Silt Trapping Efficiency of Vegetative cover in the Catchment Area,

By

*MR. AMIR AHMAD KHAN W. P.F.S.I.

During the last 15 years or so the intensity and frequency of floods in the Indus River system are on the increase. Beside the erratic behaviour of the monsoons, the denudation and deterioration of the watershed areas of our rivers are largely responsible for these abnormally severe and/frequent floods. The climate, cover, topography, soil, and substratum of a watershed form a natural reservoir which acts in much the same way as a man-made reservoir, to store and control run-off from the watershed. This natural reservoir has a limited storage capacity dependent on the porosity and depth of the soil and rock mantle. A man cannot change any of the above factors except cover which ranges widely in form in response to the activities of man and the variations in climate. The later restricts the veriety of crop that can be grown in any area, leaving only a limited number of plants from which to chose.

1. Every vegetative cover is made up of three parts, the canopy of living and dead stems and leaves that stands clear of the soil, the accumulation of deed and decaying plant remains that lies on or in the soil surface, and the living and dead roots and subsurface stems that permeate the soil.

2. For a long time it has been recognized that plant cover exerts a considerable influence on the run-off of precipitation and tends to reduce the erosion of the soil on sloping lands. The canopy above ground and the surface litter accumulation operate as barriers interposed between the atmosphere and the soil. They intercept precipitation and thus hamper the delivery of water to the soil. At the soil surface vegetation obstructs the overland flow of water and the pickup and transport of soil material. This is accomplished by stems and litter accumulations that form miniature anchoned dams and diversion walls, and by roots and decaying organic matter that mat the soil or bind it. Beneath the soil surface, to depths reached by roots, vegetation acts both directly and indirectly.

3. Erosion by water is a geological process occuring in all countries wherever rains fall and snow banks melt. Every year the mountains, the hillsides, and the slopes are worn down and the seas, lakes, valley and

*Chief Conservator of Forests, West Pakistan.

watercourses gradually filled with water-transported materials. Under most conditions the rate of erosion is slow because the plant cover of trees, shrubs, and grass serves as a shield and a blotter, protecting the soil beneath, but if the plant cover is inadequate serious damage may result.

4. Erosion is the process by which soil particles are detached from the soil surface. Transportation is the process of moving these detached soil particles to another location. Deposition is the process of dropping these soil particles at a new location. Erosion, transportation and deposition are natural processes which have sculptured many of the topographic features of our landscape. These processes have been functioning throughout geologic history. This type of normal or geologic erosion is generally beneficial, because it proceeds at a rate slower than that at which new soil is being formed and it helps to keep the soil in a productive condition. This natural balance is easily destroyed by a change in the density or character of the native cover which may result in the accelerated erosion.

5. Erosion is of two general types: sheet erosion and channel erosion. The latter includes rlll and gully erosion as well as stream channel erosion.

6. Sheet erosion is the removal of soil more or less uniformally over the entire soil surface. This type of erosion is not as spectacular as channel erosion and is often not readily apparent to the casual observer. Evidences of sheet erosion are: plants standing with part of the root system exposed indicating that the soil has been washed away arround it; soil pedestal; the invasion of plant indicators of a deteriorated soil; and a silt load in streams in the absence of channel erosion. While not as obvious as channel erosion, sheet erosion is probably responsible for damaging a greater land areas.

7. Rill erosion results from accuring of microchannels in which water concentrates as it runs downslope. This type of erosion is more readily recognizable and the rills merge to form gullies which are almost impossible to overlook. Channel erosion may take place also in streams and rivers as evidenced by bank-cutting and changes in channel alinement.

8. The relative quantities of soil movement resulting from sheet and channel erosion is highly variable. Generally, sheet erosion is higher in areas of high rainfall, while channel erosion is greater in more arid regions.

9. The problem arises when man steps into the picture. In his efforts to gain a livelihood at lumbering or farming or at some other industry he clears the land. Seldom does he restrict his efforts to level areas, but attacks the slopes and the hills. The protective cover is cleared away and the soil beneath exposed.

10. Precipitation water that reaches the soil but does not immediately enter it lies upon the soil surface and if the surface is inclined it flows

toward lower places. This surface flowing water is important in contributing the flashiest peak flows to streams during storms. It has a capacity to detach and transport soil particles making it a most important agent in erosion soil. The rate of water flow on the soil surface depends upon the gradient of the slope, the roughness of the surface, and the degree to which the flow is concentrated. Water flows faster on steep slopes than on gentle ones. It flows more slowly on rough surfaces than on smooth ones. And surface water concentrated in rills or gullies moves more quickly than water flowing as thin sheets well distributed over the soil.

11. Water flowing on the soil surface cuts through the surface, and can move soil material, in channels and streams. Soil particles can be picked up from the land by water acting in two ways. Raindrops fall toward the ground with considerable speed, and when they strike bare soil their energy is usually great enough to dislodge particles of soil. Large drops have a greater striking force than small drops and intense rains bring a greater number of drops to the soil each minute than light rains (Laws 1940). Besides dislodging soil particles, raindrops can also dash them into the air and thus spur their downhill travel.

12. Moving water expends the energy of its mass in abrasing the resisting bed or bank material. The kinetic energy "K" of a mass "m" moving with a velocity "v" is

$$K = \tfrac{1}{2} mv^2$$

Thus the cutting or erosive power of water is proportional to V^2, that is, if the velocity is doubled, the cutting power is increased four times. The carrying power, or quantity of material of a given size that can be carried by the water, varies as V^5. In other words, as the velocity doubles, the carrying power is increased thirty-two fold. The size or volume of particles carried by pushing or rolling varies as V^6, that is, as the velocity doubles, the size increases sixty-four fold.

13. The rate of erosion depends upon the length and degree of slope, rainfall intensity, type and density of vegetal cover, and the inherent erodibility of the soil. Erodibility, the tendency of soil to wash away,—varies with the soil texture, and the amount of organic matter and colloids in the soil. Both the particles size and the aggregation, or binding together of soil particles, are important. Clay, for example, has very small particles which are easily transported by water but they are not easily detached because of the high aggregation. Sand on the other hand is very easily detached, but is not easily transported because of the larger particle size. Soil particles may be detached either by the impact of raindrops falling on the bare soil or by water flowing over the soil surface.

14. Forage dynamics in soil conservation is the active power and strength of the trees and grasses when properly used to conserve and im-

prove soil. One facet of this power comes from the dense canopy furnished by these plants and their great efficiency to dissipate raindrop energy. The speed of the raindrop falling through space has been shown to be about 6 to 20 miles per hour, depending on raindrop size. It has been calculated that the energy from an inch of rain may exceed 2 million foot-pounds per acre. This amount of energy is sufficient to raise a 7-inch acre of soil, one foot. Ellison has shown that splash erosion on bare soil to be one of the greatest causes of soil erosion. Not only does the dense forage canopy, dissipate the raindrop energy but it may intercept as much as 10 inches of the rainfall during the growing season.

15. Vegetation also acts upon erosion and deposition indirectly through its influence over infiltration and the velocity of surface flow, and directly through its shielding, binding, and filtering action. Increased infiltration means decreased surface flow, and hence less water available to cause erosin. Decreased velocity means lowered eroding power and decreased capacity to carry sediment. The direct effects of vegetation upon erosion are exhibited in channels as on soil surfaces. Litter and plants slow the flow of water in gullies and, besides this, trap soil material carried by the water.

16. Vegetation's influence over sediment load does not stop with control of run-off and erosion on the soil surface and in rills and gullies that feed water to streame. Directly as has been explained, stream channel plants provide protection for beds and banks. The indirect influence of vegetation turns upon vegetation tendency to favour prolonged, rather than prompt, delivery of water to streams.

17. In mountainous northern regions, watersheds also store winter's precipitation as snow to be melted and released later for irrigation and other uses. This water, or inflow, is also under some form of control, since different amounts and kinds of vegetation will intercept different amounts of snow. The pattern of forest openings may serve to trap, store, and slowly melt greater quantities of snow. Major changes in storage and in melting rates can be made by manipulating the cover.

18. The objective of watershed management is to meet the problems of land and water use, not in terms of any one resource, but on the basis that all resources are Interdependent and must therefore be considered together.

19. Within the natural basic limitations of the watershed, great changes can be made in the rate and volume of run-off by manipulations in vegetative cover. However, changes in cover required to achieve maximum water production may not be compatible with the optimum production and use of other resources. In so far as cover changes improve and maintain the soil base, other resources may also benefit.

20. Vegetation offers obstacles to the free fall of precipitation, which cause changes in the quantity, rate and time of water delievery to

the ground and in the ariel distribution of rain or snow upon the soil surface. Interseption of precipitation occurs at two levels within the vegetative cover, in the crown canopy, and in the ground litter.

21. Ground litter operates like the crown canopy, to detain and retain precipitation that reaches it. Litter intercepts water and exposes it to evaporation. Litter causes little if any redistribution of precipitation, and since it lies directly upon the soil it delivers water to the soil as liquid flow and hence without impact. Litter intercepts and reduces the impact of water falling from the canopy, and acts as an insulator against the heat of the soil to delay the melt of snow.

22. Liquid water that reaches the soil surface moves in one of two directions : downward through the soil surface, or laterally upon it. Downward movement of water through the soil surface is called infiltration. Three forces act to control the rate of infiltration ; hydrostatic pressure from above, gravitational pull, and capillary forces from within the soil. Gravitational pull is, of course, constant. The other two forces are variable and subject to influence by vegetation.

23. The experiments conducted on the runoff in the experimental form at Ottawa Canada have shown in the last 13 years. The following results :—

Drainage area cover	Slope %	Renion	Drainage area in acres					
			5	10	25	50	100	200
			(runoff in cubic feet per second)					
Timbered land.	5—10 (rolling)	E & WC[3]	8	15	16	56	91	186
		Prairie	7	13	23	48	77	150
	10—30 (hilly)	E & WC	9	17	31	64	108	184
		Prairie	8	15	27	55	91	150
Pasture.	5—10	E &WC	17	30	61	109	185	319
		Prairie	15	27	54	94	155	260
	10—30	E & WC	22	37	72	161	214	369
		Prairie	20	30	63	100	180	300
Cultivated land.	5—10	E & WC	32	53	116	181	306	332
		Prairie	29	47	102	156	257	425
	10—30	E & WC	40	64	124	217	369	630
		Prairie	36	57	107	187	310	512

As regards the amount of sediment transported from the watersheds, experiments having been conducted in the United States—give actual sediment traped from small experimental water sheds having various cover

conditions. The following table will show the results obtained for various cover conditions, good, fair, poor and bare :—

	Cover condition	Sediment production (Tons/ c. f. s. daily)				Relative rate			
		Good	Fair	Poor	Bare	Good	Fair	Poor	Bare
Boise—[1] 1939-40	Forest	5	5	15	...	1.0	1.0	3.0	...
	Forest (cun-over, burned)	...	12.5	40	...	...	1.0	3.2	...
	Browse	5	10	25	...	0.5	1.0	2.5	...
	Sagebrush	...	25	40	50	...	1.0	1.6	2.0
	Grass	...	25	60	150	...	1.0	2.4	6.0
				Average :—		0.7	1.0	2.5	4.0
San-[2] Jaun-1928-41	Conifer	0.3	0.5	...	...	0.6	1.0	...	...
	Browse	0.3	0.5	...	...	0.6	1.0	...	. .
	Sagebrush	1.0	1.5	3.0	...	0.7	1.0	2.0	. .
	Juniper	1.5	2.5	4.0	...	0.6	1.0	1.6	...
	Grass	1.0	2.5	5.0	...	0.4	1.0	2.0	...
				Average :—		0.6	1.0	1.9	...

[1] Six small watershed silt smapling and discharge, 1939-40 (5-20 sq. mi.).

[2] Sediment sampling and discharge of San Jaun River at Bluff, 1928-41 (24,000 sq. mi.).

24. With the posibility of the existence of such important relationships and consequences, it is highly important to know more about this mantle of low vegetation and to discover its actual relation to runoff and erosion. Much literature is available on the effect of forest cover on runoff erosion, and climate. The earlier information has been summarized by Son 1927, who has also compiled a bibliography on the subject. Munns (1923 discusses the matter in some detail as it applies in California. More recently Bates and Henry have published a detailed report on a co-operative experiment by the Forest Service and the Weather Burreau on the influence of forest cover on the water supply in Central Colorado. Recent work by Lowdermilk shows the tremendous importance of vegetable matter on the ground to assist absorption of moisture by the soil.

25. Several investigators of forest and grazing land conditions in the mountain regions of the West, among them Leiberg, Corman, Langille, Plummer and Gowsell, and Rixon, have pointed out that overgrazing was evidently responsible for the denudation of mountain slopes, for increased surface runoff and erosion of the soil, and in some instance for the reduction of mountain slopes to barren wastes.

26. In one of the several experiments conducted in the States, two areas, small but complete watersheds in themselves, were equipped with devices for measuring the precipitation and the runoff and removal of sediment which resulted. Two standard weather Burreau rain gauges were placed on each area, and an additional standard gauge and an automatic tipping-bucket rain gauge were placed at central station halfway between the two areas. Fifteen snow stakes were installed at selected places over each watershed for measuring snow depth and as stations for determining the water equivalent of the snow. A settling basin equipped with a trangular 90° weir and an automatic water height-stage recorder for the measurement of run-off and sediment eroded was installed at the lower end of each erosion area. The settling basin at the lower end of 'A' consisted of three compartments, the upper 6′ × 12′ feet in basal dimensions and 56″ inches deep, the middle 12′ × 12′ feet and 56″ inches, and the lower 12′ × 12′ feet and 39″ inches deep, below the bottom of the weir. The basin on 'B' consisted of two compartments, each 6′ × 12′ feet in basal dimensions, the upper 54″ inches deep and the lower 39″ inches deep, below the bottom of the weir. The precipitation during each storm from July 1 until winter snows occurred in the fall was measured each year from 1914 to 1929, inclusive. The water and sediment which reached the settling basins as a result of surface runoff were also measured for each of these storms. Supplemental records of snow depth and water content in the spring and surface runoff and sediment removed by melted snow were obtained for several of these years.

27. The density of the herbaceous vegetation on the watersheds was controlled by grazing and artificial reseeding. Throughout the period from 1915 to 1929, inclusive, watershed 'B', which at the outset had a plant cover that occupied approximately 40 per cent of the surface of the ground, was grazed by sheep or cattle once or twice each summer, sufficiently heavily to prevent increase but not so heavily as to result in decreased density of the vegetation. Watershed 'A', which had only a 16 per cent cover to begin with (p. 1. I, A), was grazed from 1915 to 1919, inclusive, in the same manner as 'B'. During the subsequent 5-year period (1920-1924, inclusive), 'A' was not graved at all, the vegetation was left to improve as rapidly as it might under natural conditions, and in addition a small quantity of grass seed was sown. Under this method of treatment the density of the vegetation on 'A' increased from 16 to 40 per cent of a complete cover from 1920 to 1924.

28. The experiment has shown the effectiveness, in reducing erosion, of restoring the herbaceous vegetation on the depleted slopes of watersheds. A 40 percent vegetative cover as compared to one of 16 per cent vegetative cover as compared to one of 16 per cent, reduced the amount of erosion caused by each 1,000 cubic feet of runoff from melted snow by pproximately 57 per cent and the average annual quantity of erosion from summer rains by approximately 54 per cent (as found by the A/B ratio). The average annual precipitation on the areas studied was 29.51 inches.

29. Only 4.6 per cent cof the average annual surface runoff was

caused by summer rainstorms when there was a 16 per cent cover of vegetation, but this runoff caused 84.5 per cent of the erosion. The remainder of the runoff, which was from melted snow, caused far less erosion. After the vegetation had increased to 40 per cent of a complete cover only 1.3 per cent of the annual runoff was from summer rains.

30. The quantity of sediment eroded by summer rainfall runoff varied more or less directly with the quantity of runoff although it was influenced to some extent by the size of runoff. The trampling of livestock, and the dryness of the soil when a runoff storm occurred.

The increase in the density of the vegetation from 16 to 40 per cent of a complete cover and the replacement of certain plants by others with more extensive and more fibrous root system reduced the rain-fall surface runoff 64 per cent and rainfall erosion 54 per cent.

31. The results show the importance of herbaceous vegetation in reducing rainfall runoff and floods and in controlling erosion. They also show the need for regulating grazing to prevent depletion of the herbaceous cover on sloping lands subject to torrential rainfall.

32. The results of the experiments conducted in other areas on the same lines have been depicted in the enclosed graphs/which show average relationship of overland flow to total ground cover and average relationship of sediment eroded to total ground cover, for storms with high moderate and low intensities. These results have been published by the United States Forest Service Intermountain Station.

33. Some studies of runoff and soil losses with different types of soil cover were also carried out in the past in the low hills at Nurpur, Kangra district and at Banni, Gujrat district by the Forest Department of the un-divided Punjab. The results of some of these investigations carried out during 1939-42 are given hereunder :—

Station	Particulars	Grass cover (Trays 1 & 2)	Grass & bush (Trays 3 & 4)	Bare soil Grass Clipped Every 8 days (Trays 5 & 6)
1	2	3	4	5
	1939-40			
Nurpur (Kangra district)	A-(i) Percentage of rainfall which runoff on 63 wet days for the total rainfall of 42.26" from 1st April, 1939 to 31st March, 1940.	10.2	10.3	59.5

1	2	3	4	5
	(ii) Weight of soil (in lbs.) lost per acre during 63 storms from 1st April, 1939 to 31st March, 1940.	1,343	1,214	24,455
	B. Weight of soil (in lbs.) lost per acre during 198 storms from 9th July, 1937 to 31st March, 1940.	6,204	6,192	68,630
Banni (Pabbihills Gujrat District)	A-(i) Percentage of rainfall which ran-off on 52 wet days for total rainfall of 21.92″ from 1st May, 1939 to 31st March, 1940.	20.0	18.0	47.4
	(ii) Weight of soil (in lbs.) lost per acre during 52 storms from 1st May, 1939 to 31st March, 1941.	7,262	6,328	32,752
	1940-1941			
Nurpur (Kangra District).	A-(i) Percentage of rainfall which ran-off on 58 wet days for total rainfall of 43.26″ from 1st April, 1940 to 31st March, 1941.	7.5	8.5	62.5
	(ii) Weight of soil (in lbs.) lost per during 58 storms from 1st April, 1940 to 31st March, 1941.	1,025	1,560	17,961
	B. Weight of soil (in lbs.) lost per acre during 256 storms from 9th July, 1937 to 31st March, 1941.	7,230	7,735	68,590
Banni (Pabbihills Gujrat District).	A-(i) Percentage of rainfall which ran off on 48 wet days for total rainfall of 24.82″ from 1st April, 1940 to 31st March, 1941.	21	18.5	47
	(ii) Weight of soil (in lbs.) lost per acre during 48 storms from 1st April,			

1	2	3	4	5
	1940 to 31st March, 1941.	9,353	7,194	61,046
	Weight of soil (in lbs.) lost per acre during 100 storms from 1st May, 1939 to 31st March, 1941.	16,615	13,522	93,798
	1941-1942			
Nurpur (Kangra district.)	A-(i) Percentage of rainfall which ran off on 18 wet days for total rainfall of 9.85" from 1st April to 30th June, 1941.	5.5	10.0	52.5
	(ii) Weight of soil (in lbs.) lost per acre during 18 wet storms from 1st April to 30th June, 1941.	178	281	5,217
	B. Weight of soil (in lbs.) lost per acre during 274 wet storms from 9th July, 1937 to 30th June, 1941.	4,408	8,034	91,808
Banni (Pabbihills Gujrat district)	A-(i) Percentage of rainfall which ran off on 58 wet days for total rainfall of 43.77" from 1st April, 1941 to 31st March, 1942.	46.4	20.1	64.5
	(ii) Weight of soil (in lbs.) lost per acre during 58 wet storms from 1st April, 1941 to 31st March, 1942.	29,398	11,371	130,362
	B. Weight of soil (in lbs.) lost per acre during 158 wet storms from 1st May, 1939 to 31st March, 1942.	46,013	24,894	224,260

34. The run-off losses from bare soil were about 5 to 9 times the runoff losses from grass covered, and grass and bush covered soil at Nurpur. At Banni in the Pabbi-hills the runoff losses from bare soil were 1½ to 3 times the runoff losses from grass covered, and grass and bush covered. Soil similarly, the cumulative soil losses from bare soil trays at Nurpur and Banni were about 12 times and 5 times the soil losses from grass covered soil trays, respectively, at the two places. Thus it will be seen that

excessive deforestation and denudation not only result in heavy losses of precipitation in the form of surface runoff but it also results in much heavier loads of silt and detritus in flood waters of our rivers.

35. A complex relationship exists between woodland cover, the use and treatment of this cover, the soil, and runoff. Species, age of stand, stand density, burning, grazing, cutting, and logging affect the physical characteristics of the surface soil horizons which in turn affect the kind and amount of runoff. It is obvious that with several cover types, numerous age classes, and several kinds of use and treatment, there could be as many as several hundered different cover complexes in the woodland areas occurring in a single watershed.

36. The rate at which the hydrologic condition of a forest area is improved, providing the ultimate hydrologic condition for the site has not been attained, depends upon the use and treatment given to the area. With the installation and maintenance of good forest management practices the rate of improvement in forest hydrologic condition can generally be accelerated considerably over that without management. The measures necessary for attaining the accelerated rate of improvement include ; (I) protection from fire, grazing, over-cutting, damaging logging, and epidemics of disease and insects which endanger forest cover, (2) tree planting in open fields, woods' openings, or as a phase of hydrologic stand improvement to induce stand conversion necessary for accelerating the improvement of hydrologic condition, (3) hydrologic stand improvement for the establishment and maintenance within the stand of hydrologically desirable species or for the improvement of soil conditions necessary for accelerating the improvement of hydrologic condition.

37. Mr.M.I.R. Khan in his paper "Forestry in relation to flood Prevention and control in West Pakistan" has rightly suggested the following measures for having effective control on floods and sediment transportation. He says that in order to be able to effectively tackle the gigantic problemes of widespread accelerated soil erosion and the more recent abnormally high floods, with which West Pakistan is faced at present, we must have a well considered and comprehensive programme of scientific watershed management and proper land use in our river catchments. In this connection the following matters which need our immediate attention are briefly discussed and explained below :—

(*i*) Fgrest Influences and Watershed Management Research :— Foresters, engineers and hydrologists need to join hands together to conduct research on forest influences for the development of suitable watershed management techniques.

Griffith (1952) emphasised the need of intensive research on watershed studies in tropical and sub-tropical countries as the application of results obtained in the U.S.A. to other countries would be very doubtful. Thus, it is very essential that watershed research be started by

BIBLIOGRAPHY

1. GORRIE, R.M., (1937). — The measurement of soil erosion and runoff. An attempt and some results. Ind. For 63 : 839-846

2. GORRIE, R.M., (1946). — Soil and Water Conservation in the Punjab viii + 290pp., Supdt. Govt. Print.Pb. Lahore

3. KITTERIDGE, J., (1941) — Forest influences. First ed. × + 394 pp., McGrraw-Hill Book Co., Inc., NY.

4. FORSLING, C.L. (1931). — A study of the influence of Herbaceous plant cover on surface run-off and soil erosion in relation to grazing on the watershed plateau in Utah U.S. Department of Agri. Washington D.C.

5. FOREST HANDBOOK Nos :

U.S. Department of Agri. Washington D.C.

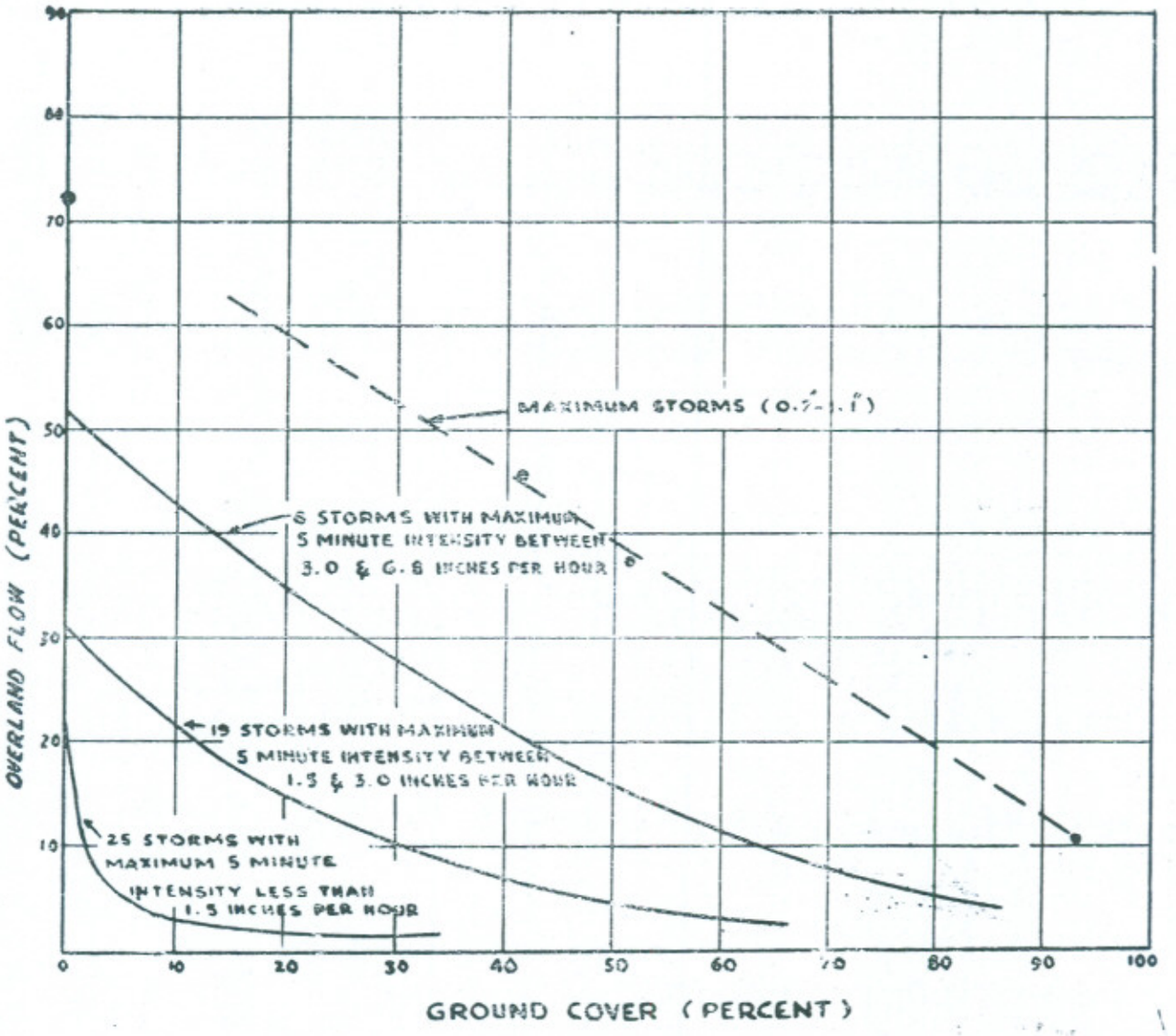


FIGURE 2 3 — AVERAGE RELATIONSHOP OF OVERLAND FLOW TO TOTAL GROUND COVER FOR STORMS WITH HIGH, MODERATE & LOW INTENSITIES, PARRISH PLOTS, 1936-53
U.S. FOREST SERVICE - INTERMOUNTAIN STATION

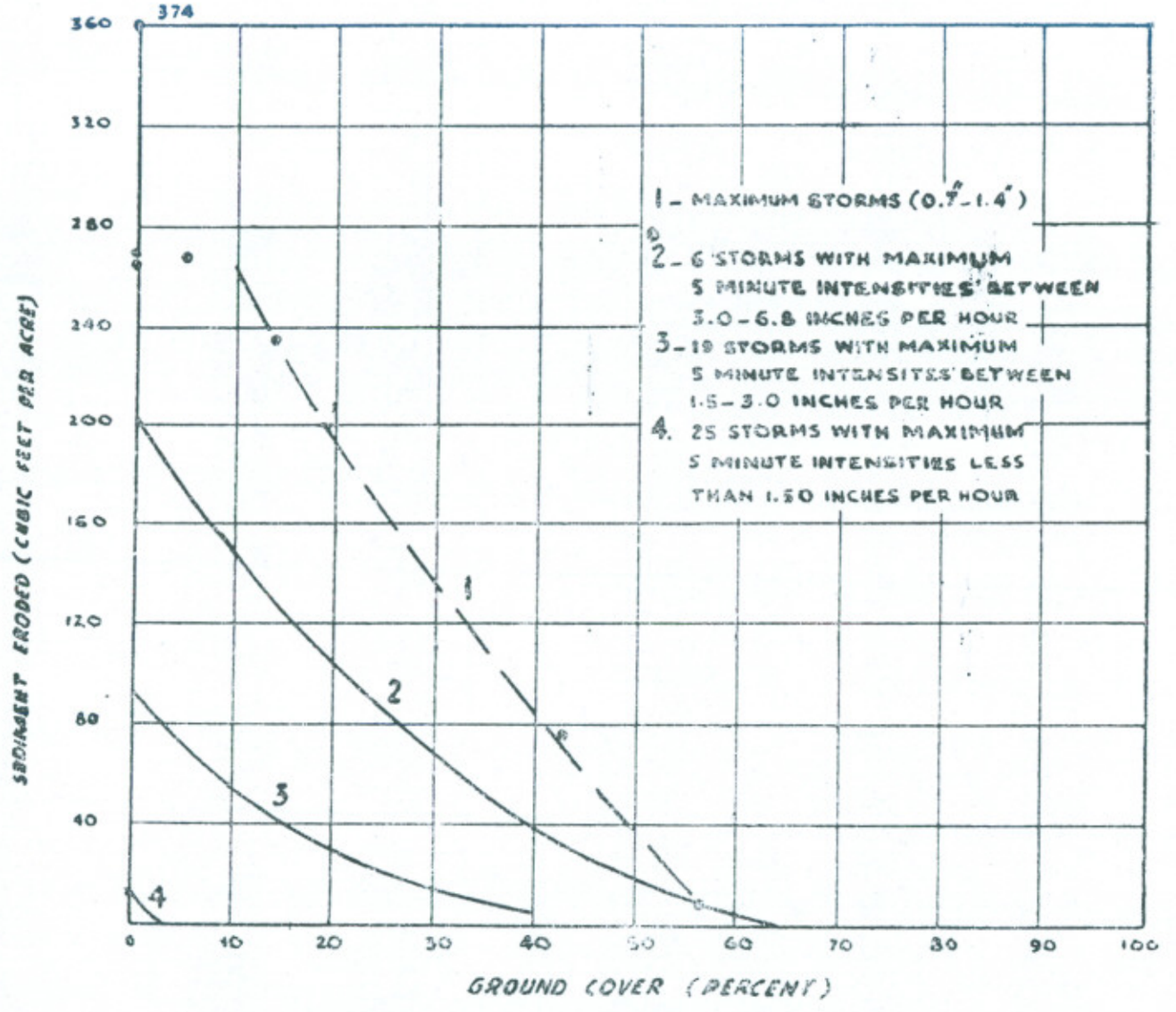


FIGURE 24 - AVERAGE RELATIONSHIP OF SEDIMENT ERODED TO TOTAL GROUND COVER FOR STORMS WITH HIGH, MODERATE & LOW INTENSITIES, PARRISH PLOTS, 1936-53
U S FOREST SERVICE - INTERMOUNTAIN STATION