OBSERVATIONS ON MISSA COMPARATIVE WATERSHEDS STUDY

Mohammad Hanif *

Summary. *To study the effectiveness of erosion control practices in the catchment of Kanshi river, two watersheds, Missa Experimental and Missa Control,* 81 *hectares each, and more or less identical in morphometric characteristics, were selected about* 55 *kilometers SE of Islamabad. Missa experimental had* 8098 *trees of various species,* 29 *check dams and* 7 *spillways, Missa control,* 3218 *trees and* 3 *spillways.*

During the period of study (January 1973 *to December* 1978) 4828 *mm rainfall was received in* 348 *rainy days. Of this,* 3536 *mm* (73%) *occurred in* 143 *rainstorms and was effective to produce runoff. Runoff and sediment release from experimental and control areas were:*

	Experimental	*Control*
Runoff as % of effective precipitation	20.7	26.7
Sediment release (tonnes)	10401	14716
(cubic metres)	5541	7792

The capacity of the experimental watershed to reduce runoff and sediment decreased from 1973 *to* 1977 *due probably to the siltation of cheek dams and the destruction of vegetation. It started rising in* 1978 *due probably to repairs to spillways, and better protection from grazing.*

Introduction. This experiment was started to assess the effect of tree planting, construction of check-dams and spillways, and reduction in grazing intensity on surface runoff and sediment yield. In March 1969 two watersheds were selected in the Kanshi river basin by Anwar Masrur, the then Watershed Management Officer of the Institute, and R.C. Beamish, U.N. consultant in Hydrology. An instrumentation plan was prepared by Beamish in April 1969 and the execution of the project was undertaken in collaboration with the Watershed Management Circle of WAPDA, Rawalpindi the latter contributing funds and constructing gauging flumes, the Forest Institute providing the equipment and personnel for recording climatological data and watershed variables. The construction of flumes and installation of instruments was completed by September 1970.

Watershed characteristics. The study area is 55 km SE of Islamabad (elevation 460 m). Both watersheds are adjacent and parallel to each other. The treated watershed, Missa Experimental, is along the G.T. road while the untreated watershed, Missa Control,

*The author is Research Officer in Watershed Management Branch Pakistan Forest Institute, Peshawar.

is about half a km from this road. Both areas are about 81 hectares each, direction of flow is similar and differences caused by solar insulation on the slopes and effect of prevailing winds are negligible.

Both watersheds are underlain by the same series of beds, Missa series and Rajar series, comprised of loess of silty-loam texture. Missa series with a slope of 0 to 3% and subject to slight erosion are mostly under agriculture. Rajar series have a slope of 9-16% and are cut up by severely eroding ravines (5). Land capability classes in both watersheds are III to VI. Poor cemented sand stones, mud stones and silt stones occur in both areas. General physiography of each is given in Fig 1.

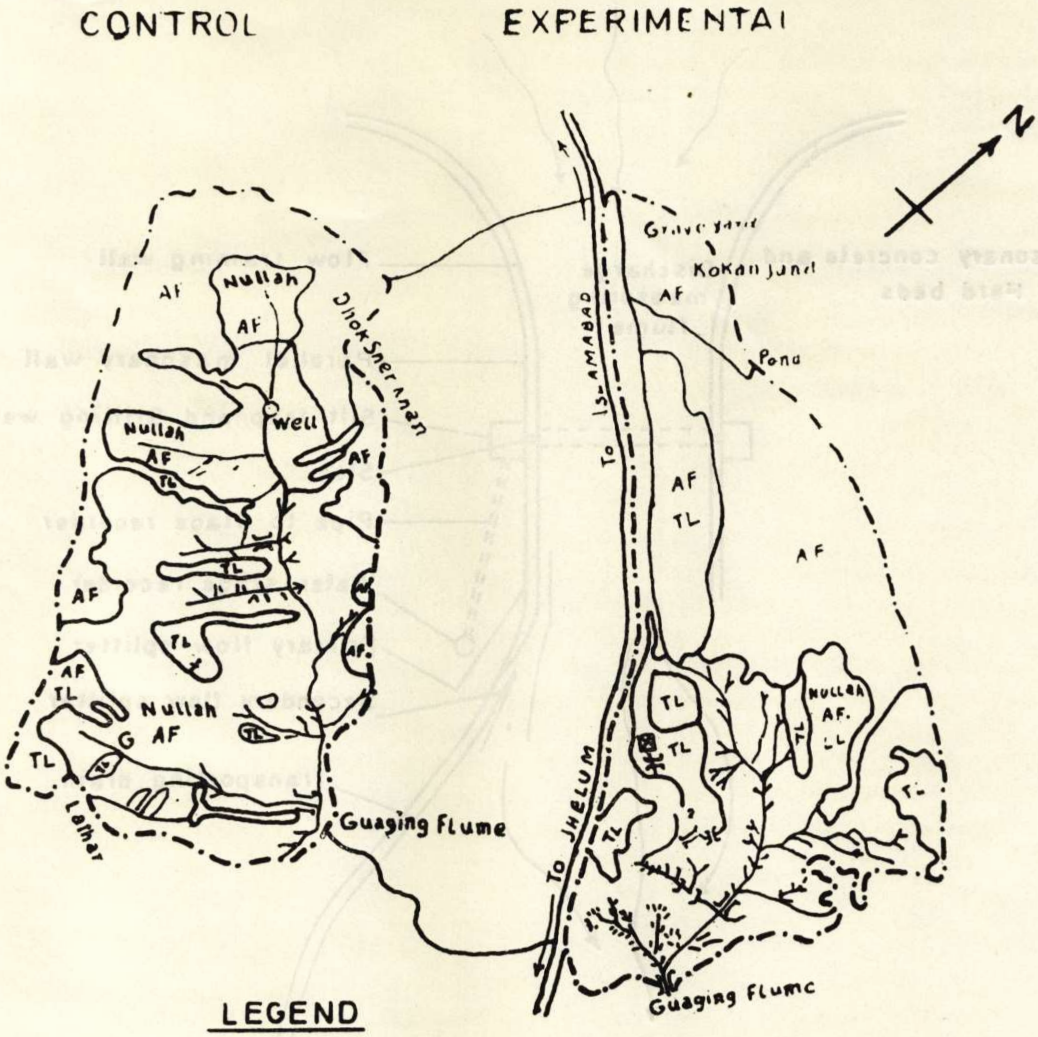
Land holdings are scattered, fragmented and jointly owned by aged and retired soldiers. Their children are either outside Pakistan or go to school. The latter help their parents in ploughing and grazing after school hours. The grazing in experimental area is partially controlled.

About 40-50% of each watershed is under agriculture. The usual practice is to grow wheat from September to April. After first monsoon showers in July, pulses, broad beans, maize or hemp crops are raised. The area is then kept fallow for one year. During this period the soil is ploughed and prepared for the next year's crops.

Afforestation and engineering works. About 55-60% area in the lower part of both the watersheds is gullied, broken, piped, sliding, overgrazed and not fit for agriculture. The experimental area was partially planted by WAPDA in 1960-61; and check dams and spillways were constructed. There are 29 check dams and 7 spillways in experimental area and 3 spillways in control. In 1973, the stocking of trees in the two watersheds was as follows:

Diameter class (cm)	Number of trees	
	Experimental area	Control area
Below 2.5	4019	678
2.6 to 10	3102	1316
10.1 to 20	655	925
20.1 to 30	267	236
30.1 to 40	49	54
40.1 to 50	6	9
Total	8098	3218

(41% *Acacia arabica,* 34% *Acacia modesta,* 10% *Dalbergia sissoo,* 6% *Prosopis juliflora, and* 9% miscellaneous).



LEGEND

AGRICULTURE FIELDS — AF
TOP LAND — TL
LOW LAND — LL
WATERSHED BOUNDARY
NULLAH
CHECK DAMS (29)
SPILLWAYS (7) (3)
OBSERVATORY

SCALE

1 CM = .150 KM

RF = $\frac{1}{15,000}$

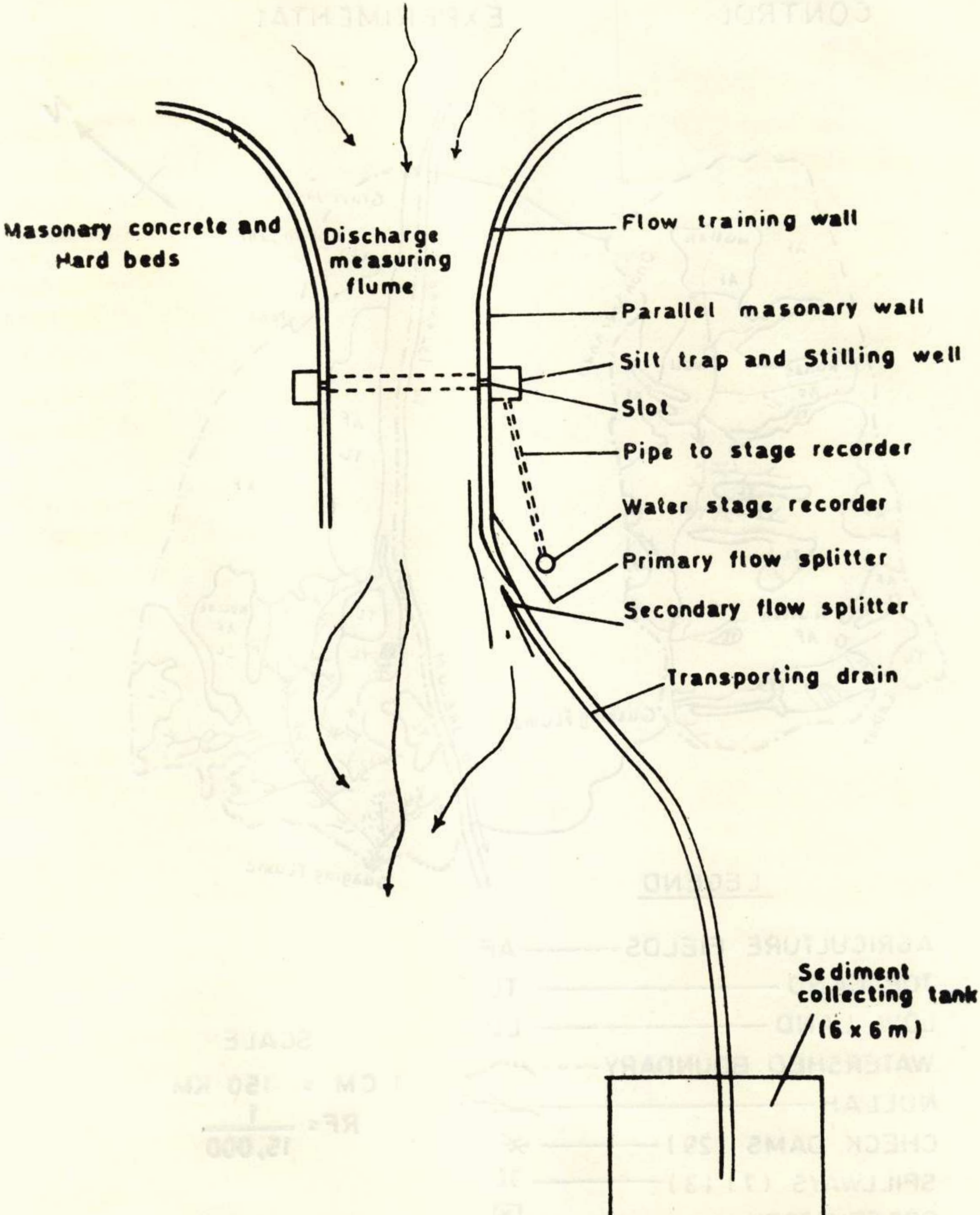


Fig. 2 Layout Sketch of Missa Gauging Devices

Subsequently the people started cutting the trees and only about 10% of them are left now which are mostly along the roadside in the experimental area. All the checkdams are now filled with transported sediment.

Climatic data. A meteorological observatory installed on the fringe of the experimental watershed and near the G.T. road adequately serves both the areas. This observatory is equipped both with recording as well as non-recording instruments. Observations on rainfall, maximum and minimum temperature, evaporation, relative humidity and wind speed are recorded daily at 9 a.m. The data for 1973 to 1978 are given in App. 1 to 4. Five raingauges have been installed in each watershed to average out local differences in rainfall. The equivalent uniform depth of rainfall has been calculated using the Thiessen polygon method[1] for adjusting runoff and sediment data.

75% of the annual rainfall is received from June to September. During this period, the rains come as torrential downpours and intensities in excess of 10 mm/hour for an hour produce runoff.

Layout. The runoff from the entire watershed is directed to the stream through a masonry flume. A part of the runoff is taken to the sediment tank through two splitters to determine the sediment content. The devices used in the process and their mode of working is described below.

Discharge measuring flume. The flume has two flow training walls which lead the incoming runoff into the measuring section consisting of two parallel walls. Connected to each parallel wall by a 2 cm wide vertical slot is a stilling well 0.5 x 0.5 m and 2.75 m deep. The two stilling wells are connected by a channel 0.3 x 0.5 m, 10 cm below the floor of the flume. The bottom of the stilling wells is 0.5 metre below the floor level of the flume to trap the silt in the runoff. Two 1.3 cm diameter galvanized iron pipes connect the stilling well to the stage recording well placed horizontally at dead level, one at the level of the flume bottom and the other 5 cm below it. The stage recorder well is made up of a galvanized iron pipe of 15 cm dia over which the water stage recorder is fitted. The water level in the recorder well remains equal to that in the flume because it is connected with the flume through the slot, stilling well and two pipes.

Water stage recorder. Flow level is recorded in the water stage recorder with a floater which moves with the rise or fall in the water level. The floater automatically puts marks on the chart, placed in the recorder. The recorder is set at a ratio of 1:6, for instance 2 cm on the chart would indicate a water level of 12 cm in the recorder well and at the flume slot.

Splitters. Part of the runoff is directed to the sediment tank through two splitters fixed in the flume. The primary flow splitter made of 6 mm steel plate with a sharp upstream edge is located at one of the side walls of the flume, at a distance of 0.3 metre from the slot. It directs 30% of the flow at very low water level and 8% of the flow at high level

[1]Thiessen, A.H., Precipitation averages for large areas, Monthly Weather Rev., Vol. 39, pp. 1082-1084, 1911.

towards the sediment basin. Another splitter (secondary flow splitter) made of 3 mm steel sheet with sharp upstream edge is located 1.3 metres away from the slot along the flume wall. One twentieth of the initial water sample is taken to the sediment tank and the balance is allowed to pass on to the upstream.

Sediment tank. A 6×6 m tank, connected with the flume serves to retain the entire flow received through the secondary splitter from small storms, and to collect a percentage of suspended and bed load sediment from large storms causing the tank to overflow. The water is dropped in the tank through a drain, slightly off the centre to unload as much sediment as possible.

Procedure for recording and evaluation. *Runoff.* The following observations are recorded:

(*i*) Time when rainfall started and ended;

(*ii*) Time when the runoff started and ended;

(*iii*) Time corresponding to rise or fall of 3 cm height of flow in the flume.

During monsoon these observations are taken manually with the gauge attached to the flume. The height of flow and time traced on the stage recorder is also checked to find out whether it is according to callibration or not; so that this chart could be used to estimate runoff in the absence of an observer.

The flume has been designed to give a stable relationship between stage (height of flow) and discharge (m³/sec.). Whereas the splitters direct a certain percentage of discharge to flow towards sediment tank at a particular stage. These values are given in the following table:

Stage (cm)	Discharge (m³/sec)	Discharge towards sediment tank
3	0.014	1.60
6	0.028	1.60
9	0.056	1.60
12	0.070	1.60
15	0.099	1.66
18	0.128	1.20
21	0.184	0.90
24	0.283	0.77
27	0.453	0.65
30	0.566	0.60

Stage (cm)	Discharge (m^3/sec)	Discharge towards sediment tank
33	0.708	0.57
36	0.906	0.55
39	1.067	0.54
42	1.218	0.53
45	1.388	0.52
48	1.586	0.52
51	1.784	0.52
54	1.982	0.52
57	2.180	0.52
60	2.350	0.52
63	2.549	0.51
66	2.747	0.51
69	2.973	0.51
72	3.200	0.51
75	3.426	0.51
78	3.653	0.51
81	3.880	0.50
84	4.106	0.50
87	4.361	0.50
90	4.616	0.50
93	4.899	0.50
96	5.182	0.50
99	5.465	0.50
102	5.776	0.50
105	6.087	0.49
108	6.398	0.49
111	6.709	0.49
114	7.020	0.49
117	7.303	0.49
120	7.586	0.49
123	7.869	0.48
126	8.152	0.48
129	8.435	0.48
132	8.718	0.48
135	9.001	0.48

After finding the values of discharge corresponding to a particular stage, a graph is plotted between the time on X-axis and discharge on Y-axis according to the convenient scale. A specimen is reproduced in Fig. 3. The area under the hydrograph in this Figure, as measured by planimeter is 2.75 in.[2] The scale of time on X-axis is 1 in = 1/3 hr and discharge scale on Y-axis is 1 in = 10 cfs.

$$1 \text{ in} = 1/3 \times 10 = \frac{10}{3} \text{ cfs. hr.}$$
$$= \frac{10}{3} \times 60 \times 60 \text{ ft}^3$$
$$= \frac{10}{3} \times 60 \times 60 \times .028 \text{ m}^3$$

As the area under the hydrograph = 2.75 in^2

$$\therefore \text{ Discharge} = \frac{10}{3} \quad 60 \times 60 \times 0.028 \times 2.75 = 924 \text{ m}^3$$

To find runoff in mm, the above discharge is divided by the area of the watershed which is 81 hectares.

$$\therefore \text{ Runoff (mm)} = \frac{924 \times 10 \times 10}{81 \times 10{,}000} = 1.14$$

Rainfall on 14-8-77 = 18 mm

$$\therefore \text{ Runoff as \% of rainfall} = \frac{1.14 \times 100}{18} = 6.3$$

In this way runoff can be calculated for any rainstorm.

In the same way plotting the splitter discharge against time, the amount of runoff transported to sediment tank can also be calculated. This computed value can be compared with the actual amount of runoff received in the sediment tank and in this way the accuracy of the splitters can be checked. This comparison helps to find the fraction of flow which was transported to sediment tank when the observer is not there or the stage recorder is out of order.

Sediment. During monsoon, runoff samples are taken manually with the change in the turbidity of runoff water. The efficiency of the splitters is also checked simultaneously. Splitters and the drain taking water to sediment tank are kept clean and the following data are collected:

(*i*) The level of sediment tank at the beginning of the rainstorm and at the end of runoff is recorded from the staff gauges provided in the tank to determine the quantity of water added to sediment tank in a particular storm.

(*ii*) In case of overflow, the time at which overflow begins is recorded. Overflow samples are taken at hourly intervals during the overflow period to determine the wash load of the overflow.

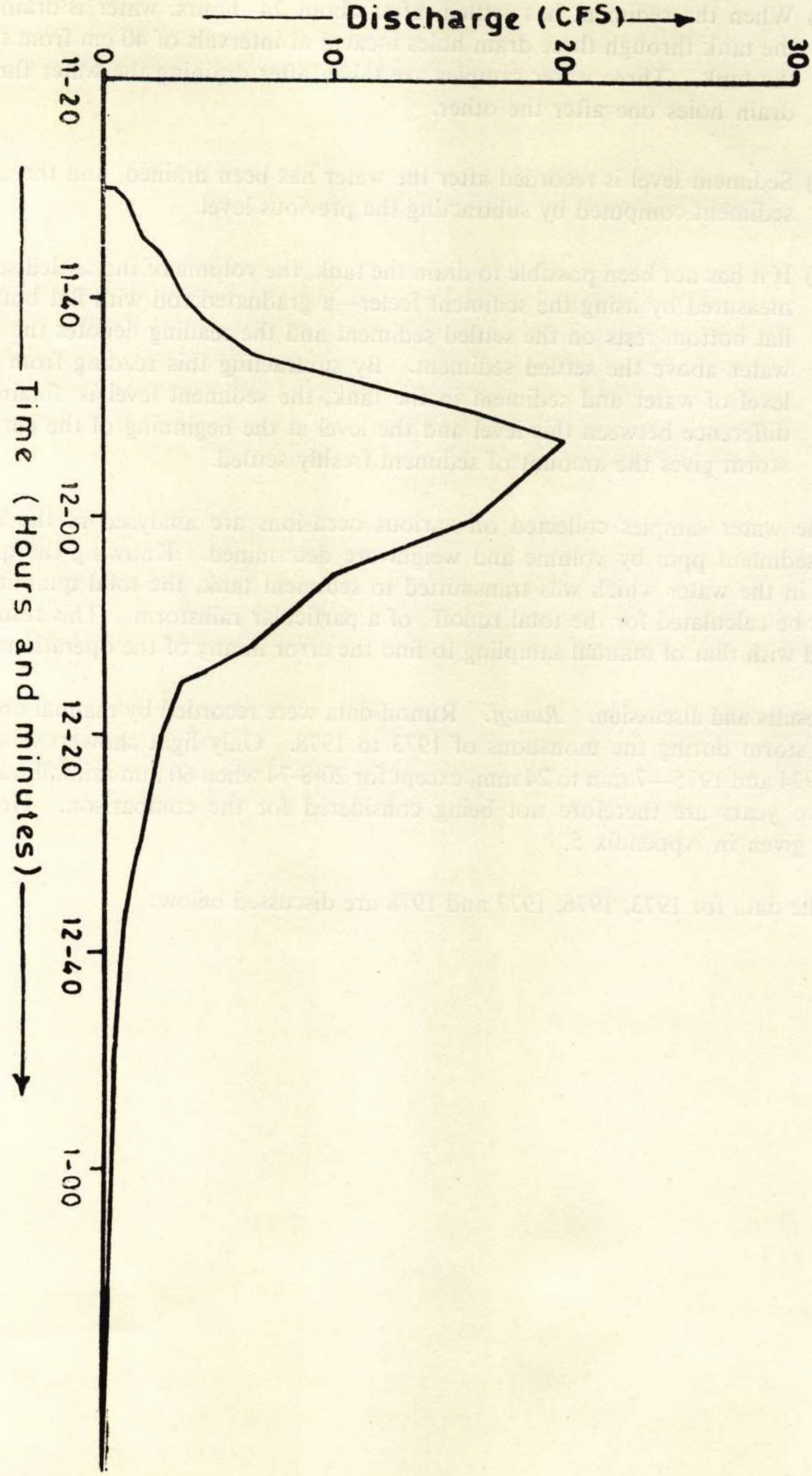


Fig 3. Hydrograph for 14.8.1977 for Experimental Watersheds

(*iii*) When the sediment has settled, after about 24 hours, water is drained out of the tank through three drain holes located at intervals of 40 cm from the top of the tank. Three water samples are taken after draining the water through the drain holes one after the other.

(*iv*) Sediment level is recorded after the water has been drained, and the amount of sediment computed by subtracting the previous level.

(*v*) If it has not been possible to drain the tank, the volume of the settled sediment is measured by using the sediment feeler—a graduated rod with flat bottom. Its flat bottom rests on the settled sediment and the reading denotes the heigh of water above the settled sediment. By subtracting this reading from the ttotal level of water and sediment in the tank, the sediment level is obtained. The difference between this level and the level at the beginning of the current rainstorm gives the amount of sediment freshly settled.

The water samples collected on various occasions are analysed in the laboratory and the sediment ppm by volume and weight are determined. Knowing the quantity of sediment in the water which was transmitted to sediment tank, the total quantity of sediment can be calculated for the total runoff of a particular rainstorm. This result can be compared with that of manual sampling to find the error in any of the operations.

Results and discussion. *Runoff.* Runoff data were recorded by manual observations for each storm during the monsoons of 1973 to 1978. Only light showers were received during 1974 and 1975—7 mm to 24 mm, except for 20-8-74 when 60 mm rainfall was received. These two years are therefore not being considered for the comparison. However the data are given in Appendix 5.

The data for 1973, 1976, 1977 and 1978 are discussed below:

1973

Date	Rainfall mm	Discharge					
		Experimental			Control		
		Period of runoff above 3 cm stage	Volume m^3	% of rainfall	Period of runoff above 3 cm stage	Volume m^3	% of rainfall
		h m			h m		
4-8-73	33	6— 0	2570	9.7	6— 0	2952	11.0
6-8-73	70	13— 0	14611	25.7	13— 0	19963	35.3
7-8-73	10	4— 0	391	5.0	4— 0	654	8.0
8-8-73	64	9— 0	12658	24.6	9— 0	20388	37.9
31-8-73	61	5— 0	12658	25.6	5— 0	15971	30.6
3-9-73	20	3— 0	1433	8.8	3— 0	1699	10.4
12-9-73	58	4—30	7170	15.2	4—30	12488	26.4
Total	316	44—30	51491	20.1	44—30	74115	28.6

For each rain storm, the runoff for Control is greater than the runoff for Experimental watershed. The relationship between runoff from the two watersheds is described by the equation.

$$Y = 0.1854 + 1.4020 X$$

where Y is the runoff from the control watershed and X that from the experimental.

1976

Date	Rainfall mm	Discharge: Experimental: Period of runoff above 3 cm stage	Experimental: Volume m³	Experimental: % of rainfall	Control: Period of runoff above 3 cm stage	Control: Volume m³	Control: % of rainfall
		h m			h m		
31-7-76	10	1—55	176	2.1	0	0	0
1-8-76	51	20—10	16775	40.8	21—30	26263	63.9
2-8-76	25	3—45	5921	28.8	3—35	6630	32.3
5-8-76	25	3—55	4617	22.5	3—50	5813	28.3
6-8-76	10	1—15	170	2.1	1—20	249	3.0
7-8-76	51	11—30	17007	41.4	11—30	19633	47.8
12-8-76	29	3—40	6620	27.8	3—07	9364	39.3
15-8-76	11	1—05	195	2.2	0	0	0
17-8-76	33	5—20	8352	31.3	5—00	10726	40.2
19-8-76	27	7—10	4047	18.7	6—30	6044	28.0
20-8-76	74	6—45	21648	36.3	7—30	26725	44.8
24-8-76	17	5—35	916	6.9	6—00	1217	9.1
30-8-76	18	3—45	1098	7.6	3—55	1783	12.4
12-9-76	13	0—45	116	1.2	1—36	260	2.5
Total:	394	76—35	87658	27.5	75—23	114707	36.0

As in 1973, the runoff from control watershed is again higher for almost all rain storms from the Control watershed as compared to the Experimental. The only exceptions are the rain storms on 31-7-76 and 15-8-76, 10 mm and 11 mm respectively, when no runoff resulted from the Control watershed. This could be ascribed to its some what coarser soil. The relationship for this year:

$$Y = 0.0950 + 1.2963 X$$

1977

Date	Rainfall (mm)	Discharge: Experimental: Period of runoff above 3 cm stage (h m)	Experimental: Volume m^3	Experimental: % of rainfall	Control: Period of runoff above 3 cm stage (h m)	Control: Volume m^3	Control: % of rainfall
7-7-77	18	1—10	740	5.1	1—00	888	6.2
8-7-77	51	4—35	10624	25.7	4—15	14236	34.5
13-7-77	19	1—30	843	5.5	1—40	1765	11.5
14-7-77	55	6—20	20593	46.0	5—00	14614	61.8
16-7-77	13	1—17	335	3.2	1—45	531	5.1
17-7-77	66	7—06	29024	54.3	6—55	32070	60.0
23-7-77	40	4—15	9781	30.1	5—36	11906	36.7
25-7-77	47	5—40	12899	34.1	6—00	15573	41.2
5-8-77	22	1—30	1057	5.8	1—48	1259	7.0
8-8-77	14	1—40	15	0.1	0—00	0	0
14-8-77	18	1—20	925	6.4	2—15	1358	9.4
16-8-77	10	0—00	45	0.6	0—00	23	0.3
18-8-77	23	4—02	1425	7.7	4—10	2038	11.0
22-8-77	15	2—30	950	7.7	2—15	1816	14.7
23-8-77	10	0—30	60	0.7	0—00	0	0
24-8-77	36	2—00	9577	32.8	2—25	14219	48.7
28-8-77	22	0—55	1063	6.1	1—12	1473	8.4
Total:	508	50—50	113472	27.6	50—39	137513	33.4

As in 1976, the runoff for each rain storm in Control is more than for the Experimental watershed except for 8-8-77 (14 mm), and 23-8-77 (10 mm) when Control did not yield any runoff. The relationship between runoff from Control and Experimental was:

$$Y = 0.6288 + 1.1311 X$$

1978

Date	Rainfall (mm)	Discharge: Experimental: Period of runoff above 3 cm stage	Experimental: Volume m³	Experimental: % of rainfall	Control: Period of runoff above 3 cm stage	Control: Volume m³	Control: % of rainfall
		h m			h m		
23-7-78	24	10—50	3309	16.9	9—45	4052	20.7
24-7-78	16	3—32	1693	13.3	2—50	2579	20.2
25-7-78	8	1—27	373	5.5	1—40	444	6.6
2-8-78	9	2—02	722	9.7	1—45	528	7.1
3-8-78	51	11—15	8145	19.8	10—44	9273	22.5
4-8-78	51	5—30	9988	24.3	5—25	11743	28.5
5-8-78	22	2—35	3151	17.8	2—24	3600	20.4
6-8-78	14	3—57	1734	15.0	4—04	2290	19.9
10-8-78	63	8—25	12830	24.9	9—04	15731	30.6
11-8-78	10	1—10	687	8.8	1—12	738	9.4
14-8-78	27	4—05	3730	17.1	3—59	4849	22.2
19-8-78	36	4—30	4938	17.2	4—35	7024	24.4
20-8-78	9	6—00	625	8.4	7—05	613	8.3
Total:	340	65—18	51925	18.9	64—32	63464	23.0

The runoff for each rainstorm in control is more than for the Experimental watershed except for 2-8-78 and 20-8-78 (9 mm rainfall). The relationship between runoff from control (Y) and Experimental (X) was:

$$Y = 0.0953 + 1.203 X$$

The relationships between Control and Experimental watersheds for 1973, 1976, 1977 and 1978 are compared in Figs. 4 and 5. Fig. 4 indicates that for all years the runoff for the same quantity of rainfall is higher in Control as compared to the Experimental, and that this difference has progressively been decreasing with time with the exception of 1978, due probably to better protection from grazing and repair of spillways. Fig. 5 also indicates that the difference between the Control and the Experimental watersheds has been decreasing with time, since 1973. This could be due to the progressive loss of efficiency of check dams through siltation and the cutting of trees and deterioration in ground vegetation since 1973.

Annual rainfall and runoff. *Rainfall:* The total rainfall (mm) received from January 1 to December 31 during 1973, 1976, 1977 and 1978 is given below:

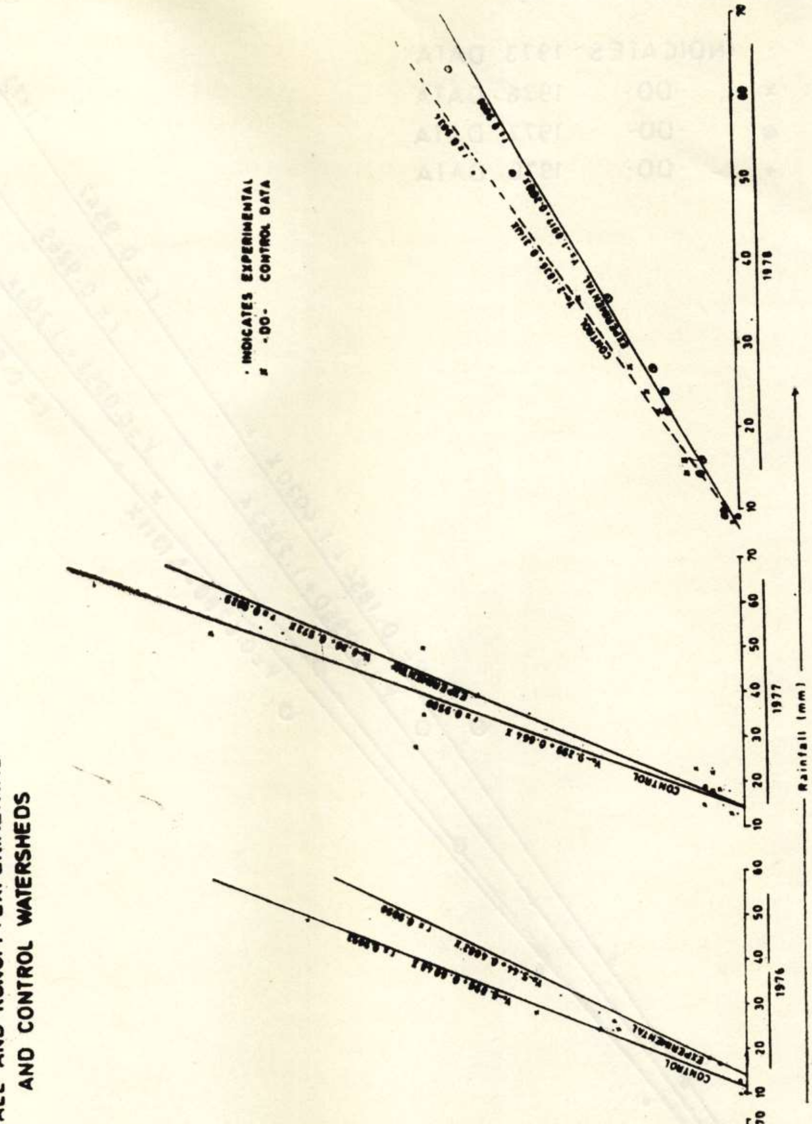


FIG. 4 RAINFALL AND RUNOFF: EXPERIMENTAL AND CONTROL WATERSHEDS

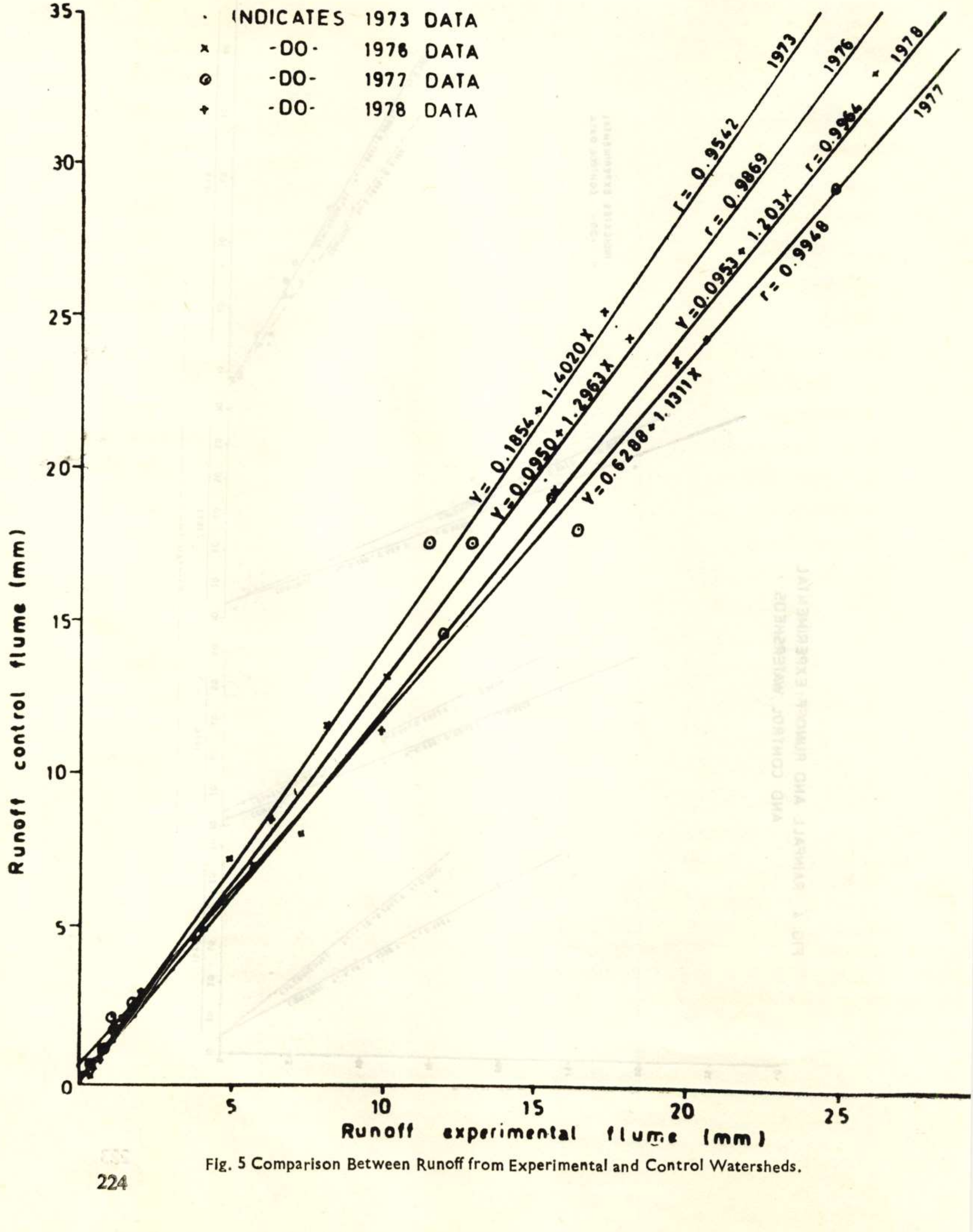


Fig. 5 Comparison Between Runoff from Experimental and Control Watersheds.

Year	Total rainfall	Rainfall producing runoff	Rainfall not producing runoff
1973	799	547	252
1976	1089	814	275
1977	945	764	181
1978	859	669	190

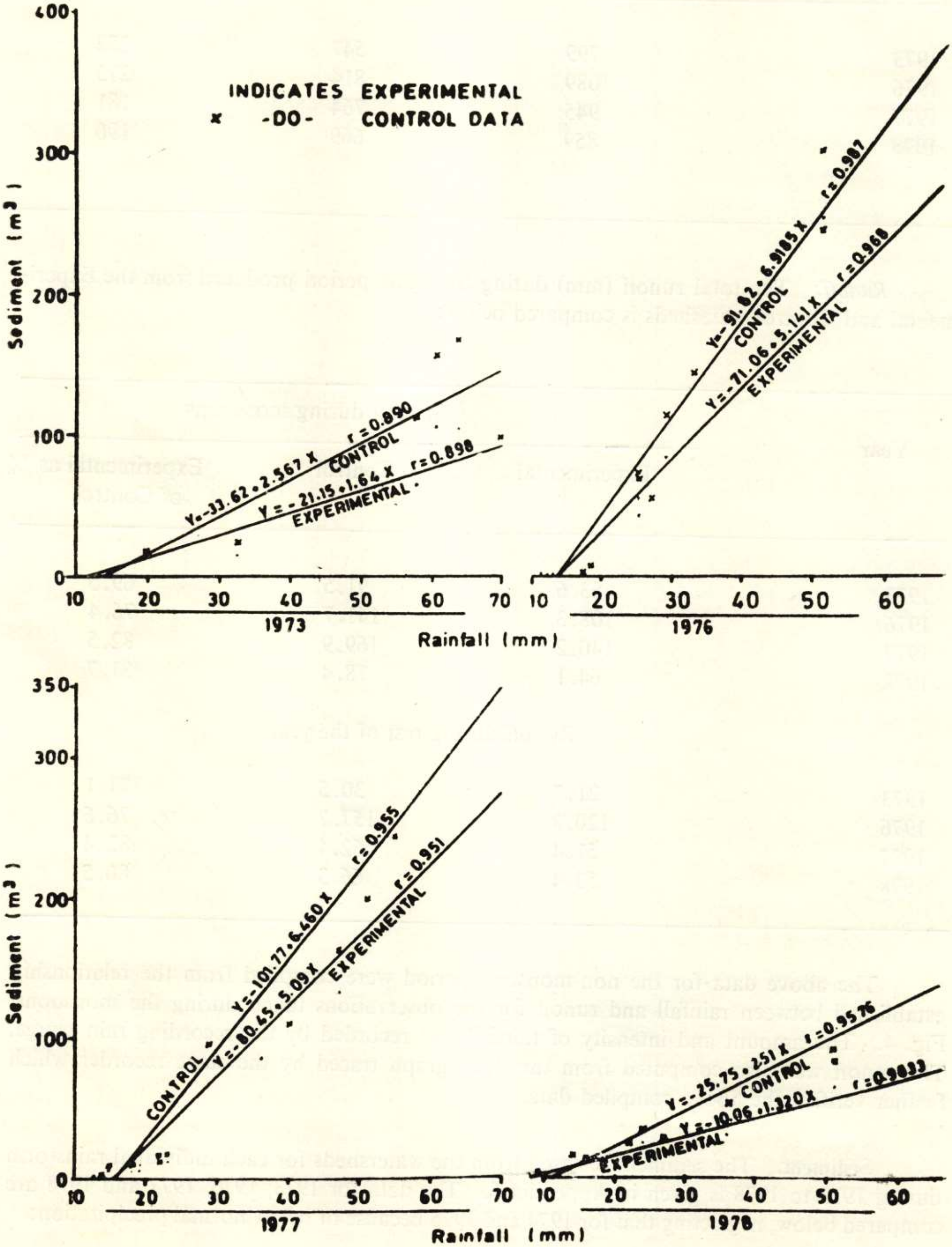
Runoff: The total runoff (mm) during the same period produced from the Experimental and Control wateshes is compared below:

Year	Runoff during monsoons		
	Experimental	Control	Experimental as % of Control
1973	63.6	91.5	69.5
1976	108.3	141.7	76.4
1977	140.2	169.9	82.5
1978	64.1	78.4	81.7
	Runoff during rest of the year		
1973	21.7	30.5	71.1
1976	120.8	157.7	76.6
1977	51.4	62.4	82.4
1978	53.4	66.3	80.5

The above data for the non-monsoon period were compiled from the relationship established between rainfall and runoff for the observations taken during the monsoons, Fig. 4. The amount and intensity of rainfall was recorded by the recording rain gauge. The runoff was also computed from the hydrograph traced by the stage recorder which further verified the above compiled data.

Sediment. The sediment released from the watersheds for each individual rainstorm during 1973 to 1978 is given in Appendix 6. The data for 1973, 1976, 1977 and 1978 are compared below, neglecting that for 1974 and 1975 because of below normal precipitation:

FIG 6 RAINFALL & SEDIMENT: EXPERIMENTAL AND CONTROL WATERSHEDS



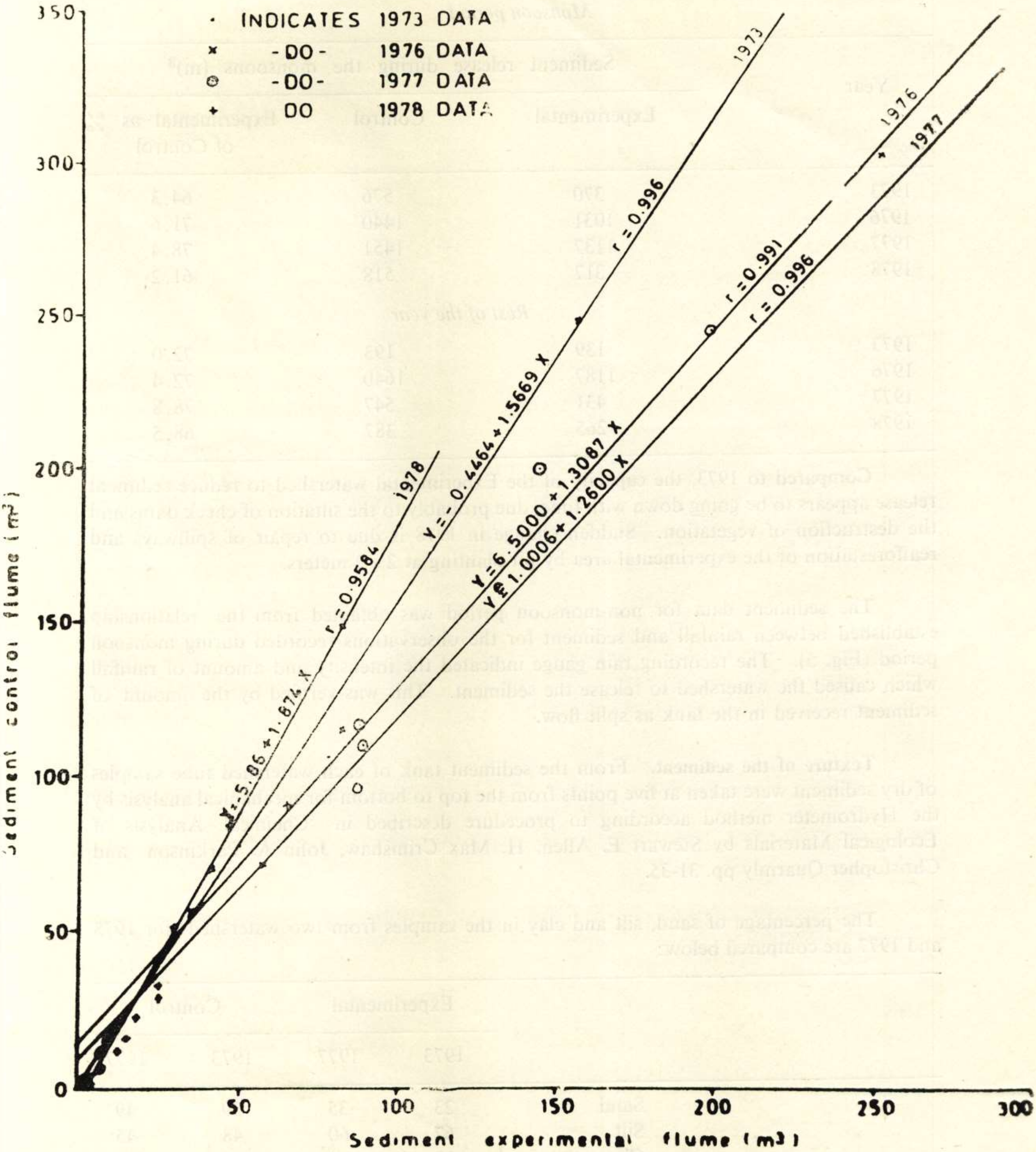


Fig. 7 Comparison Between Sediment Release from Experimental and Control Watersheds.

Monsoon period

Year	Sediment release during the monsoons (m)^3		
	Experimental	Control	Experimental as % of Control
1973	370	576	64.3
1976	1031	1440	71.6
1977	1137	1451	78.4
1978	317	518	61.2
		Rest of the year	
1973	139	193	72.0
1976	1187	1640	72.4
1977	431	547	78.8
1978	265	387	68.5

Compared to 1973, the capacity of the Experimental watershed to reduce sediment release appears to be going down with time, due probably to the siltation of check dams and the destruction of vegetation. Sudden change in 1978 is due to repair of spillways and reafforestation of the experimental area by pit planting at 2 × 2 meters.

The sediment data for non-monsoon period was obtained from the relationship established between rainfall and sediment for the observations recorded during monsoon period (Fig. 5). The recording rain gauge indicated the intensity and amount of rainfall which caused the watershed to release the sediment. This was verified by the amount of sediment received in the tank as split flow.

Texture of the sediment. From the sediment tank of each watershed tube samples of dry sediment were taken at five points from the top to bottom for mechanical analysis by the Hydrometer method according to procedure described in 'Chemical Analysis of Ecological Materials by Stewart E. Allen, H. Max Crimshaw, John A. Parkinson and Christopher Quarmly pp. 31-35.

The percentage of sand, silt and clay in the samples from two watersheds for 1973 and 1977 are compared below:

	Experimental		Control	
	1973	1977	1973	1977
Sand	23	35	39	49
Silt	67	60	48	45
Clay	10	5	13	6

Thus in the sediment from both watersheds the percentage of sand has increased over time due to the exposure of poorly cemented sandstones and sandy parent material at various locations.

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Appendix 1

Total Rainfall (mm) and number of rainy days

Month	1973		1974		1975		1976		1977		1978	
	Rain-fall	Rainy days	Rain-fall	Rainy days	Rain-fall	Rainy days	Rain-fall	Rainy days	Rain-fall	Rainy days	Rain-fall	Rainy days
January	40	6	29	4	13	4	53	7	62	5	37	5
February	32	3	36	4	43	7	109	8	0	0	27	4
March	46	5	14	4	33	5	64	8	0	0	60	7
April	10	3	38	2	10	1	38	3	18	3	9	3
May	36	3	16	5	32	4	23	3	11	3	27	2
June	56	6	76	6	25	4	47	4	108	8	25	3
July	178	11	154	8	207	10	333	11	423	13	168	16
August	212	9	105	7	108	11	389	18	177	11	332	16
September	151	7	44	5	106	7	28	3	55	3	118	6
October	8	2	0	0	0	0	5	1	41	4	25	4
November	3	1	0	0	0	0	0	0	8	1	23	2
December	27	2	47	5	0	0	0	0	42	4	8	1
Total:	799	58	599	50	577	53	1089	66	945	55	859	66

Appendix 2

Average air temperature °C

Month	1973		1974		1975		1976		1977		1978	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
January	16.1	3.9	16.7	—	18.9	7.8	18.3	8.3	18.0	3.0	18.5	2.6
February	21.1	7.2	17.8	—	19.4	8.3	18.3	9.4	26.0	4.0	22.0	6.2
March	23.9	11.1	27.8	—	25.6	12.2	23.3	12.8	31.0	10.0	22.4	9.6
April	33.3	16.7	33.9	20.0	36.1	18.9	31.7	16.7	36.9	16.6	31.8	17.2
May	38.3	22.8	37.8	21.7	38.3	23.3	36.1	20.0	35.0	19.0	40.4	22.6
June	40.0	26.7	38.3	24.4	40.0	26.7	38.9	21.1	37.2	23.2	39.3	25.9
July	35.6	24.4	35.0	25.4	35.0	25.6	33.9	24.4	32.8	23.5	32.6	24.8
August	33.3	23.4	55.0	25.6	33.9	26.1	32.2	23.3	32.7	23.8	32.3	24.0
September	33.9	—	36.7	25.6	32.8	23.3	32.8	21.1	33.1	21.9	31.4	21.5
October	31.7	—	33.9	16.7	32.8	15.6	27.8	16.1	30.9	17.6	33.2	15.1
November	26.1	—	28.8	11.7	26.7	9.4	29.3	6.5	29.6	10.9	25.7	9.7
December	18.9	—	17.8	8.3	22.8	8.3	21.1	3.0	21.0	6.0	22.0	3.7
Average	29.3	17.0	29.9	21.8	30.2	17.1	28.6	15.2	29.9	15.0	29.3	15.2

Appendix 3

Average Evaporation/day (mm) and average relative humidity at 9 a.m. (%)

Month	1973		1974		1975		1976		1977		1978	
	Evap.	R.H.	Evap.	R.H.	Evap.	R.H.	Evap.	R.H.	Evap.	R.H.	Evap.	R.H.
January	1.62	60	1.07	76	1.82	70	2.11	78	1.75	60	1.53	28
February	2.52	70	2.21	78	2.22	78	1.81	82	3.16	53	2.36	75
March	4.28	67	4.69	60	4.44	58	3.53	65	5.83	45	3.53	66
April	7.60	46	7.50	41	7.37	42	5.60	51	6.15	55	6.65	50
May	—	33	9.53	30	10.00	25	8.88	27	6.74	55	11.57	35
June	—	50	10.09	33	11.00	33	10.65	36	9.36	—	10.94	74
July	6.52	72	6.89	57	7.00	55	5.99	69	5.78	86	5.35	85
August	4.40	69	6.56	66	5.00	75	3.03	83	5.31	85	4.93	90
September	5.22	74	6.38	54	4.51	63	4.39	63	5.39	73	4.87	72
October	4.75	74	4.77	41	5.02	41	3.99	48	4.08	62	4.04	64
November	2.44	75	3.09	44	3.31	48	3.23	42	2.68	58	2.24	56
December	1.77	77	1.45	79	2.19	60	1.86	49	1.95	70	1.40	71
Average	4.09	64	5.35	55	5.32	54	4.59	58	4.85	64	4.95	68

Appendix 4

Average wind speed (km/day) at 0.6 and 2.4 metres heights

Month	1973		1974		1975		1976		1977		1978	
	0.6 m	2.4 m	0.6 m	2.4 m	0.6 m	2.4 m	0.6 m	2.4 m	0.6 m	2.4 m	0.6 m	2.4
January	32.0	52.0	21.7	37.0	27.7	45.2	21.1	32.3	23.7	41.3	17.8	32.2
February	39.9	65.2	33.0	56.5	35.4	56.8	38.9	61.5	31.7	61.4	26.4	48.7
March	48.3	78.2	44.6	79.2	61.1	98.2	43.4	73.1	25.1	80.1	41.8	70.1
April	65.0	111.0	60.2	106.2	61.1	102.0	48.3	85.4	42.8	78.0	42.1	80.3
May	70.8	113.8	69.2	113.3	69.4	106.7	46.7	82.1	44.9	81.6	58.7	109.4
June	71.6	117.8	61.1	105.1	70.8	117.5	53.4	93.3	46.0	87.9	69.7	141.3
July	45.4	79.0	50.0	89.5	49.9	90.1	41.8	80.5	35.2	80.8	31.4	67.1
August	32.8	58.3	37.0	68.7	37.0	66.0	29.0	54.7	25.4	61.8	21.1	45.7
September	26.9	44.9	35.9	66.0	24.1	48.3	16.7	37.3	21.4	42.5	19.5	40.2
October	26.4	46.3	23.0	48.3	20.9	39.3	22.8	46.2	11.7	25.2	15.0	30.7
November	16.1	29.0	19.3	37.0	21.6	39.3	15.8	32.3	19.0	36.7	21.2	40.5
December	17.1	28.8	24.6	40.9	29.0	48.3	18.8	34.6	15.9	30.1	14.6	26.4
Average	41.0	68.7	40.0	70.6	42.3	71.5	33.1	59.4	28.6	58.9	31.6	61.0

Appendix 5

Comparison of runoff from Experimental and Control Watersheds, Missa

		h m			h m		
			1974				
2-8-74	8	0—32	93	1.5	0—30	103	1.7
3-8-74	8	0—09	52	0.9	0	0	00
4-8-74	18	1—20	1665	11.6	1—35	3351	23.3
5-8-74	8	0—46	32	0.5	0	0	0
20-8-74	60	3—31	16467	33.9	3—25	19921	41.1
Total:	102	6—18	18309	22.5	5—30	23375	28.7
			1975				
29-7-75	13	1—41	308	3.0	1—75	370	3.6
2-8-75	11	0—53	196	2.1	1—20	328	3.6
3-8-75	24	2—40	1730	8.9	3—00	3405	12.3
5-8-75	10	0—55	137	1.7	0—45	173	2.1
17-8-75	7	0—11	24	0.4	0	0	0
22-8-75	19	2—50	978	6.5	2—40	1720	11.5
29-8-75	8	0—30	98	1.6	0	0	0
Total:	92	9—40	3471	4.7	9—00	4996	6.7

Appendix 6

Comparison of Sediment from Experimental and Control Watersheds, Missa

Date	Rainfall mm	Sediment release during monsoon					
		Experimental			Control		
		ppm	m³	tonnes	ppm	m³	tonnes
				1973			
4-8-73	33	5576	14.3	25.468	7559	22.0	41.798
6-8-73	70	4684	68.5	100.633	4898	97.8	156.213
7-8-73	10	6522	2.5	4.814	6710	4.4	8.286
8-8-73	64	8100	102.5	164.731	8147	166.1	86.805
31-8-73	61	8369	105.9	168.734	9933	158.6	242.039
3-9-73	20	8178	11.7	14.059	8500	14.4	20.296
12-9-73	58	9044	64.8	101.799	9000	112.4	181.711
Total:	316	7193	370.2	580.238	7772	575.7	737.148
				1974			
2-8-74	8	4508	0.4	0.87	7192	0.7	1.36
3-8-74	8	5123	0.3	0.50	0	0	0
4-8-74	18	8949	14.9	25.83	7213	24.2	45.12
5-8-74	8	4112	0.1	0.28	0	0	0
20-8-74	60	7882	129.8	341.05	9389	187.0	508.48
Total:	102	7947	145.5	368.53	9067	211.9	554.96

Appendix 6 —(*Continued*)

Comparison of sediment from Experimental and Control watersheds, Missa

Date	Rainfall mm	Sediment release during monsoon					
		Experimental			Control		
		ppm	m^3	tonnes	ppm	m^3	tonnes
				1975			
29-7-75	13	8819	2.7	5.42	11505	4.2	7.64
2-8-75	11	5939	1.2	2.22	8212	2.7	5.65
3-8-75	24	5446	9.4	20.50	6967	16.7	32.03
5-8-75	10	3608	0.5	0.73	6710	1.4	1.73
17-8-75	7	3257	0.1	0.18	0	0	0
22-8-75	19	6220	6.1	15.46	9576	16.4	31.55
29-8-75	8	3586	0.3	0.41	0	0	0
Total:	92	5848	20.3	44.3	8226	41.1	78.60
				1976			
31-7-76	10	2170	0.4	0.44	0	0	0
1-8-76	51	9420	158.0	240.52	9443	248.0	400.25
2-8-76	25	9655	57.2	110.77	10901	72.3	133.80
5-8-76	25	9172	42.4	89.98	12143	70.6	125.89
6-8-76	10	2351	0.4	0.42	3033	0.8	0.99
7-8-76	51	14995	225.0	335.24	15465	303.6	404.79
12-8-76	29	12519	82.9	131.26	12262	114.8	195.80
15-8-76	11	1483	0.3	0.60	0	0	0
17-8-76	33	9954	83.1	158.09	13788	147.9	250.81
19-8-76	27	8538	34.6	80.66	9296	56.2	118.38
20-8-76	74	14257	308.6	574.32	15508	414.5	748.30
24-8-76	17	710	0.7	1.15	1330	1.6	3.10
30-8-76	18	5874	6.4	9.54	5293	9.4	12.99
12-9-76	13	5440	0.6	0.61	2070	0.5	0.67
Total:	394	11757	1030.6	1733.60	12555	1440.2	2395.67

Appendix 6 (*Continued*)

Comparison of sediment from Experimental and Control Watersheds, Missa

	Rainfall mm	Sediment release during monsoon					
		Experimental			Control		
		ppm	m³	tonnes	ppm	m³	tonnes
1977							
7-7-77	18	8771	6.5	14.50	9667	8.6	18.06
8-7-77	51	13629	144.8	225.13	14081	200.5	302.27
13-7-77	19	8459	7.1	14.52	7888	13.9	26.65
13-7-77	29	6450	87.2	212.24	6578	96.1	239.93
14-7-77	55	9737	200.5	557.43	10321	245.1	706.29
16-7-77	13	7265	2.4	5.46	5187	2.8	8.03
17-7-77	66	11393	330.7	576.50	13064	419.0	685.46
23-7-77	40	9098	89.0	185.85	9235	110.0	228.56
25-7-77	47	10327	133.2	242.57	10392	161.8	295.62
5-8-77	22	9115	9.6	18.29	9535	12.0	23.48
8-8-77	14	9619	0.1	0.44	0	0	0
14-8-77	18	8398	7.8	15.06	8311	11.3	20.81
16-8-77	10	6498	0.3	0.67	9672	0.2	0.45
18-8-77	23	8976	12.8	28.98	8891	18.1	39.15
22-8-77	15	8859	8.4	18.63	5766	10.5	21.29
23-8-77	10	4573	0.3	0.83	0	0	0
24-8-77	36	9087	87.0	179.18	8979	127.7	265.50
28-8-77	22	9183	9.8	19.05	9297	13.7	26.33
Total:	508	10024	1137.51	2315.33	10552	1451.3	2907.88
1978							
23-7-78	24	7639	25.3	45.5	8064	32.7	58.1
24-7-78	16	6972	11.8	17.4	6882	17.7	33.6
25-7-78	8	1103	0.4	0.6	1400	0.6	1.0
2-8-78	9	3796	2.7	5.0	6276	3.3	5.7
3-8-78	51	5972	48.6	69.9	8980	83.3	133.7
4-8-78	51	6618	66.1	111.0	7672	90.1	199.0
5-8-78	22	5854	18.4	33.9	6091	21.9	41.4
6-8-78	14	6581	11.4	20.6	6657	15.2	31.1
10-8-78	63	5857	75.1	118.3	10706	168.4	491.9
11-8-78	10	1470	1.0	1.6	1969	1.5	3.0
14-8-78	27	6832	25.5	48.3	6045	29.3	54.0
19-8-78	36	6044	29.8	48.4	7352	51.6	73.3
20-8-78	9	1568	1.0	1.8	3960	2.4	5.0
Total:	340	6107	317.1	522.3	8162	518.0	1130.8