Simulation of water levels in the model to water levels at the prototype at different discharges is called calibrations. It is achieved by adjusting slope, friction and discharge on the model. Proper calibration is a pre-requisite for achieving the desired results from the testing programme.

The model was run for discharge varying from 5000 to 150,000 cusec. The observations of flow conditions and water levels were recorded. Water levels recorded at the gauges are given in Table 7. Flow conditions in the Nallah for the design discharge are shown in Figure 6.

Following observations were made:

1. The flow remained within the Nallah upto 25,000 cusec after which it spilled. Greater spill depth were noticed along left because natural ground levels are higher on the right.

2. Turbulent flow with higher order of velocity was obtained on the model similar to the prototype flow.

3. The model water levels matched with the prototype water levels as the Nallah bed roughness attained on the model simulated the roughness conditions at site.

4. Water levels observed at the model tally with the prototype water levels at different discharges as inquired/confirmed from local residents at site.

5. As the Nallah discharge decreases the flow returns to within the banks like before the spill.

That completed the calibration test after which the following tests were conducted under the main programme.

TEST 2 – WITH ORIGINAL PROPOSAL

This test was conducted with the original proposal of the structure.

The total length of weir structure was divided in to segment hereafter named as main weir and diversion weir separated by a divide wall.

Total length of structure between guide banks	= 1082 m (3550 ft).
Length of main weir	= 655.33 (2150 ft).
Crest level	= RL 281.64 m (924 ft).
Length of diversion weir	= 426.73 m (1400 ft).
Crest level	RL 282.25 m (926 ft).
Length of divide wall	= 243.84 m (800 ft).

Discharge downstream of the diversion weir was measured through a sharp crested weir placed at the end. Water levels downstream of main weir were controlled with the help of flap gates.

Water levels observed are given in Table 8, discharge distribution between main weir and diversion weir given in Table 9. Flow condition is represented in Figure 7.

The results of distribution of flow indicate that with the proposed configuration of structure the distribution of flow between the main weir and the diversion weir was not according to the desired proportion of 42% and 58% into diversion channel and Deg Nallah respectively. And some adjustments in the design and other parameters of the structure were necessary.

TEST 3 – IMPROVEMENT NO. 1 TO ORIGINAL PROPOSAL

For this test, total length of the diversion structure as well as the lengths and crest levels of main and diversion weirs was kept in test No.2. Right side of the Nallah upstream of structure was protected from spill by extending the right back upstream. The test was run for same set of fixed discharge as in test 2.

Water levels recorded are given in Table 10. Flow distribution in this test was measured for design discharge only and is given in table 11. Flow conditions at various design discharge is shown in Figure 8. Results of this test indicate only slight improvement in the results from that of test No. 2. Additional tests were conducted with further adjustments.

TEST 4 – IMPROVEMENT NO. 2

For this test crest level of both the main weir and diversion weir were brought to the same level RL 926 and their lengths changed to 2066 ft and 1484 ft respectively. Length of divide wall reduced to 225 ft from 800 ft.

Water levels at the model observed during the test are given in Table 12 and distribution of flow obtained is given in Table 13. Flow pattern is shown in figure 9.

Results of this test indicate significant improvement in the distribution pattern getting closer to the desired values but further improvement to the designs are needed.

TEST 5 – IMPROVEMENT NO. 3

For this test the design features of the structure were kept the same as in test 4. The model was laterally shifted to observe the effect of approach conditions on the flow distribution.

Observations of water level etc. were not considered necessary in this test.

TEST 6 – IMPROVEMENT NO. 4

In this test, the total clear waterway of the structure between guide banks reduced to 3000 ft with 1746 ft and 1254 ft for main weir and diversion weir respectively. Water levels recorded during this test are given in table 14. Flow patterns are shown in Figure 10.

TEST 6 – FINAL DESIGN

The final configuration of the structure which provided the desired distribution is as follows:

Total clear waterway of structure	= 914.41 m (3000ft)
Length of main weir	= 532.19 m (1746ft)
Length of diversion weir	= 382.22 m (1254ft)
Crest level (main and diversion weirs)	= 282.25 m (926ft)
Length of the horizontal part of the upstream divide wall	= 68.58 m (225ft)
Slope of upstream end of divide wall	= 1:10
Distance of divide wall from base line	= 198.12 m (650ft)

With this configuration the required distribution of floodwater was achieved. Observations of the test are given in Table 15 and table 16. Flow pattern is shown in Figure11.

DISCUSSION

Consolidated Table 16 shows comparison of the discharge distribution through the main weir and diversion weir for 1982 m^3/sec (70,000 cusec) which has been taken as 10 years return period design flood against the actual 1897.48 m^3/sec (67,000 cusec) for ease of model operation.

The distribution of this discharge is in the ratio 41.8% and 58.2% and is accepted.

Analysis of the results in Table 8 and other data from tests highlight the following points:

1. The flow conditions in all the tests with diversion structure in position were almost similar to the flow conditions noticed in test-1 carried out without the diversion structure. The proposed weir caused local afflux the effect of which did not travel much upstream due to steep slope (1/640).

2. The discharge did not pass evenly through the main weir in test-2.

3. With different crest levels RL-281.25 m (926 ft) for diversion weir, the latter drew only 12% of the discharge against the desired 42%.

4. Significant improvement in the distribution was achieved by reducing the length of divide wall and making a diving nose at the end. The other improvement, which contributed toward improving the distribution, was placement of the structure with respect to natural flow characteristics of Deg Nallah. This is because Deg Nallah is shallow, wide, has steep slope and is straight. Oblique approach flow conditions which cause non-modular flow conditions across the structure are not likely due to steep and bed slope. These conditions helped in reducing the total length of diversion structure.

CONCLUSIONS AND RECOMMENDATIONS

Comprehensive planning and model testing programme conducted on the structure demonstrated efficacy of design and ensured satisfactory performance of the structure after construction. Modifications incorporated at the model during testing for optimization of the structure were theoretically not possible. The diversion structure with overall length of 1082 m (3550 ft) was put to model testing to optimize its placement in the Nallah bed, crest level, lengths of weirs, length and shape of divide wall and guide banks. After a number of adjustments in the model the length of structure was optimized to 914.35 m (3000 ft) with a saving of 167.65 m (550 ft) in length, uniform crest level of 287.25 m (926 ft) and proportionate widths of diversion and main weirs of 382.33 m (1254 ft) and 532.19 m (1746 ft) respectively ad optimized length and shape of divide wall.

CONCLUSIONS

Following conclusions are drawn from the results of Physical Hydraulic model study:

- Width of flood diversion structures on wide, shallow, and steep seasonal streams should be fixed on the basis of actual stream width and depth of flow considerations and not on wetted perimeter and discharge given by the famous Lacy formula:

$$P = 2.67SQRT(Q)$$

- Where, P is a wetted perimeter unit can be taken equal to width for major streams having large width to depth ratio and Q is discharge in cusec.

- Conventional energy dissipation structures involving hydraulic jump formation can be avoided by keeping the crest level at or close to the natural bed.

- When continuity is provided to sediment movement across the structure the flow remains modular over the crest and the flow distribution remains consistent. Diversion channel designed for carrying the diverted flow should be capable of transporting sediment load of the floodwater.

- Placement of the structure across the cross section of the stream is sensitive for efficient and desired prototype performance. For straight streams with steep slope, additional training works for improving river approach conditions to the structure are not needed. Proper placement of the structure in the river section is important for trouble free service.

- For proportionate divide structures without gate control facilities, distribution of flow is best achieved by adjusting the width of openings and keeping crest level uniform. Alternative solution by controlling crest levels of weirs does not produce desired distribution as proved at the model.

RECOMMENDATIONS

The proportionate divide structure proposed across Deg Nallah after making a number of tests at the model was adjusted to fulfil the objectives of part diversion in the ratio of 42% and 58% into Basantar Nallah and Deg Nallah respectively.

Final configuration of the diversion structure would help in saving 167.64 m (550 feet) length of the weir from 1082 to 914.41 m (3550 to 3000 ft) which is 16.5 % saving in the project cost. Final dimensions of the structure are as follows:

Total width between guide banks	914.41 m (3,000 ft)
Crest level of weir	287.25 m (926 ft) uniform
Width of Deg Nallah weir	532.19 m (1,746 ft)
Width of Diversion channel weir	382.22 m (1,254 ft)
Length of guide banks	782.00 m (2,500 ft)

Length of divide wall	68.58 m (225 ft)
Slope of upstream nose of divide wall	1:10

REFERENCES

1. Calvin Victor, 1952. "Handbook of Applied Hydraulics," Megraw-Hill Book Company, New York.
2. Chang H. H. (1988) Fluvial Processes in River Engineer, John Wiley and Sons, New York.
3. Chen, C. L., An evaluation of the Mathematics and Physical Significance of the Soil Conservation Service Curve Number Procedure for estimating Runoff Volume Proc. Int. Symp. Water Resources Pub. Littleton Colo., PP 387-415, 1982.
4. Dedow, HRA "Simulation, Technique at the boundaried of hydraulic Models", Hydraulic Research Station 1977.
5. Ganathan, K. S. 1980. Mobile Bed Models, Hydraulics Research, Wallingford.
6. Hawkins, R.H., "Infiltration and Curve Numbers: Some pragmatic and Theoretic Relationships", Proc. Symp. Watershed Management 1980, Boise Idaho, Vol. II ASCE PP 925-937, 1980.
7. Helmet, Kobus, 1980. Hydraulic modeling. German Association for Water Resources and Land Improvement, Stuttoart.
8. Hjelmfelt, A.T., Empirical Investigation of Curve Number Technique, J. Hydrand, Eng., Vol. 106, PP 1471-1476, 1980.
9. Jansen, P.Dh., Bend ean. L. Van Den. 1979. Principles of river engineering. The non-tidal alluvial rier. Pitman publishing Ltd. London.
10. Khalid Mehmood, 1966. Technical paper on hydraulic Research in West Pakistan.
11. Mahmood K. Koelzer V.A and Schulz E.F "Floods and Drought" Proceedings of the Second International Symposium in Hydrology, September 11-13, 1972, Fort Collins, Colorado, U.S.A.
12. Maidment D.R. Handbook of Applied Hydrology, McGraw Hill Inc. New York, PP 9.1 – 9.42.
13. Miller, J.F. Rainfall Runoff Relationship for Small Basins Trans. Am. Geophys Union Vol. 38 No. 2 PP 216 – 218 April, 1957.

14. Nespak, "Flood management of Deg Nallah" PCI Proforma, January, 1999.

15. Novak, P. and Cabelka, J. 1981. Models in Hydraulic Engineering, Pitman, London.

16. Rabbani L. "Water Resources of Pakistan – Some Policy Guide lines" Engineering Review, Supplement 21 years of Leadership, August 16-31, 1996.

17. Rabbani L. "Living Amicably with Rivers New concepts in River Training" – Unpublished.

18. Rabbani L. "Taming of Notorious Lai Nallah Rawalpindi", Engineering Review 1-15 April, 1997.

19. Rabbani L. "Flood management of Deg Nallah by Part diversion into Basantar Nallah" 1999. MSc. Thesis CEWRE.

20. Rouse, Hunter. 1950. Engineering Hydraulics.

21. Saul A.J. (1992) "Floods and Flood Management" Proceedings 3rd International Conference on Floods and flood management 24-26 November, 1992. Florena, Italy.

22. Sharp, J. J. 1981. Hydraulic modeling, Butterworths, 1981, London.

23. Sheikh M. B, Chaudhry G. K Study for Flood Management of Deg Nallah – Deg Diversion Structure, IRR 1073 Lahore, February 1999.

24. Spreen, W.C. A determination of the effect of topography upon precipitation Trans. Am. Geophys Union Vol 28, PP 285-290, 1947.

25. Synder, F. F. Synthetic Unit Hydrogrpahs Trans. Am. Geophys Union Vol. 19, Pl. Pp 447-454, 1938.

26. U.S. Soil Conservation Service 1964-1973.

27. Varies. M. de. 1973. Application of physical and mathematical models for river problem. DHL Publication No. 12

28. Yalin, M. S. !998. Fundamentals of Hydraulic Physical Modelling. Deptt. Of Civil Engineering, Queen's University, Kingston, Canada.

29. Young, K.B. A comparative study of Methods for computation of discharge" U.S. Geographical Survey, Feb. 1948.

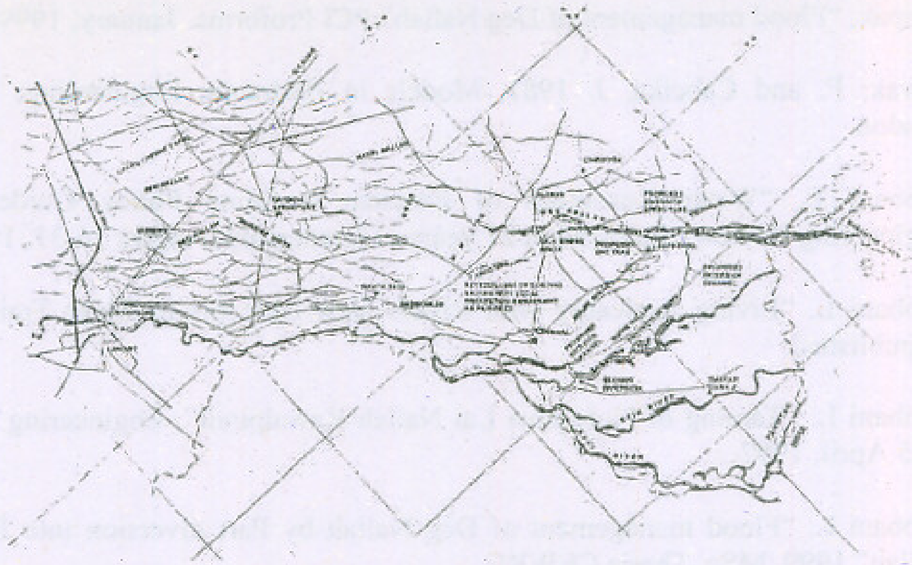

Figure 1 Deg Nallah

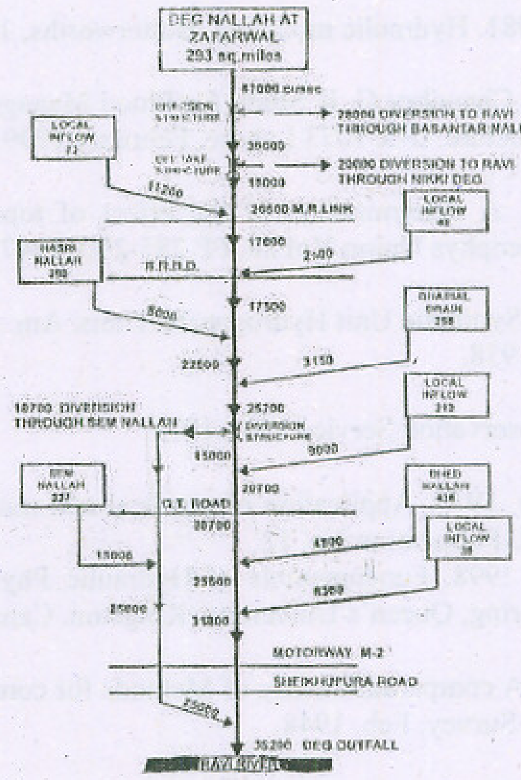

Figure 2 Schematic Diagram of Flood Diversion

Table 3 : One Day Maximum Rainfall in a month at Sialkot (Source: Met. Deptt.)

(Rainfall in (mm))

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Rainfall 1-Day Ann. Max
1952	23.4	14.7	16.5	2	3.8	33.3	39.4	82.7	0	0	0	1.5	82.7
1953	41.5	6.1	3.8	3.8	5.6	129	28.7	43.2	51.6	0	2.5	2.5	129
1954	16.8	38.1	18	3.8	9.1	3.6	18	23.9	90.7	17.5	7.4	6	90.7
1955	11.7	0	13.5	45.7	12.4	11.7	71.4	106.7	31	81.3	0	14.7	106.7
1956	31.3	2.5	19	9.1	4.6	59.4	63.2	36.1	8.6	47	0	6.4	63.2
1957	31.5	12.7	24.3	38.6	7.6	5.8	66.5	234.2	4.3	18.6	66.2	14.2	234.2
1958	0	1.8	10.7	6.8	0	10.7	98.3	49.3	65.3	3.3	6.3	58.6	98.3
1959	24.9	19	17	.0	8.6	0	181.6	66	101.9	35.4	51.8	0	181.6
1960	12.2	0	18	8.1	12.7	20.3	118.6	23.1	17.3	6.9	0	30	118.6
1961	0	0	0	7.1	0	32.8	257	37.1	65.8	8.1	18.3	51.5	257
1962	3	10.7	16.8	10.7	0	47	64.8	63.8	125.5	11.7	6.3	17.3	125.5
1963	0	0	35.8	19	16.3	28.4	54.6	55.9	16.8	7.9	31.8	31.5	55.9
1964	27.9	0	2.5	13.5	21.6	7.6	198.6	75.9	81.3	0	0	13.2	198.6
1965	51.3	20.3	27.9	31	15.7	0	12.7	33	0	3.6	4.3	0	51.3
1966	0	47	5.8	8.8	17.3	50	41.5	67.3	209	0	0	17.3	209
1967	0	23.1	52.1	36.1	0	7.6	0	56.4	0	6.3	4.1	61.2	61.2
1968	37.1	30.5	15.2	4.1	0	0	111.8	43.2	0	7.6	5.1	17.3	111.8
1969	19	0	10.4	0	0	0	107.2	50.8	177.8	39.4	0	0	177.8
1970	0	0	0	0	0	0	37.6	131.8	62.7	18.3	0	2.5	131.8
1971	0.3	74.4	15.2	13.5	14	92.5	73.9	116.3	22.4	7.9	2	3.7	116.3
1972	26.7	22.4	12.2	18.5	3	45.7	61	63.8	39.4	11.4	4.1	16.5	63.8
1973	11.9	9.7	8.8	2.3	23.6	81.3	121.9	247.6	43.7	40.6	0	33.5	247.6
1974	8.4	4.3	5.6	6.6	13	50.1	59.5	76.8	21.6	1.5	0	13.3	76.8
1975	6.6	33.7	42.9	4.1	10.2	76.9	182.6	66.3	71.3	0	0	0	182.6
1976	32.8	18.2	14.6	9.4	29	34.6	43.5	339.7	102.6	6.9	0	0	339.7
1977	68.9	0	2.3	18.6	27.7	68.8	95.7	37.1	21.6	10.7	4.6	1.5	95.7
1978	6.6	7.6	34.2	33.7	0.4	31	74.5	143	31	0	1.8	0	143
1979	8.7	17.7	18.6	8.9	10.2	22.1	44.2	46.5	34.4	5.8	15.9	4.8	46.5
1980	14.4	49.2	5.6	7.4	0	99.1	67.4	48.6	11.9	3.3	33.8	3.6	99.1
1981	33.5	29	30.2	2.8	16.3	18.1	117.3	18.1	11.7	0	5.4	0	117.3
1982	19.7	12.9	37.6	22.3	48.4	7.3	42.2	43.8	6.5	15.6	34.3	31.5	48.4
1983	27.1	22.1	53.6	65.7	61.1	16.5	97.3	63.4	62.9	14.6	0	0	97.3
1984	0	20.4	46.9	3.5	3.4	38.5	133.9	46.1	29.1	3.7	9.3	14.6	133.9
1985	5.3	2.2	2.3	15.7	11.3	41.6	92.5	74.6	81.9	37.3	13	37.7	92.5
1986	4.3	15	14.9	12.7	7.7	40.1	49.5	125.4	40.1	4.4	18.7	23.6	125.4
1987	5.5	21	8.2	17	18.7	4.4	46.5	84.1	25.8	15.8	0	0	84.1
1988	27.5	12.6	55.2	19	0.9	63	107.4	103.5	98.7	1	0	27.2	107.4
1989	22.3	14.3	12	14.3	12	18	273.7	47.6	37	1.5	2.3	20.5	273.7
1990	9.3	52.2	20.4	11	8.1	7.7	62	115.8	79	10.1		70.4	115.8
1991	0.9	15.8	12.5	44.8	3.7	26.7	68.6	43.8	23	4.7	5.8	18.1	68.6
1992	47.7	24.7	42.5	15.4	16.8	24.6	46.3	193.1	71.2	20.3	11.4	3	193.1
1993	5.9	21.1	21.9	23.9	10	18	69	42.4	38.8	0		0	69
1994	37.1	17.3	4.8	9.3	15.1	33.8	69.5	95.6	18.2	26.4	0	22.3	95.6
1995	12.1	30.3	21.7	5.2	1	30.8	160.8	82	19.3	10	1.8	1	160.8
1996	27.7	61.4	12.3	1.2	7.2	54	132.2	198.4	27.9	45.7	0	0.5	198.4
Max.	68.9	74.4	55.2	65.7	61.1	129	273.7	339.7	177.8	81.8	51.8	70.4	339.7
Min	0	0	2.3	0	0	0	12.7	18.1	0	0	0	0	51.3

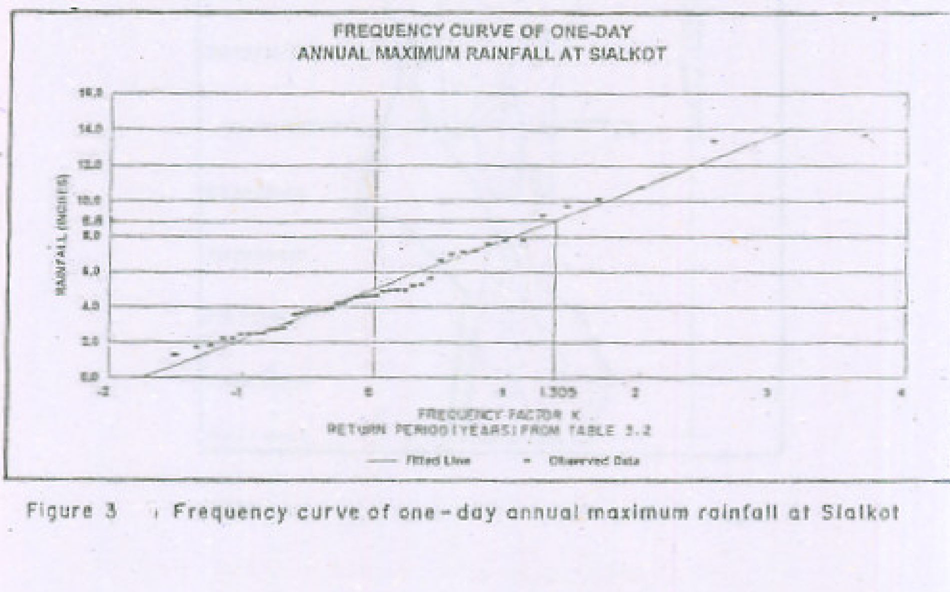

Figure 3 : Frequency curve of one-day annual maximum rainfall at Sialkot

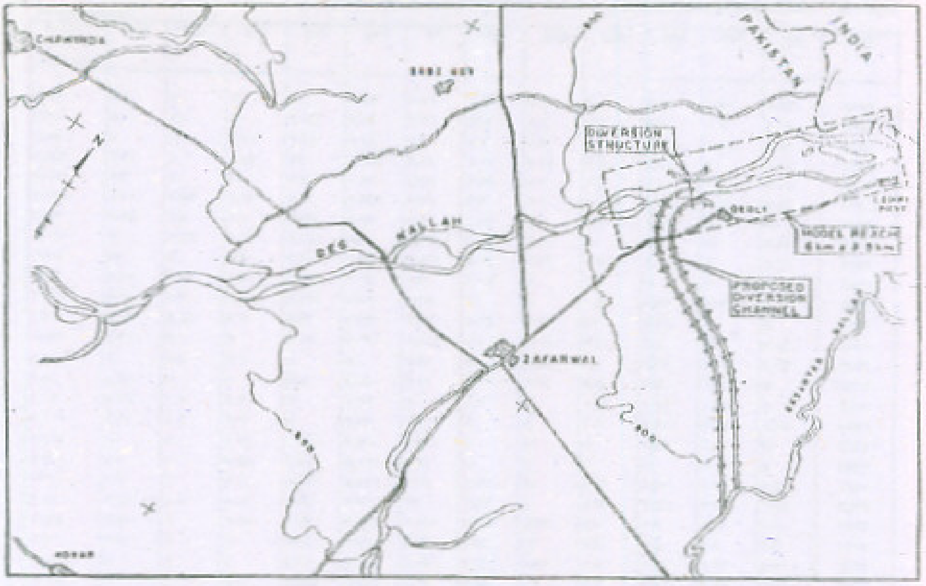

Figure 4 Deg Nallah Model Reach

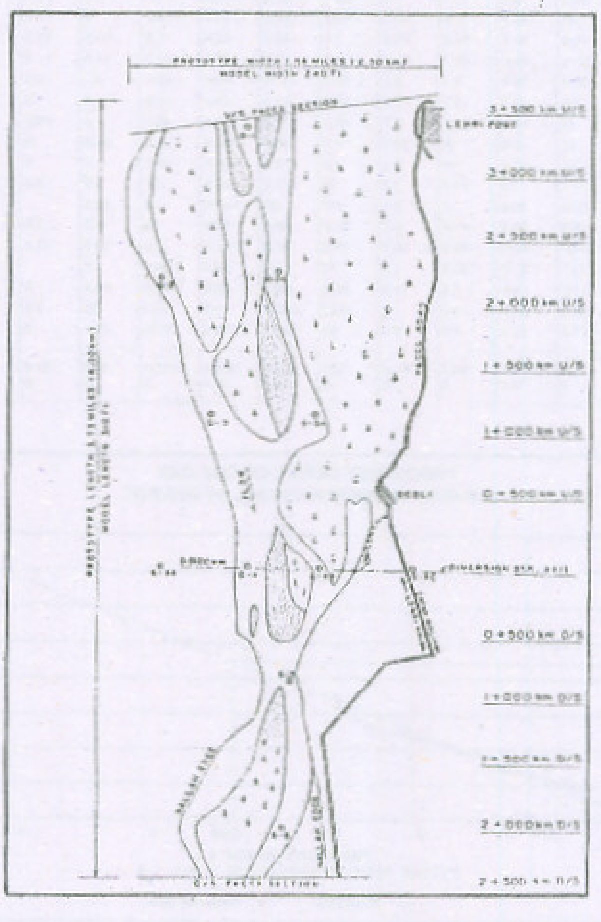

Figure 5 Deg Nallah Model Gauges Location

Table 7: Test No. 1 – Water levels at different discharges

Discharge in Nallah (Cusec)	Water Levels											
	G–1	G-1A	G–2	G–2A	G–3	G–3A	G–4	G–4A	G–4B	G–4C	G–5	G–6
5,000	945.5	945.5	937.0	939.0	930.1	933.5	924.5	–	–	–	919.2	914.0
10,000	946.3	945.0	937.5	939.5	930.7	934.0	925.5	–	–	–	920.5	915.0
20,000	946.5	946.5	938.0	941.0	932.0	934.5	926.5	–	–	–	921.7	916.0
30,000	947.0	947.0	938.5	942.0	932.5	934.8	927.5	–	925.0	–	922.5	916.6
50,000	948.0	948.0	939.5	942.5	933.7	935.0	928.8	–	926.0	–	924.0	917.7
70,000 *	948.5	948.5	940.0	943.0	935.0	936.0	929.8	926.0	926.7	–	924.8	918.5
100,000	949.0	949.0	941.3	944.0	935.5	936.3	930.8	927.0	927.5	925.5	925.0	919.5
150,000	950.0	950.0	943.5	945.0	937.0	937.0	931.5	929.0	929.5	927.0	926.0	921.0

Location of guages shown in Fig 6. Levels are in feet Above Mean Sea Level (AMSL)

* Design discharge

Note: Results are in FPS units because HRD Nandipur works in this system

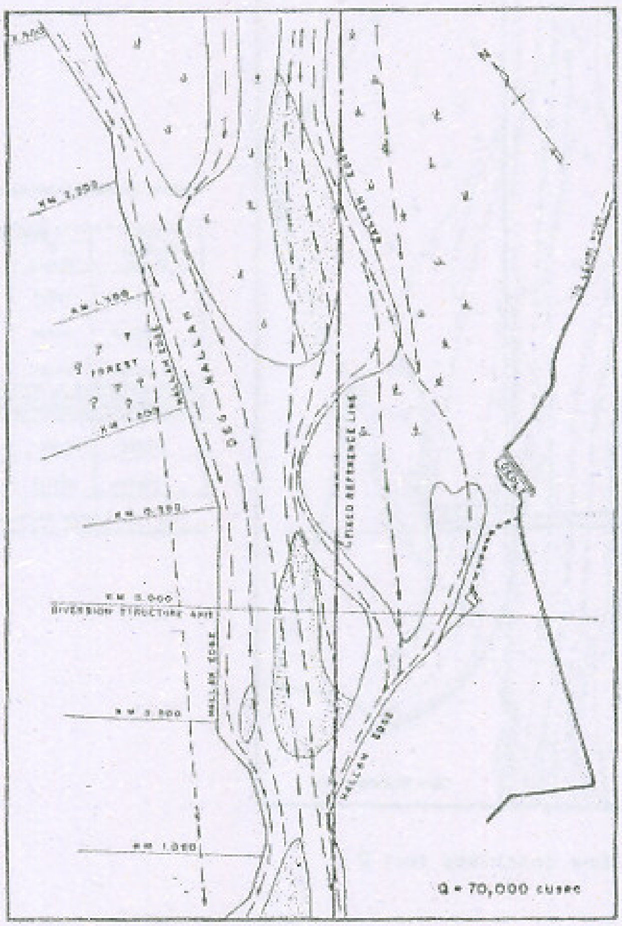

Figure 6 Flow conditions test I calibration test

Table 8: Test No. 2 – Water levels at different discharges

Discharge in Nallah (Cusec)	Water Levels													
							Deg Nallah		R. Bund	Diversion Channel		L. Bund		
	G–I	G/A	G–2	G–2A	G–3	G–3A	U/S G–4	D/S	U/S G–4A	U/S G–4B	D/S IV–A	U/S G–4C	G–5	G–6
5,000	945.6	945.5	936.8	938.6	930.0	933.8	925.5	924.7	–	925.9	–	–	920	915.2
10,000	946.2	946.0	937.3	939.5	930.7	934.0	927.4	925.5	–	*926.8	923.0	–	921.0	915.8
20,000	946.8	946.7	938.0	940.8	932.3	934.7	928.1	926.3	–	927.0	924.5	–	922.0	916.2
30,000	947.1	947.1	938.3	420.0	932.7	933.0	928.8	927.1	–	927.4	925.0	–	923.0	917.1
50,000	948.0	947.8	939.3	942.3	933.7	935.2	929.5	928.4	–	928.0	925.5	932.0	924.0	917.5
70,000*	948.5	948.5	939.9	942.6	934.7	935.8	930.0	929.4	932	928.0	926.0	929.5	924.8	918.7
100,000	949.0	949.0	941.5	944.0	935.2	938.0	931.0	930.3	935.5	929.0	927.2	934.5	925.2	919.5
150,000	949.8	949.7	943.2	944.5	937.6	937.5	932.0	931.2	937.5	931.2	931.0	935.0	928.0	920.3

Location of gauges shown in Figure 6.
* Design discharge
Note: Results are in FPS units because HRS Nandipur works in this system

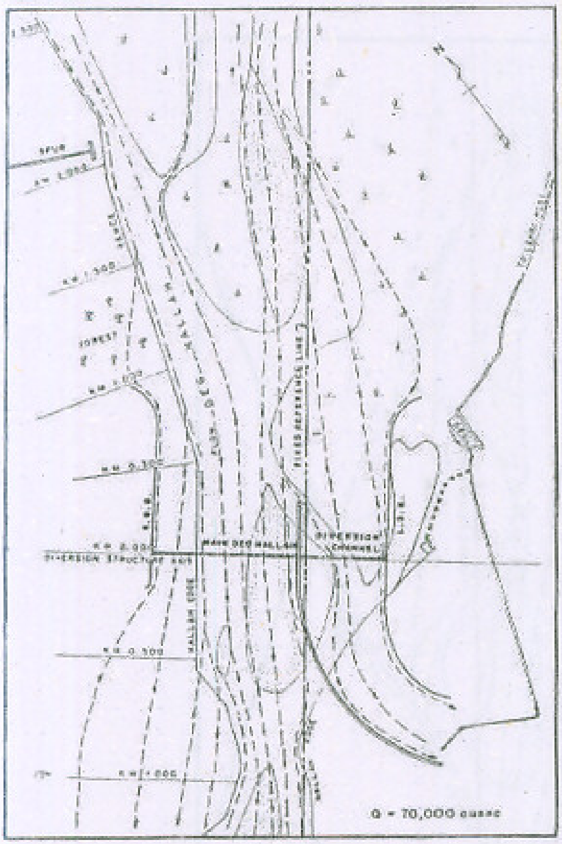

Figure 7 Flow conditions test 2

Table 9: Test No. 2 – Discharge distribution at different discharges

Total Discharge (Cusec)	Main Channel		Diversion Channel	
	Q (Cusec)	% Age	Q (Cusec)	% Age
20,000	18617	93.00	1383	6.91
30,000	26634	88.8	3366	11.2
50,000	44287	88.6	5713	11.4
70,000*	61615	88.0	8385	12.0
100,000	87812	87.8	12188	12.2
150,000	125730	83.8	24270	16.2

* Design discharge
Note: Results are in FPS units because HRS Nandipur works in this system

Table 10: Test No. 3 – Water levels at different discharges

Discharge in Nallah (Cusec)	Water Levels													
							Main Nallah		R. Bund	Diversion Channel		L. Bund		
	G–I	GIA	G–2	G–2A	G–3	G–3A	U/S G–4	D/S	U/S G–4B	U/S G–4A	D/S	U/S G–4C	G–5	G–6
5,000	945.5	945.5	936.8	938.6	930.1	931.8	926.7	924.7	–	926.0	922.7	–	20	915.3
10,000	946.2	946.0	937.2	939.4	930.7	934.0	927.7	925.5	–	927.0	923.2	–	921.0	915.8
20,000	946.8	946.5	937.0	940.8	932.5	934.5	928.2	926.2	–	927.3	924.5	–	922.0	916.0
30,000	947.1	946.6	938.2	941.8	932.8	934.9	929.0	927.0	–	927.8	925.0	–	923.0	917.0
50,000	948.0	[illegible]	939.5	942.2	933.8	935.4	929.7	928.2	–	928.0	925.7	932.0	924.0	917.2
70,000 *	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	930.2	[illegible]	931.5	[illegible]	[illegible]	930.3	[illegible]	918.5
100,000	[illegible]	[illegible]	941.5	944.0	935.3	936.0	931.2	930.2	934.8	929.2	927.3	934.5	925.0	[illegible]
150,000	949.7	949.5	943.2	944.5	938.9	935.8	932.0	931.0	937.5	931.2	930.8	938.0	925.9	920.2

Location of gauges shown in Figure 8.
* Design discharges
Note: Results are in FPS units because HRS Nandipur works in this system.

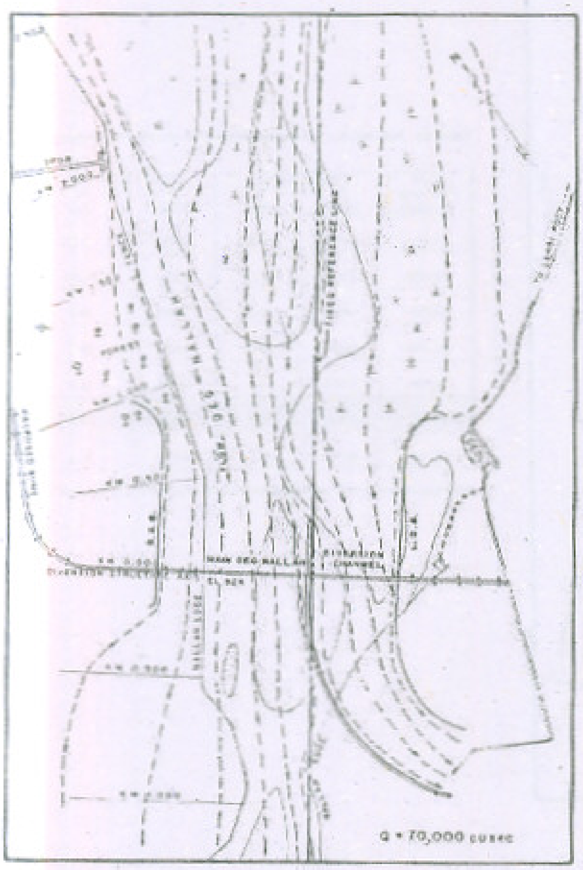

Figure 8 Flow conditions test 3

Table 11: Test No. 3 – Discharge distribution

Total Discharge in Cusec	Main Channel		Diversion Channel	
	Q Cusec	% Age	Q Cusec	% Age
70,000*	[illegible]	[illegible]	[illegible]	[illegible]

* Design discharge

Note: Results are in FPS units because HRS Nandipur works in this system

Table 12: Test No. 4 – Water levels at different discharges

Discharge in Cusec	Water Levels													
							Main Channel		R. Bund	Diversion Channel		L. Bund		
	G–I	G/A	G–2	G–2A	G–3	G–3A	U/S G–4	D/S	U/S G–4A	U/S G–4B	D/S	U/S G–4C	G–5	G–6
5,000	945.5	945.3	936.8	939.0	930.8	933.1	927.3	924.2	–	925.9	925.0	–	919.2	914.0
10,000	946.3	946.0	937.3	939.2	930.5	933.7	926.0	925.0	–	927.1	925.5	–	919.6	914.5
20,000	946.7	946.7	938.0	940.7	932.3	934.5	928.2	925.9	–	927.8	926.0	–	921.0	915.3
30,000	947.0	947.6	938.3	941.6	932.4	934.8	929.0	926.8	–	928.1	926.5	–	921.6	916.4
50,000	948.0	947.7	939.3	942.2	933.1	935.1	930.0	927.9	–	929.0	927.0	932.0	923.2	916.9
70,000 *	948.1	948.1	939.8	942.8	934.4	935.5	930.5	928.5	933	929.7	928.0	933.5	924.4	917.9
100,000	948.7	948.7	941.3	944.0	935.0	936.0	931.0	929.5	933.5	930.5	929.0	934.5	925.6	918.5

Location of gauges shown in Figure 8
* Design discharge
Note: Results are in FPS units because HRS Nandipur works in this system.

Figure 9 Flow conditions test 4

Table 13: Test No. 4 – Discharge distribution at different discharges

Total Discharge in Cusec	Main Channel		Diversion Channel	
	Q Cusec	% Age	Q Cusec	% Age
5,000	4375	87.5	625	12.5
10,000	7977	79.77	2023	20.23
20,000	14760	73.8	5240	26.2
30,000	21094	70.3	8906	29.7
50,000	36506	73.0	13494	27.0
70,000 *	[illegible]	76.8	16425	23.2
100,000	69727	69.7	30273	30.3

Note: Results are in FPS units because HRS Nandipur works in this system.

Table 14: Test No. 6 — Water levels at different discharges

Discharge in Cusec	Water Levels													
							Main Nallah		R. Bund	Diversion Channel		L. Bund		
	G-1	GIA	G-2	G-2A	G-3	G-3A	U/S G-4	D/S	U/S G-4A	U/S G-4B	D/S	U/S G-4C	G-5	G-6
5,000	945.6	945.5	936.8	939.0	930.0	933.7	927.2	924.0	–	927.0	925.0	–	918.9	914.3
10,000	946.3	946.6	937.3	939.2	930.5	933.8	928.0	924.8	–	927.2	925.3	–	919.0	914.7
20,000	946.7	946.7	938.0	940.6	932.3	934.7	928.4	925.1	–	928.0	926.0	–	920.8	915.2
30,000	947.0	947.0	938.3	941.7	932.5	934.5	929.0	925.9	–	928.5	926.5	–	921.6	916.3
50,000	947.8	947.3	939.2	942.2	933.7	935.0	930.0	926.7	–	929.2	927.8	931.8	923.2	916.8
70,000 *	948.3	948.0	939.0	942.5	933.0	935.2	931.0	928.0	–	929.8	927.5	933.0	924.2	917.4
100,000	947.8	949.0	940.5	943.0	934.0	935.5	931.5	928.7	933.0	930.7	928.6	924.0	925.3	918.3

Location of gauges shown in Figure 6

* Design discharge

Note: Results are in FPS units because HRS Nandipur works in this system.

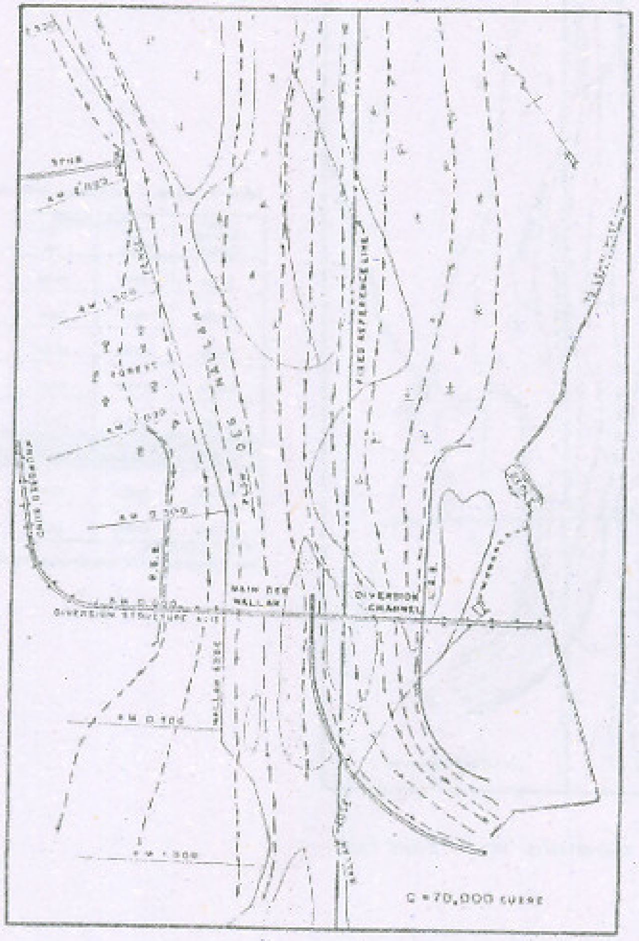

Figure 10 Flow conditions test 6

Table 15: Test No. 7 – Water levels at different discharges

Discharge in Cusec	Water Levels																	
							Main Nallah		R. Bund	Diversion Channel		L. Bund			Left Spur		Right Spur	
	G–1	GIA	G–2	G–2A	G–3	G–3A	U/S G–4	D/S	U/S G–4A	U/S G–4B	D/S	U/S G–4C	G–5	G–6	U/S	D/S	U/S	D/S
5,000	945.5	945.5	935.8	930.0	930.0	933.7	927.2	924.0	–	927.0	925.0	–	916.8	913.5	–	–	–	–
10,000	946	946.0	937.4	939.3	930.5	933.8	928.0	924.8	–	927.2	925.5	–	919.5	914.4	–	–	–	–
20,000	946	946.7	936.0	940.8	932.5	934.7	925.5	925.7	–	928.0	925.8	–	920.8	915.3	–	–	–	–
30,000	947.0	947.0	938.2	941.8	932.5	934.7	929.2	926.2	–	928.7	926.8	–	921.5	916.2	–	–	–	–
50,000	948.0	947.8	939.3	942.3	933.5	935.8	930.0	927.4	–	929.4	927.2	931.8	923.0	916.7	936.3	934.0	–	–
70,000*	[illegible]	948.1	[illegible]	[illegible]	[illegible]	935.8	931.0	928.3	931.8	930.0	928.5	933.5	924.0	917.3	937.2	935.2	–	–
100,000	948.8	949.0	941.5	944.0	935.3	936.8	931.5	929.2	933.5	931.0	929.0	934.2	924.7	918.1	938.0	934.8	937.0	933.5
150,000	949.8	949.8	943.2	944.8	936.8	936.8	932.5	930.4	935.5	932.0	930.0	935.0	925.5	920.2	939.0	935.5	938.0	934.5

Location of gauges shown in Figure 8

* Design discharge

Note: Results are in FPS units because HRS Nandipur works in this system

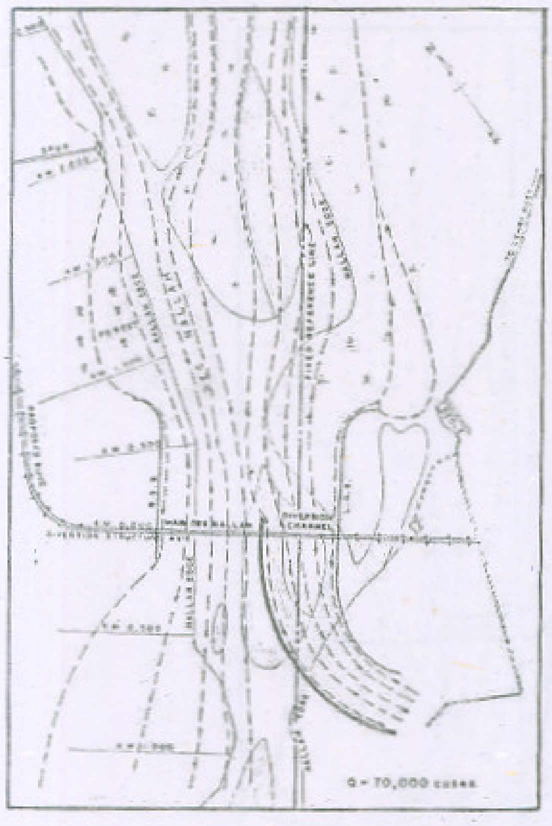

Figure II Flow conditions test 7 Final test

Table 16: Test No. 7 – Discharge distribution at different discharge

Total Discharge (Cusec)	Main Channel		Diversion Channel	
	Q Cusec	% Age	Q Cusec	% Age
5,000	3434	68.68	1566	31.32
10,000	6951	69.5	3049	30.5
20,000	13330	66.66	[illegible]	33.34
30,000	18725	62.4	11275	37.6
50,000	31505	63	18495	37
70,000*	42229	60.3	27771	39.7
100,000	58910	58.9	41090	41.1
150,000	85800	57.2	64200	42.8

* Design discharge

Note: Results are in FPS units because HRS Nandipur works on this system

Photograph: MODEL IN OPERATION - FLOW DISTRIBUTION AT Q = 70,000 CUSEC