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THE CONSERVATION OF PUNJAB WATER SUPPLIES

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Normal and Acccleratcd Erosion.

Those of you who have seen an intensive artillery bombardment probably consider that modern high explosives are the most destructive agent known, but the Punjab contains many square miles of desolation more terrible in its starkness than any battlefield in Flanders. The worst of the old battlefields of Passchendael and the Ancre are once again smiling fields but large parts of the Punjab foot-hills from Ambala to the Indus are being obliterated more effectively and more permanently by erosion. That this is not a local problem is proved by the ever increasing volume of evidence about the menace of soil erosion and flood damage from other continents. Practically every newspaper now-a-days contains some reference to erosion or flood losses either in America, Africa, Australia or Asia. *The Daily Telegraph* of 30th September, 1937 had a leader headed "Erosion on Five Continents may mean Food shortage", so we cannot claim that our local problem is in any way unique. Unfortunately however our local conditions do lend themselves to erosion on a gigantic scale because climatic extremes, soft rocks, steep slopes, poor plant cover, a dense population, and peculiarly thoughtless and destructive methods of farming all combine to speed up to a fantastic pace the normal processes of geological erosion on our sloping lands. In the study of stream behaviour, floods, and silting we ought to try to distinguish wherever possible between the two conceptions of normal geological erosion which is a slow but inevitable process, and the abnormal man-made erosion brought about by the destruction or alteration of the natural plant cover.

Normal geological erosion is very slow indeed. Everywhere except on desert slopes the soil accumulates more rapidly than it disintegrates under the usual natural growth of forest or grassland, and accumulation is therefore generally more active than attrition. Directly this balance is upset, losses increase at the expense of the valuable top soil which is filched away and carried off to the plains and the sea. To appreciate the effect of these changes in terms of run-off control we must know something about the storage of water in the soil. The ideal catchment area is one completely clothed in either forest or grassland, where the natural vegetation has been preserved undisturbed and has been allowed to build up a deep soil profile. The gradations from the living plant cover on top through the humus layer to the mineral subsoil below are blended into one physical unit, and this is nature's own provision for efficient disposal of rainfall. The porosity and capacity to absorb surface moisture through any complete natural soil profile is truly amazing.

Value of Plant Cover.

No matter how heavy the rainfall, a very large part of it is delayed by this surface mat of vegetation and passed downwards through the porous layers to the rock cavities and underground storage reservoirs which are the chief support of perennial springs. Anything which interferes with the porosity of the soil or with the healthy condition of the plant cover must inevitably affect the percentage of rainfall which finds its way underground. Of the various factors affecting the plant cover, such as clearing of grass-land or forest by burning or felling, ploughing, grazing, etc., grazing is probably the most widespread and most insidious. Constant heavy grazing by underfed animals such as occurs on village common lands throughout India, leads inevitably to the thinning out of the vegetation and to compacting the soil into a solid mass, so that the reduced cover is less capable of checking surface run-off and the altered soil profile or cross-section is less capable of absorbing it. This phase of soil erosion was discussed by the Punjab Engineering Conference of 1930 when Messrs. Glover and Holland presented a paper on "Erosion in the Punjab Himalayas". The gloomy picture then painted is still accurate, in fact the need for action is now greater because the effects of erosion are cumulative, the vegetation is dwindling and pressure of human and animal population upon the land continues to increase. The only encouraging features are that we now know a little more about the application of control measures, and a start in organizing effective control has actually been made in certain very limited areas.

The human population of India is increasing at the rate of 3 millions per annum and much of this increase is occurring in the drier foot-hill tracts where the rainfall is not too heavy for the persistence of natural grass-lands. In the heavier rain-fall areas further east, the re-growth of dense tropical jungle and conditions inimical for livestock have discouraged settlement. Much pressure is therefore bearing upon the *tension belt* where grassland can persist only under reasonable treatment, and if once destroyed it cannot reassert itself as easily or as quickly as it can under a heavier or better distributed rainfall. Thus it is that in many of the foot-hill grazing lands of the Punjab and N. W. F. Province, grassland as such has already disappeared and the huge herds of ravenous village livestock are dependent upon bush growth and tree loppings for their daily ration. In most countries livestock ordinarily have a ration of grass, and the bush growth of the grazing grounds is looked upon as a reserve which should be used only in times of acute shortage. In the Punjab foot-hills unfortunately the last vestiges of shrub growth form the ordinary daily ration of the village herd.

Run-off for Grazing Lands.

The amount of erosion and its effect upon the water regime caused by this state of affairs in sloping lands are clearly shown by some data of torrent intensity which have been collected in an arid tract of low hills known as the Pabbi Range which stretches south from the main foot-hills along the eastern bank of the Jhelum river opposite the cantonment and city of Jhelum. The Pabbi is a low ridge of heavily eroded Siwalik sandstone and shale and shows a variety of conditions of plant cover. The run-off or rather the peak flood discharge for a large number of separate torrents has been collected by the Irrigation staff, as they have had considerable difficulty in maintaining the Upper Jhelum Canal in face of these torrents which run at right angles to it and have to be provided with some form of syphon or discharge weir to prevent damage to the canal.

Recognizable cover types in this foot-hill jungle and the run-off data associated with them are as follows :—

(1) Part has been under a regime of afforestation and counter-erosion work for about 50 years ; such land, although not fully covered even when fully protected, yields a maximum run-off of less than 100 cusecs per square mile, enables land to be cultivated close to the streams which drain from it, and yields a revenue of one rupee per acre for grass cutting.

(2) Similar land under a passive regime of protection against grazing but with no active afforestation or building of small bunds in *nalas* yields a maximum of 600 cusecs per square mile.

(3) Similar land under grazing, partially but ineffectively controlled, yields 1,000 cusecs. Its revenue is one anna per acre grazing, and no cultivation is possible within a very wide strip of sandy waste which borders the resulting torrent bed in the flat lands below.

(4) Where persistant cattle and buffalo grazing has destroyed the cover and reduced the area to slopes of shifting sand anchored only by the relics of scrub jungle, the run-off rises to the alarming figure of 1,600 cusecs.

These figures are for small individual catchments of 2 to 10 square miles area, and this last figure therefore represents an extremely high percentage of run-off, in the neighbourhood of 90 per cent. of the rain-fall for the typical sudden torrential downpour falling on ground previously parched by drought.

Effect of Farm Cultivation on Run-off.

A further serious source of damage to the plant cover which nature originally provided is to be found in the system of field cultivation in the foothills and also in the higher hills up to the level at which summer cultivation is attempted, namely, about 10,000 feet. In the lower hills and on gentle slopes the standard of terracing is on the whole fairly good, and in certain tracts such as the Jhelum Salt Range the standard in levelling fields is very efficient indeed, either by means of stone walls or ploughed earth scooped up into contour ridges. This, however, is the exception and elsewhere the use and maintenance of *watt bandi*, the Punjabi equivalent of contour ridging, is sadly neglected or unknown. But effective terracing on slopes is unfortunately confined to the immediate neighbourhood of the homesteads where permanent fields are found. Further afield the lands are roughly ploughed for catch-crops and as the fertility of the soil dwindles the cultivation is abandoned and the lands are left fallow till they have either recovered or have been wasted away. In the hilly and more primitive tracts the steepest hill-sides are skinned of their cover, often by burning the forest, and dug by hand because they are too steep to plough. The result is an appalling waste of soil, which is washed away at the rate of as much as 150 or even 200 tons per acre per annum and each field is capable of producing potatoes for only 3 or 4 years, after which it reverts to village grazing. Persistent grazing prevents the re-establishment of the previous forest cover and the ground is eventually reduced to a bare and unstable scree of stones. With this destruction taking place over large areas of tremendously steep country exposed to the terrific onslaught of the monsoon rains, it can be imagined just how serious the effect is likely to be upon the water regime of the country as a whole.

In ploughed fields of course the plant cover provided originally by nature has been removed; in grazing grounds some vegetation still persists, while under forest it has been preserved to a much greater extent though even there the plant cover is subject to much abuse. Wherever destruction or deterioration of the plant cover has taken place, changes in the soil texture also occur. A fully preserved forest or grassland soil shows in its profile, or vertically cut exposed section, a very gradual transition through many grades down to the parent rock below, but these changes are all so gradual that there is no sudden break anywhere in the profile. Such soil with its vegetation is a living entity carefully built up through thousands of years and capable of diverting a large percentage of rain down into the subsoil and the rocks below. Whenever this capacity for absorption is upset, either by forest fires, heavy grazing or clearing for cultivation, less rain is absorbed and rate at which the water flows over the surface is increased with the natural process of erosion is completely altered. It is the quick release of this surface drainage which adds so tremendously to the problems of the water users in the plains below.

Run-off Data for Farm Lands.

At Lacrosse, Wisconsin, measurements made by H. F. Scholtz over a 3-year period have shown that 20·6 per cent of all the rain and snow falling on land continuously under maize was lost as run-off. Under a 3-year rotation of maize, barley and clover, the same kind of land lost 12·1 per cent of the total precipitation; but where covered continuously with grass, only 1·7 per cent of the water was lost as immediate run-off. These test fields were on a 16 per cent. slope and the average annual rainfall was 34 inches. The soil, a silt loam, was typical of the principal farm land in an area of some 12 million acres in the Central States, and somewhat similar to the rolling uplands and light silty loam of Jhelum district.

The corresponding losses from the different types of land were as follows: 88·3 tons an acre annually from corn land, 25·3 tons from the rotated area, and only 38 *pounds a year from grassland*, or 4,647 *times less than the loss from corn land.*

On the basis of these measurements, only 11 years would be required, under continuous corn, to remove 7 inches of this Wisconsin topsoil, which is about the average depth of the surface soil in the locality. To wash away an equivalent depth of soil from the field in rotation would require 40 years and for grass 53,000 years. The exceedingly slow rate of erosion taking place under grass (normal or geological erosion) probably means that the soil is stabilized, that is to say, soil under good plant cover builds from beneath faster than it is removed from the surface.

In view of the small loss of rain water from land having a good vegetation cover, together with the greatly reduced water losses where cropping practices are supported by protective strips of vegetation and by other adaptable control measures, such as terracing and *watt bandi*, the farmer who tries to save and protect his soil contributes substantially to the prevention and control of floods.

Types of Erosion Damage.

(*a*) *Sheet washing plugs soil pores.* The first effect of releasing a larger surface flow is for soil particles to be swept along and carried over the surface of the ground, for even when the ground is practically level, rain water gains some momentum while running off a bare surface. The effect of this is that the natural pores or spaces in the soil become clogged up with this sediment which is being washed along. This immediatley interferes with further seepage or percolation by the soil. By introducing 2 per cent. of sediment into water and making this mixture percolate through a soil surface, Lowdermilk has shown that *the rate of percolation falls off 90 per cent. in 6 hours as compared with clear water; and reverting to the use of clear water does not accelerate it afresh.* This plugging acts as if a paste were spread over the ground surface, sealing up pores and spaces. Thus silt-laden water has a disastrous effect in reducing the amount of seepage, so that more water is forced into the paths of surface drainage. It is only recently that Lowdermilk's work has given us exact information about this very important sealing effect of silt-charged run-off water.

The next thing that happens further down the slope is a sort of sand-papering action, because silt-laden water rubs away the floor and sides of the channels in which it flows. In an open field these channels form a fine net-work of "finger gullies" only a fraction of an inch deep, and in each of these fresh soil is abraded and swept away. The effect over the whole field is to carry away a thin skin of soil from the whole surface, and this is known as "Sheet Washing".

When this has occurred on a field, ploughing immediately hides all traces of this net-work of finger gullies, so that the process is not commonly recognized as it ought to be. When it occurs on grazing ground, it is checked to some extent by the mat of the plant cover, but on the other hand nothing is done to fill the finger gullies up, and so they go on cutting deeper.

(*b*) *Soil is early robbed of its valuable chemicals.* In addition to robbing the top-soil by the mechanical removal of soil particles, accelerated erosion has been proved to remove a relatively greater amount of soluble chemicals which are vital to the plant—in other words it robs the still undisturbed soil of its best chemical properties before it actually washes it away. This has been proved repeatedly by growing wheat and other plants in pots containing soil from eroded and uneroded spots from the same field: the plants in the eroded soil are always much poorer. As an example of the value of top soil lost the following figures from Rhodesia are very convincing :-

	Soil loss tons per acre.	Depth of soil eroded in inch.
Unprotected land.	30	0·2052
Protected by a contour ridge sloped 1 in 400	0·91	0·0062
Protected by a contour ridge sloped 1 in 1000 ..	0·67	0·0046

Large run-off and soil tanks were made to catch the entire run-off from these 2 contour ridges, draining areas 5·59 and 4·69 acres. The loss of plant food material was 2 to 4 lb. per acre as compared with 70 to 126 lb. per acre from the unprotected land. The value of the potassium, phosphorus, calcium and nitrogen thus lost in one year was £4-12-0 per acre from the unprotected soil.

Waksman has shown that the soil which is left behind after erosion is also poorer in the micro-organisms which are so important for the proper developent and function of roots.

(c) *Gullying destroys subsoil moisture reserve.* When these finger gullies are allowed to deepen, the next stage of deeper gullies comes on, and clefts are formed which bite down through the top-soil to the subsoil. This may be more easily eroded than the top-soil, and if it is, the surface is very soon cut up into blocks separated from each other by ever deepening gullies. Not only is cultivation rendered difficult by these obstacles ; the ground is also artificially drained to a greater extent than formerly, so that the blocks of soil that are left are much drier and less productive. Similarly in grazing land or in forest where deep gullies are allowed to form, the previous moisture balance is up et and the existing plants can no longer remain healthy because the moisture ration has been reduced. In the case of deep rooting trees such as oaks, the old crop will persist for some time but the regeneration of young trees to take their place will be prevented by lack of moisture, and so that crop inevitably dies out.

Effect of Single Heavy Storm. Deep gullies are often formed as a result of one phenomenal storm of sustained and heavy downpour falling on land which has been unduly exposed by misuse in the past. Once these gullies have been cut out, the ground can never return to its former productive capacity because the whole drainage regime has been changed. It is not the average rainfall that does most damage, but a single infrequent but exceeding heavy storm which by cutting out fresh gullies starts a new cycle of erosion. Many local instances of this could be quoted for September 1924 in the Eastern Punjab hills and for August 1929 in the N. W. F. Province. Examples of actual erosion measurements for single storms are :-

WATER AND SOIL LOSSES FROM RAINS OF RECORD INTENSITY AT FIVE SOIL AND WATER CONSERVATION EXPERIMENT STATIONS.

Station.	Date of Rain.	Rainfall. Amount	Rainfall. Duration	Intensity. Actual Rate.	Intensity. Max. Rate	Cover.	Slope.	Run-off.	Soil Loss
		Inches.	Hours.		Inches per hour.		Per Cent	Per Cent. precipi-tation.	Tons per acre.
(Tyler, Texas fine sandy loam).	May, 8 & 10 1936.	4·7 5·13	9·17	1·08″ in 5 min.	12·96	Bare, Grass, Forest.	8·8 16·5 12·5	34·92 ·35 ·36	44·49 None ·010
(Guthrie, Oklahoma fine sandy loam).	May, 31, 1932.	3·04 3·04 2·81	10	1.5″ in 20 min.	4·5	Bare, Grass, Forest.	7·7 7·7 5·2	53·06 2·30 0·26	2·59 ·015 ·005
Hays, Kansas silt loam).	August, 1, 1932.	1·50	·66	1.4″ in 20 min.	4·2	Bare. Grass.	5·0 5·0	59·2 1·2	4·07 ·01
(Bethany, Mo. silt loam.)	April, 3, 1934.	3·75	9·25	2·85″ in 90 min.	1·90	Bare, Grass.	8·0 8·0	52·7 39·2	28·50 ·09

General Increase in Draught Damage and its Cause

Frequent references are to be found in Revenue settlement revisions in both the Punjab and N. W. F. Province (e. g., Mansehra Tahsil) which indicate very clearly that there is a progressive desiccation being experienced in cultivated lands. This deterioration is widely distributed throughout all the *barani* lands (bearing rain-fed crops), but naturally one would not expect it to be noticeable in the larger canal colonies. Even in these, however, the shortage of winter water for *rabi* crops is a common complaint, except in those relatively small areas which are actually suffering from water-logging through a cumulative rise in the subsoil water-table. Our chief concern is with the rest of the farm tracts which are not irrigated except from small local streams or by wells. In these the increase in drought damage is too great to be explained by minor changes in the climate cycle. The increase is undoubtedly due to the growing in ability of the soil to retain whatever moisture falls upon it, because through erosion the wasted top-soil is being replaced by the less absorptive clay which usually forms the sub-soil. This cumulative failure of the soil itself to soak up and retain rain water is of far more importance in causing drought than any minor changes in the actual amount of rainfall, though its importance has not yet been grasped by either zamindars or officials. Its effect is most evident in *barani* lands which are directly dependent upon the storage of a part of the rain which falls upon them, but indirectly, though no less surely, it must affect well levels for *chahi* irrigation and also the winter level of small streams which depend upon springs and underground seepage of water for their winter flow. This failure to absorb and pass downwards a share of the surface run-off should be felt least of all in the larger rivers which depend upon the great snow-fields and glaciers for most of their supplies, so that the big canal colonies are least likely to be affected, but even in these big rivers *the winter flow* depends to a great extent upon the subsoil drainage which reaches their foothill tributaries, and so they too are bound to deteriorate in their winter flow owing to the widespread desiccation in the foothills. Drought damage is often regarded as being an inevitable scourge, particularly amongst the fatalistic Punjab peasantry. Actually a well directed programme of water conservation would do a great deal towards improving the position both of the unirrigated tracts and of the *rabi* supplies for the canal colonies. In the unirrigated parts of the province the most pressing water supply problems are in the semi-arid northern districts where the rainfall is uncertain, though the problem occurs in some form throughout the Punjab. Where the Forest Department has had full control their areas form the sole examples of effective conservation but unfortunately the department has no control over common grazing lands.

Winter Runoff Localized in Uhl Catchment Area

The Punjab run-off problem was discussed at the 1937 meeting of the International Commission of Snow by Dr. J. E. Church, the president of that body. He drew a detailed comparison between the Californian Sierra and the Punjab Himalayas as regards topography, climate, latitude, temperatures, storm seasons, and snowfall and showed that in both countries the ground above the 9000 feet contour contributes practically nothing to the winter run-off. The higher ground is frozen under its mantle of snow during the winter months and seepage from the snow itself is small. The main winter supply therefore must come from the foothills and lower slopes of the main range below the 9000 feet line and as the majority of this is not under forest but is either cultivated or heavily grazed, the lack of an efficient water-conserving plant cover is likely to be seriously felt in dwindling nadir flow each winter.

This prognostication from a well known outside authority is borne out by our own experience. From the changing colour of the water in the Kangra streams we know that winter rain or snowfall carries practically no silt from the higher ground, but a heavy silt load from the lower slopes. A recent survey of erosion conditions in the Uhl valley which supplies the Mandi Hydroelectric Plant showed that the extremely low nadir flow in January each year is directly traceable to the appalling condition of the valley bottom between 6000 and 9000 feet, where 55 per cent of the 21,000-acre farm belt is eroding seriously as a result of potato farming on unterraced ground and overstocking of the grazing grounds. To appreciate the effect of a good plant cover in vitally important catchment areas such as the Uhl, let me quote figures of run-off losses from the Susquehanna river basin in New York State for March 1936. This catchment is not nearly as steep as the Uhl but the method of potato farming and the types of natural plant cover on uncultivated ground are somewhat similar. The loss of water as immediate run-off from a potato field was 88 per cent of the total precipitation, on land having a slope of 14 per cent. Of 9·47 inches of rain and snow 8·38 inches was lost as runoff during this critical period. In contrast, the corresponding loss of water from a neighbouring forested area having a 27 per cent. slope was approximately 0·5 per cent of this total precipitation which included both the rain and the snow that had accumulated before the rain. It is interesting that the ground beneath the cover of forest litter was not frozen, whereas that in the potato field was frozen. Still more surprising was the fact that from neighbouring grassland, with a slope of 20 per cent, the run-off was less than 0·2 per cent. of the total precipitation, and there was no measurable erosion. In this last instance, the ground was not frozen.

Recommendations for Action in Uhl Catchment

These figures may give you some idea of what I believe to be happening in the Uhl valley. On the basis of my detailed survey of the Uhl catchment I have recommended to the Punjab Government that drastic action should be taken against the two main evils of bad farming methods and over-grazing. A committee has been formed and its report is still *sub judice*. Some action has already been taken to control the migrant flocks of goats and sheep, but nothing has yet been done to improve the cultivation, which is in this case the greater evil. My proposals which are still under consideration by the Punjab Government were that the worst unterraced fields be acquired, taken out of cultivation, and planted up under a reforestation scheme in which individual blocks will have a minimum area of about 50 acres per block so as to make fencing reasonably cheap.

From prolonged study of this subject in many lands I feel sure that the immediate afforestation of one third of the Uhl farm belt and an improved farming regime in the remainder of it would have the effect of raising the winter nadir flow by 500 per cent., i. e., that instead of the present nadir of 80 cusecs you would have a guaranteed minimum of 400 cusecs, no matter what might be the vagaries of the winter climate. It would of course take a few years for any such afforested area to develop its full value as a run-off control, so the sooner the work is started the better. Acquisition and planting of 7000 acres on a ten-year programme would cost roughly Rs. 3,50,000 or including propaganda and demonstration of better farming practices say 4 lakhs. This seems a small amount to spend as an insurance against deterioration and calamities which are inevitable unless some such action is taken. The amount of money already invested in the Uhl project is 8 crores so that those 150 square miles of mountain fastness carry an investment value of Rs. 830 per acre if you include the whole area, or nearly Rs. 4000 per acre if spread on the land yieding the winter run-off. The present revenue obtained by Government from the farming and grazing community amounts to one quarter anna per acre. These figures show strikingly how much more valuable this land is for water conservation than for any other purpose. One can only marvel at the sublime faith of the engineers who planned such a project and based all their calculations on a stable water regime when actually the water conservation is each year becoming worse, and the water regime is very far from being stable.

Recommendations for Rest of Foothill Districts.

These recommendations for the Uhl catchment are admittedly drastic and expensive, but they are framed to save a small area which is of particular and vital value for the whole province. In the rest of the province we cannot afford large expenditure, and improvement can come only in so far as we can teach the villagers to take up conservation work themselves. Great credit is due to the Punjab Government for having gone ahead in Hoshiarpur and more recently in Jhelum with encouraging wholesale closure of eroding slopes by persuading the villagers to substitute grazing with grass cutting. The point I wish to impress upon this conference is that there are really vast possibilities for improving water conservation every where without incurring any very heavy expenditure. The main lines of attack can be combined under the American's name of "upstream engineering" which combines the botanical and land management phases in producing a better plant cover, along with elementary engineering practice in building a series of low bunds in each stream bed to delay and spread out the actual run-off peak stop further erosion of the stream bed itself.

Improvement lies in a well considered programme for better farming practices to conserve run-off on all cultivated ground; better control of livestock to prevent overgrazing and conserve the soil cover; check dams and water-catching projects in all the smaller *nalas* which drain the upland grazing grounds and forests in each small catchment area. Droughts are merely the troughs or low supply periods between floods, and any work that is undertaken to check and reduce the intensity of floods will naturally have the effect of smoothing out the curve of seasonal supply and eliminating the troughs of severe water shortage. The simpler the engineering and the closer the attention to run-off conditions in the head of each small catchment where percolation helps underground storage, the better will be the results in eliminating the drought bogey.

DISCUSSION.

The **Author** in opening the discussion on his Paper, said that the subject of soil erosion had become of *news value* and Glover and Holland's Paper at the 1930 Engineering Conference had done more than any other single contribution to rivet Government's attention on this problem. Soil erosion was a very large factor in the complex problem of available water supplies.

The *simile of the sponge* used in describing the value of forest in run-off control had, like all similes, its limitations. A sponge might become completely saturated but the soil could not. If we considered the column of soil above the average water table level of 30 ft., it was capable of absorbing a much larger quantity of water than fell in any one storm. The top layers of soil might be gorged with water but the whole column formed a dynamic sponge which could not be saturated. Lowdermilk's Berkelay experiments had shown clearly that the value of a forest litter lay not so much in its capacity to absorb as in its enabling the soil column below to function at full capacity in transmitting water underground to the lower parts of this absorptive column.

The usual *forest* soil had a leached profile, *i.e.*, a deep layer of humus and powdery soil (the **A** horizon) from which the bases had been leached out and carried down deeper to form a more clay-like second layer (the **B** horizon). This denser layer was kept permeable by the penetration of roots and worms and other animals' activities, all of which together had a honey-combing effect. (See Figure 1).

Grassland gave a more shallow **A** layer and although the **B** layer might be less dense it was not so completely honey-combed, so that the water storage capacity of the top layers was soon reached and the excess water in heavy rain was discharged as surface run-off. In the case of *ploughland* a *plough sole* was formed below the over-turned layer and each ploughing tended to seal up any root holes or downward passages, so that whatever sieve action the soil had when a crop was reaped was largely destroyed before the next one was sown. The capacity of plough land to absorb was decidedly poor when compared with either grassland or forest.

In the case of village *grazing lands*, particularly in the foothills, there was nowhere a complete plant cover. Mechanical attrition of animals' feet prevented any building up of the soil. The heavy surface run-off caused constant flux of the smaller particles which plugged the pores of the surface soil during each storm so that the ground became less pervious as soon as the first few drops had soaked in and surface water movement took place.

The breaking up of rock was dependent upon the plants above it. Bare gneiss would last thousands of years if kept exposed, but the same rock acted upon by humic acids from a forest floor was rotted and broken down comparatively quickly. The weathering of rocks was hastened not by pure rain but by rain carrying plant acids.

Recent run-off data collected at Nurpur Kangra showed the following results :—

	Grass, 80% cover.	Grass and shrubs, 90% cover.	Bare soil-Grass clipped every 3 days, 20% cover.
Percentage of rain which ran off :—			
Out of total of 46 inches on 32 wet days during July-October 1937.	7%	5%	25%
Out of total of $5\frac{1}{4}$ inches in 4 hours in a single storm.	2·2%	1·7%	6%
Weight of soil lost per acre in lb. :-			
Carried away on 32 wet days.	3500 lb.	3900 lb.	18,500 lb.
Carried away by a single storm.	260 lb.	307 lb.	3500 lb.

These figures were collected on the lines laid down by the Irrigation Research Institute whose co-operation the Author gratefully acknowledged. The first set of run-off trays had been made by the Institute and set up at Madhopur, and a complete routine worked out so that volumetric analysis of run-off could be made.

American diagrams were also shown indicating the serious effect upon water supply where the forest floor was disturbed by fire or grazing, the run-off being speeded up alarmingly. Run-off from crops was also shown to be much better controlled by rotations of crops than by continuous maize. The loss of soil and water from bare fallow was also emphasized by figures and slides, and lantern pictures showed the bad condition of the farmland in the Uhl valley.

In the *analysis of stream flow* such as had been attempted by the Irrigation Research Institute for the Ravi river one could not expect to find any direct correlation between rainfall and stream behaviour for a very large catchment. Rainfall was either absorbed by the soil or ran off the surface and this was a simple phenomenon, whereas streamflow was a built-up complex result of a number of other factors beside this one, such as depth of rotted sub soil material, porosity of underlying rock, dip of rock towards or away from each stream bed, artesian water action, and the regeneration of water in channels such as the Irrigation Branch made such good use of in the Sutlej. Such factors were mostly hidden and could only be guessed at. All we were sure of was the percentage of rainfall which if not caught and redistributed by the plant cover rushed madly off to form sudden floods.

Mr. **N. D. Gulhati** said that on the authority of Dr. J. E. Church, President of the International Commission of Snow, and on the basis of his own observations, the Author stated on page 206 of his Paper, that the main winter supply of the Punjab rivers was not, as generally understood, from the perpetual snows on the Himalayas, but from the foot hills and the lower slopes of the main range below the 9,000 ft. line. This statement coming from such a high authority needed to be examined in detail by the canal engineers both as to its correctness, and as to its far-reaching implications.

The Irrigation Department had been, and was spending, and very rightly too, lakhs of rupees on the conservation of water once it had come into their possession ; but no attempts had so far been made to control and augment the river supplies at their source. That this could be done, had been amply shown in the Paper under discussion and no time should be lost by the various departments of Government and the public at large in joining hands and working for it.

Regarding the usefulness of forests and plant cover in general, there was one aspect of the problem that the Author had omitted from his Paper. It was perhaps not generally realized that the total evaporation from an area covered by forests was much more than if the same area were an inland lake. By total evaporation, the Speaker meant evaporation from the soil, transpiration by plants, and direct re-evaporation from the surface of leaves, which last was as much as 30% of the rainfall. An estimate of the quantity of water returned to the atmosphere by various kinds of vegetation had been made by Mr. W. Harrington and described in Bulletin No. 7 of the Forest Division of the U. S. Department of Agriculture. The total evaporation from the area under forests had been estimated as one and a half times that from the open water surface ; and from areas under grass, it was nearly twice as much. The existence of forests and vegetation cover in the foot hills, therefore, not only conserved the water in the sub-soil as described by the Author, but it helped in retaining in the very atmosphere of the place a good part of the total available moisture which came down later in one form or another.

The removal of vegetable cover had another indirect effect on the conservation of supplies. When erosion of soil took place at rates so enormous as described by the Author, the flowing stream became heavily charged with silt which it deposited at the first opportunity and this filled in natural pools and reservoirs, thereby reducing the storage capacity of the catchment area.

Mr. **G. R. Sawhney** said that had a little more detailed advice on the ways and means to accomplish the Author's aim been incorporated in the Paper, it would have been very much appreciated, as it would have helped the members to find some suitable solution for the various problems that were prevalent in different tracts; while others, for example, could go back and advise in the Pabbi areas on constructing adequate ridges, trenches, etc.

The Speaker said he was glad that the Author was hopeful of some control measures that he knew of and which were under investigation. He thought nothing short of very elaborate legislation would meet the necessity, if some real and lasting results were to be obtained.

He did not agree with the Author regarding his assertion that much of the annual increase in population was occurring in drier parts only, because from what he knew the Colony areas could not very well be beaten in this respect.

If the supplies could be conserved so well and so easily, surely then the Punjab Government should at once go all out for dealing with this matter and also persuade the Hill States to act in the same way; it would be comparatively easy to accomplish and be beneficial in these States.

This conservation of water supplies, if successfully done, should save us from having to construct the Bhakra Dam.

It might also save us from introducing silt excluders everywhere. It would further ensure the working of the Jogindarnagar Hydro-electric Scheme as well as making the desolate parts of the country green and productive. He hoped the Author's proposals would not lead to taking anti-waterlogging measures at the foot of the Himalayas.

He would suggest that dairy farming on a big scale with large areas as pastures and paddocks, if enforced and encouraged by the Government, would help a good deal.

Finally, in his opinion, the Commissioner for Rural Uplift could help a great deal in this matter if his staff could also carry on this propaganda with their own programme in areas in which it was needed.

Mr. **R. W. Thick** said that rainfall records had been maintained for Brot from July 1930 onwards. A tabulated statement had been prepared to show the number of rainy days in each month from July 1930 to December 1937 and also the corresponding total rainfall in each month. It would be seen from this statement that the annual rainfall at Brot had varied between 95·54 and 55·76 inches, with an average of 73·5 inches. If this figure were the true average rainfall for the whole of the catchment and if the whole of this precipitation were to be absorbed into the soil and passed back uniformly to the streams above Brot, the discharge of the Uhl would be $\frac{50 \text{sq. miles} \times 640 \text{ acres} \times 73{\cdot}5}{12 \times 365 \text{ days}}$ or 1,600 cusecs. Since however, the minimum discharge was only 100 cusecs it was inferred that run off, evaporation and losses now amounted to no less than 94% of the total precipitation.

The Author had indicated how some of this waste might be utilized.

If, as appeared probable, afforestation could reduce the run-off and other losses to 10% then the discharge that could be expected by acquiring and afforesting 7,000 acres would be :—

$$\frac{7000 \times 73{\cdot}5}{12 \times 365} \times 0{\cdot}9 \text{ or } 106 \text{ cusecs.}$$

Of this quantity some $\frac{7000 \times 73{\cdot}5 \times {\cdot}06}{12 \times 365}$, or 7 cusecs was already being yielded by this area. Therefore the afforestation of 7,000 acres as proposed might be expected to yield roughly an additional 100 cusecs.

The above estimation neglected any effect which might result from a reduction of grazing and the introduction of better farming methods, but it would appear as if the Author expected to gain another 200 cusecs from these sources. Would the Author please confirm this and give details of his calculations?

The addition of 100 cusecs to the minimum winter discharge of the Uhl by afforestation alone would be of great benefit to the Mandi Hydro-Electric Scheme because it would enable the Jogindarnagar power-house to handle a peak load of about 48,000 KW, if the daily load factor were 50% as against 24,000 KW, this being all that was possible under present water conditions.

The Author stated that the acquisition of 7,000 acres and its afforestation on a 10-year programme would cost about Rs. 3,50,000. The cost of a dam for creating an artificial storage reservoir capable of giving the same results would probably be not less than 1½ crores, and might be much more. Therefore it appeared that it would be worth while for the Punjab Government to adopt the Author's proposal.

It was observed that the Author contemplated a 10-year programme of afforestation. The Speaker was not sure whether this implied that he proposed to take 10 years to acquire and plant trees on the 7,000 acres contemplated or whether the work would be done in a much shorter time and become effective in 10 years. In either case, at the present rate of development, the growth of the electrical load in the Punjab would have outgrown the supply of water to the present station long before the proposed plantations could come into effective operation : but this need not prevent this scheme from being taken up because by building the second power station below Jogindarnagar, to use the water discharged by the present station, or by thermal stations on the plains, or other hydro-electric developments (e.g., canal falls) would be possible to cater for the load development until such time as the additional water supply resulting from afforestation became available.

In view of the probable length of time required for the proposed forests to mature it might be of advantage to deal with a larger area in the first instance by taking up, say, 15,000 acres and afforesting them on a short programme of, say, 3 to 5 years. 7,000 acres might be the worst fields referred to by the Author. The balance might consist of the worst grazing lands and any bare waste available.

It should not be overlooked that any means of increasing the supply of water to the Mandi Hydro-Electric Scheme benefited the Punjab twice over, first, by increasing its power supply and secondly by increasing the amount of water available in the Beas for the use of the Irrigation Branch.

(For particulars of rainfall at Brot, see Apendix).

Mr. **M. L. Mehta** said that the most important point brought out by the Author was the extreme utility of the vegetation cover in preserving rain water and preventing run-off. A statement had been prepared to show that on account of denudation in the hills and the consequent greater run-off, the intensity of the floods had increased and the rabi supplies in the rivers had decreased. The investigations carried out in the Irrigation Research Institute had shown that, unless the ratios of run-off to the total amount and the intensity of rainfall were worked out on the basis of exact measurements for Punjab conditions and unless the methods for the measurement of vegetation and denudation were evolved, the river discharge data and figures for total rainfall were not enough for investigating the effect of these factors on the *rabi* supplies in the rivers. Work in this direction had been in progress in the Irrigation Research Institute. The apparatus for collecting run-off and the eroded soil had been evolved. A botanical survey of the vegetation in the area under examination had been made with a view to getting out standards for vegetation. For finding out the intensity of rainfalls a recording rain gauge had been installed. Investigations for collecting the necessary data had been started at Madhopur in land having a slope of 1 in 4. From the data collected so far, it appeared that the percentage run-off depended more on the intensity of rain than on the total quantity.

From the point of view of erosion, results obtained for the monsoon period of 1937 showed that land devoid of vegetation lost approximately 28,000 lb. of soil per acre, whilst those carrying vegetation lost 1,100 to 1,600 lb., depending upon the type of vegetation.

It was well known that phosphatic manures caused a much more enhanced development of the underground collective apparatus of the plant, especially the lateral and fibrous roots which bound the soil particles. It was suggested that, where quick results were needed, for example, in preventing erosion in the catchment areas of some of the siphons on the Upper Jhelum Canal, phosphatic manures might be tried simultaneously with other methods of establishing vegetation.

There was one other important point which Dr. Gorrie had mentioned and that was the loss of the manurial ingredients from the eroded soil. This was perfectly true and confirmed the cultivator's practice of keeping his *wats* intact and allowing very little rainfall to drain off from his fields. In this connection one should remember that approximately 70 per cent. of the area lay fallow in the *kharif*. This brought us to the question of the rise in the water-table in the canal colonies. If surface drainage were made more efficient by taking as much water out of the fields as possible the manurial constituents were lost. If this were neglected the rise in the water-table would be more rapid. It became extremely difficult to choose between the two evils. To the Speaker it looked as if the future of Punjab agriculture in the colonies should be calculated in terms of a high water-table and a combined system of irrigation and drainage.

There was one question that the Speaker would like to ask the Author and that was with regard to the influence of the water-table on run-off. The preliminary observations made by the Irrigation Research Institute indicated that the run-off was affected by the upward pressure on the water-table. If the Author had any observations for hill areas they would be very helpful in interpreting the data obtained in the plains. In the hills also, the water-table varied very considerably, *e.g.*, in Kangni near Manali in the Kulu Forests Division the water-table was very high, in spite of the fact that the land had a very steep slope.

Mr. **C. C. Garbett**, Financial Commissioner, Development, was invited to speak. He said that he had come not to speak but to learn from the technical specialists. Advice already tendered was under the careful consideration of the Government, who realized the necessity of better management of village estates in forests areas. One speaker had suggested that everything could be put right by the magic wand of legislation. Government, however, was no longer autocratic and could not compel action against the wishes of the people. The present Government, while honestly trying to follow the wishes expressed, was trying also to spread enlightenment so that those wishes might be sound. He himself had recently been employed as President of a commission of enquiry into certain forest matters. (The report was in the press). It contemplated in effect the preparation of a working plan for each village as an economic unit in order to provide for the prevention of erosion and the better utilization of all waste land; and also the association of the villagers in the execution of the plan. He had found the villagers quick to understand the danger of erosion and ready to co-operate where facts were clearly explained to them. But a passing commission could only have a temporary effect. Success in the future demanded education.

The Engineering Conferences of the past and present had proved that erosion was a menace. The Government recognized that menace and was actively following the advice given. What was now wanted was a more specific indication of the areas in which the erosion was greatest. For this, Government looked to the advice of the engineers and foresters. When this had been received, the conference should rest assured that action would follow.

Mr. **F. L. Brayne** was invited to speak. He said that education was the only means of awakening public interest. At present the Forest Department was "Public Enemy No. 1" largely because of ignorance of the real aims of conservation. The public must first be convinced before any legislation or programme of work was possible. He thought the Punjab Canal Projects, without proper attention to water supply conservation, were like a canning factory built without any regard to the supply of fruit which was to be canned. The cost of silt clearing in the canals was far greater than the cost of preserving the hillsides from where silt came.

Suppose, the Speaker said, when an engineering project was prepared in which floods or water supply from hills was concerned, alternative estimates were to be drawn up, one assuming reasonable care of the catchment area and the cost thereof and the other assuming continuance of the denudation which was now going on. It was possible that Government and the public would be so shocked at the difference in cost that they would prefer the cheaper and more profitable alternative which included afforestation.

Mr. **H. M. Glover**, Conservator of Forests, thought that the Congress would like to learn what had been accomplished or attempted in the matter of the control of erosion since he and Mr. Holland had been privileged to address them in 1930. Firstly, the late Colonel Battye had asked him to help to check erosion where the Jogindarnagar pipe-line was threatened by slips of the surface soil. Closure and planting were recommended and as large an area as could be obtained with the permission of the Mandi State was fenced and planted. In addition, crated bunds were erected in the nullahs at considerable cost. The response of the natural vegetation had been magnificent and the protection afforded thereby was sufficient to prevent further slips, in spite of the fact that many of the original bunds had been broken by the force of water before the vegetation had been restored.

Perhaps the most important result of the 1930 Paper was the gradual re-awakening of interest in the forests of the Himalayas and of realization by the Punjab Government and the public at large of the role played by forests and vegetation in the conservation and regulation of water supplies in the Punjab rivers. The Punjab Government had not been slow to take action ; it realized that the main cause of erosion was the destruction of the trees, bushes and grass by over-grazing. Mr. Calvert caused an economic enquiry to be held in the Dehra Tehsil of the Kangra District in which the part played by forests in the economic life of the district was clearly shown. In 1932, an Erosion Committee was appointed to enquire into conditions throughout the Province. In 1934, Mr. Hamilton, Deputy Conservator of Forests was detailed on special anti-erosion duty in the Hoshiarpur and Ambala Siwaliks where torrents from the sandy hills had destroyed thousands of acres of valuable farm lands. A committee was called by the late Mr. J. A. Ferguson, Financial Commissioner, Development, when it was decided that Mr. Hamilton should endeavour to induce the villagers to close their forests voluntarily to grazing ; failing that, Government would compulsorily close forests under the *Chos* Act. In this policy Mr. Hamilton had been remarkably successful, particularly as the landlords found that they made a large income by the sale of hay harvested from enclosures which formerly had provided only the poorest quality of grazing.

Meanwhile the Author of the Paper had obtained a travelling fellowship to study erosion in America where grazing had destroyed the vegetation over vast areas and erosion was a grave menace to farm lands and water supplies. On his return he was so impressed with the gravity of the situation in the Punjab and with the need for remedial measures similar to those being undertaken in the United States that he repeatedly urged that more drastic action should be taken, particularly as regards the conservation of the few remaining forests ; the improvement of grazing grounds ; the reduction of flocks and herds ; and the better cultivation and terracing of hill fields.

An Erosion Committee of Commissioners, District and Forest Officers met at Simla in 1936 under the presidency of H. E. the Governor at which it was decided to depute Forest Officers to study and report on erosion in the Ambala, Jullundur and Rawalpindi Civil Divisions. The need for special measures in the Uhl Catchment area of the Hydro-electric scheme was discussed and had been reported on by Mr. Sheepshanks, Commissioner of the Jullundur Division, and Mr. Glover. Their proposals, though sufficiently drastic to effect a definite improvement in conditions, did not impose a limit on local flocks as this was not legal until the current Land Revenue Settlement was revised. They had not accepted the Author's recommendation to acquire and afforest a large proportion of the existing cultivation as this was thought to be of less importance than the conservation and improvement of indigenous vegetation. Mr. Glover considered that the Author was optimistic in claiming for afforestation a 400% increase in the minimum flow of the Uhl and thought that the engineers would think that an increase of 25% would be well worth while.

During the past winter a Forest Enquiry Committee consisting of members of the Legislative Assembly and presided over by Mr. Garbett toured through the low hills and were so impressed with the poor condition of the village waste and the urgent need for its preservation that for Kangra, they had recommended that Government should constitute village forest from the Reserved and Protected Government forests and from the village waste. These village forests would, to begin with, be managed by the Forest Department according to plans drawn up, after an expression of opinion by the village committees and approved by Government. If the village estates in the hills were properly managed a check would automatically be given to erosion and it is hoped that a similar practice would eventually be adopted in other districts.

The lines of policy advocated by the Author differed from those adopted by Government only in one particular, namely, the extension of control to cultivated lands and the compulsory terracing of all fields in the hills.

The control of erosion was not however simply a technical operation as its repercussions affected the whole of the economic and social life of the hill communities. The policy must be to progress slowly but surely by making the villagers themselves realize the benefits they would receive from the proper management of the village waste.

The **Author**, in reply to the discussion on his Paper, said that practical demonstrations of the *revival of streams* could already be seen in several of the areas dealt with by the U. S. Soil Conservation Service since 1933. The South Fork Palouse River in Washington State formerly had sufficient perennial flow to harbour large trout, but 16 years ago the dry season flow had vanished altogether owing to destructive farming practices on steep slopes. 53,000 acres of farms were improved by contour ridging, stopping bare fallow, restoring permanent grass, and afforestation of the steepest slopes from 1934 onwards and already 15-inch trout were re-established in the revived perennial stream. Similar statements could be quoted for a variety of climates from the forest region of northern New York State to the wheat belt and the arid South-West, but unfortunately the Author could not quote actual stream-flow *minima* under improved land-use regime to show quantitative recovery.

As an example of what could be achieved in *altering the percolation percentage* he quoted recent figures for the terrace trenching of steep scrub jungle hillsides in Utah, with wide trenches 25 ft. apart, carefully levelled along the contour and with a vegetation cover of grass and bushes resulting from two years planting and protection. In a storm with an intensity of 1·3 inches in 15 minutes the run-off from the unterraced land caused a disastrous mud flow which dumped boulders and rock debris in the farm lands below. The same fall on the terraced portion caused no serious rise in the stream and 150,000 cubic feet of water caught in the trenches on about 100 acres disappeared by seepage in 6 hours. Such terraces had proved particularly effective in controlling snow melt where sudden thaws affected the lower fringe of the permanent snow belt and so should be of particular value in the Uhl. Snow melt in winter contributing immediately to run-off and percolation, was probably confined to (*a*) the narrow fringe along the bottom of the unmelting snow line at about 8-9000 feet on north aspects and 9-10,000 feet on south aspects *plus* (*b*) all the precipitation which fell as snow below this and which melted within a few days or even hours. American data indicated that run-off consisting of mixed rain and melted snow was distributed between surface run-off and percolation in much the same ratio as in rain storms except when the frozen condition of the surface was the controlling factor. Data already quoted in the Paper showed the effect of both forest and good grassland in *preventing the freezing of the surface* and this in itself should guarantee much better percolation and prevent flash run-off from bare frozen ground from winter storms.

As regards *transpiration and evaporation losses*, data for the basins of three American rivers with a rainfall of from 41 to 54 inches and catchments of 3000 to 6000 sq. miles showed that their normal loss by evaporation and transpiration (the difference between precipitation and total stream-flow) was from 53 to 62%; corresponding figures for Britian were 50% for the Severn and 63% for the Thames. The South Indian data quoted by Buckley were not applicable to the Uhl conditions where evaporation loss should be less than shown by him. *These losses were largest in spring and early summer and decreased to a very small amount during autumn and winter.* This was in accordance with the known facts of water used by plants. The transpiration losses for forest plantations of deodar or deciduous broad-leaf species, such as chestnut or poplar, in the Uhl would be very small during October to February. Grassland probably had higher transpiration losses during these months in the Himalayas but, the Author said, we badly needed better data on this point. Evaporation from any plant cover was in more or less direct ratio to the maximum temperature, so for these months in the Uhl it should be very low. On both counts therefore we could take it that the transpiration and evaporation losses in October-February would be very much lower than in summer.

The Author said that the good French example of the value of a forestclad catchment area was quoted recently by A. Magnein, the French delegate at the U. S. Upstream Engineering Conference, 1936.

	Percentage wooded.	Ratio of maximum to minimum stream flow.
River Verdon at Greoux.	42%	0·36
River Arc at Termignon.	16%	1·156

A combined programme for the Uhl farm belt with afforestation of 7,000 acres, contour trenching and grass cover on 11,000 acres, and efficient terracing and cropping on the remaining 3,000 acres of cultivation could therefore be expected to produce a minimum flow of 400 cusecs on the basis of the following figures, which did not differ to any great extent from those of Mr. Thick :—

Maximum flood discharge so far registered 20,000 cusecs
Minimum winter ,, ,, ,, ,, 100, cusecs

(the figure of 80 cusecs quoted in the Paper was for one hour only, the average for any 24 hours being 105).

Approximate average winter discharge by months :—

October.	November.	December.	January.	February.	March.
450	230	150	180	220	400

Judging by the present heavily eroded and bare condition of the farm belt it could be contributing only a small proportion of the winter discharge, most of which came from deep springs and regeneration of water in the river bed.

Total precipitation, if occurring as uniform stream-flow from the whole area :—

100 cusecs (See Mr. Thick's calculations).

Ditto for 21,000 acres of farm belt=175 cusecs.

Rainfall by months for Brot :—

July	16·0	inches
August	17·5	„
September	6·5	„
October	2·2	„
November	0·4	„
December	3·0	„
January	4·7	„

(The Author thought that the total annual rainfall of 73″ for Brot was a little too low for the catchment as a whole because the figure for Jatingri and the adjoining hills above 7,000 feet was considerably higher than this).

The Author's estimation for a minimum flow of 400 cusecs after afforestation, etc., was therefore built up of :—

A. Whole catchment ; residual flow minimum of 100 cusecs.

B. 21,000-acre farm belt : Rejuvenation of streams by delayed seepage from 24″ of later monsoon rains.

C. 21,000 acre farm belt : Seepage of winter precipitation by keeping ground unfrozen.

D. Top boundary of 21,000-acre farm land : More sustained seepage from snow melting in lower fringe of permanent snow.

Ratio of Water Use to Total Precipitation for the whole river system

By zoning the rainfall belts of (1) below 10″, (2) 10″-20″, (3) 20″-40″, (4) 40″-75″, and (5) above 75″, for the entire catchments of all the rivers, Jumna to Indus, it had been calculated that precipitation amounted to 365 million acre feet. Out of this the total water use in all canals averaged for 1930-32, 26 million acre feet for the *kharif* and $12\frac{1}{2}$ million acre feet for the *rabi*. This gave roughly 11% of the total precipitation fed into canals, the remaining 89% going to waste in floods and evaporation. Even a small percentage increase in water use effected through water conservation would be of enormous value to the Province, and remission of revenue as rewards for terracing, etc., in the hills would be easily made up in better canal revenues.

Water Table Level in the Hills. There were no very accurate data, the Author said, for this factor in the higher hills, chiefly because wells were so seldom built. It was true as Mr. Mehta pointed out that the level was very high at Kangni on a very steep slope in Kulu, but this was rather exceptional, and he (the Author) thought that the average hill soil could absorb enormous quantities of rain water provided the surface was kept in a porous condition.

The Author supplied a map of the Punjab showing erosion zones and catchments to illustrate his remarks. The map has been reproduced in these Proceedings.

APPENDIX.

RAINFALL AT BROT. (*See page 208 f*).

Year.	Jan.		Feb.		Mar.		Apr.		May		June		Remarks.
	D.	In.	D.	In.	D.	In.	D.	In.	D.	In.	D.	In	
1930.													
1931.	6	5·80	15	11·29	8	3·52	7	1·95	15	4·49	8	1.57	
1932.	3	1·97	9	3·66	9	4·13	4	0·45	11	4·15	12	4·71	
1933.	9	6·24	13	7·23	10	8·97	10	3·58	16	6·65	14	9·65	
1934.	16	10·52	5	1·68	10	4·57	8	4·73	7	1·58	16	8·59	
1935.	8	4·20	*1	*0·40	8	5·40	10	8·14		*Nil*	2	1·90	*Instrument defective for 18 days.
1936.	1	0·58	1	0·45	7	5·58	3	0·85	11	3·61	18	10·38	**Instrument under repairs for full month
1937.	9	3·63	11	10·39	3	1·55	**	**	6	2·78	10	10·03	
Totals.	52	32·94	55	35·10	55	33·72	42	19·70	66	23·26	80	46·83	
month	7		7		7		6		7		7		
Averages.	7·4	4·71	7·9	5·1	7·9	4·82	7	3·28	9·4	3·32	11·5	6·69	

Year.	July.		Aug.		Sept.		Oct.		Nov.		Dec.		Annual.	Totals.	Remarks.
	D.	In.	D.	In.	D.	In.	D.	In.	D.	In.	D.	In.	D.	In	
1930.	23	15·29	25	22·22	5	2·21	7	3·04	1	0·01	2	2·02	63	44·79	
1931.	19	10·40	25	12·80	21	10·98	7	3·16		*Nil*		*Nil*	131	66·96	
1932.	20	17·55	19	12·44	18	5·42	2	0·42	2	0·67	6	3·12	125	68·69	
1933.	23	23·93	23	15·60	17	9·70	9	3·40	2	0·39	1	0·20	147	95·54	
1934.	26	18·50	27	20·52	7	3·19		*Nil*		*Nil*	9	8·00	131	81·88	
1935.	23	18·68	25	11·55	6	1·81	6	2·33	2	0·50	3	0·85	94	55·76	
1936.	13	11·78	16	19·94	11	5·88	7	1·20		*Nil*	10	3·94	98	64·19	†Snow: 1/3" on 7th, 4" on 22nd.
1937.	17	12·66	27	24·82	16	12·80	6	4·20	3	1·25	10	†5·50	115	89·61	
Totals.	164	128·79	187	139·89	101	51·99	44	17·75	10	2·82	41	23·63			
month	8		8		8		8		8		8			89 Months.	
Averages.	20·5	16 1	23·4	17·48	12·6	6·5	5·5	2·22	1·25	0·35	5·1	29·5	119·45	73·5	

D. =Days when rain fell during the month.
In.= Total rainfall, in inches, during the month.

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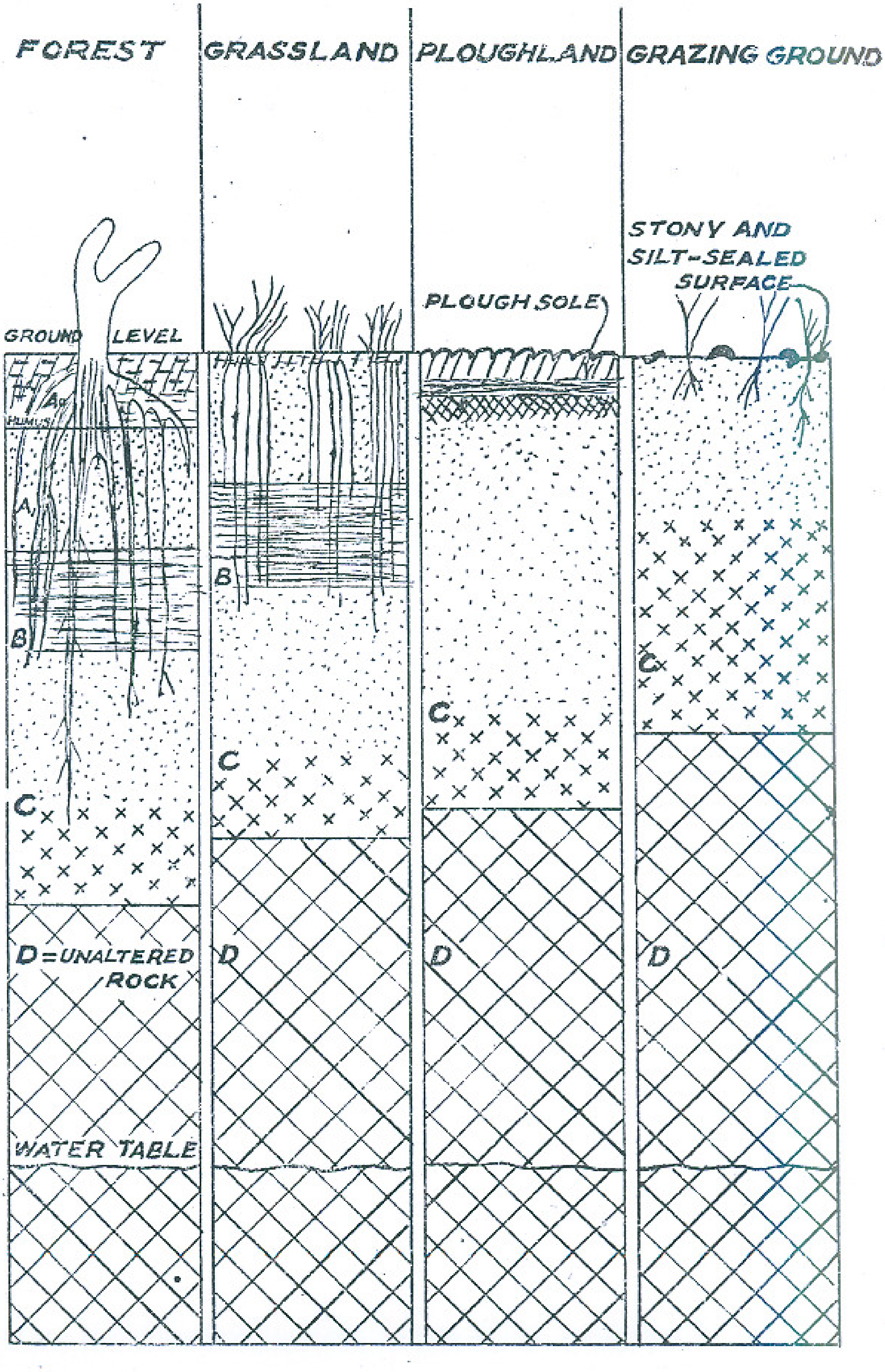
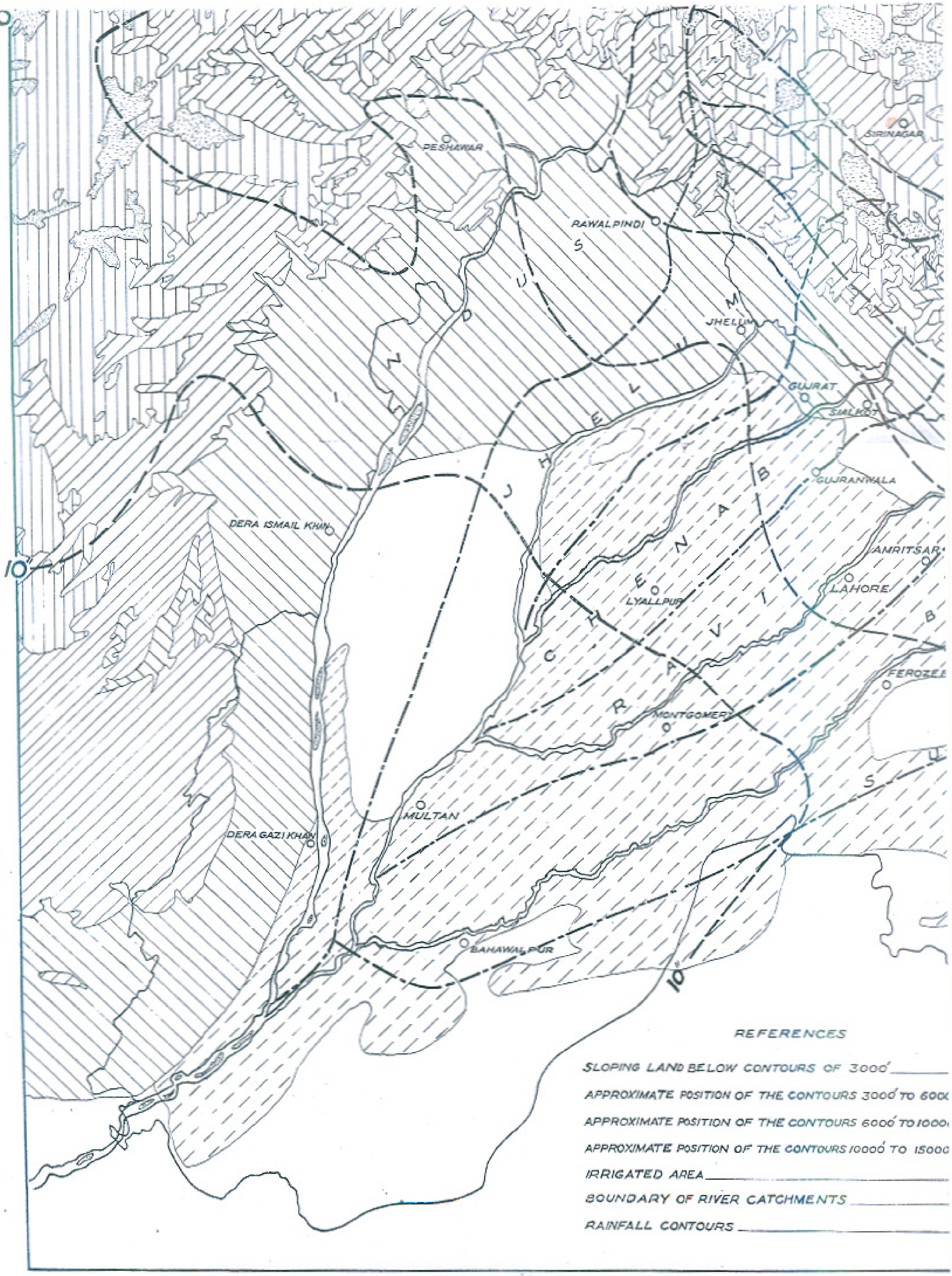
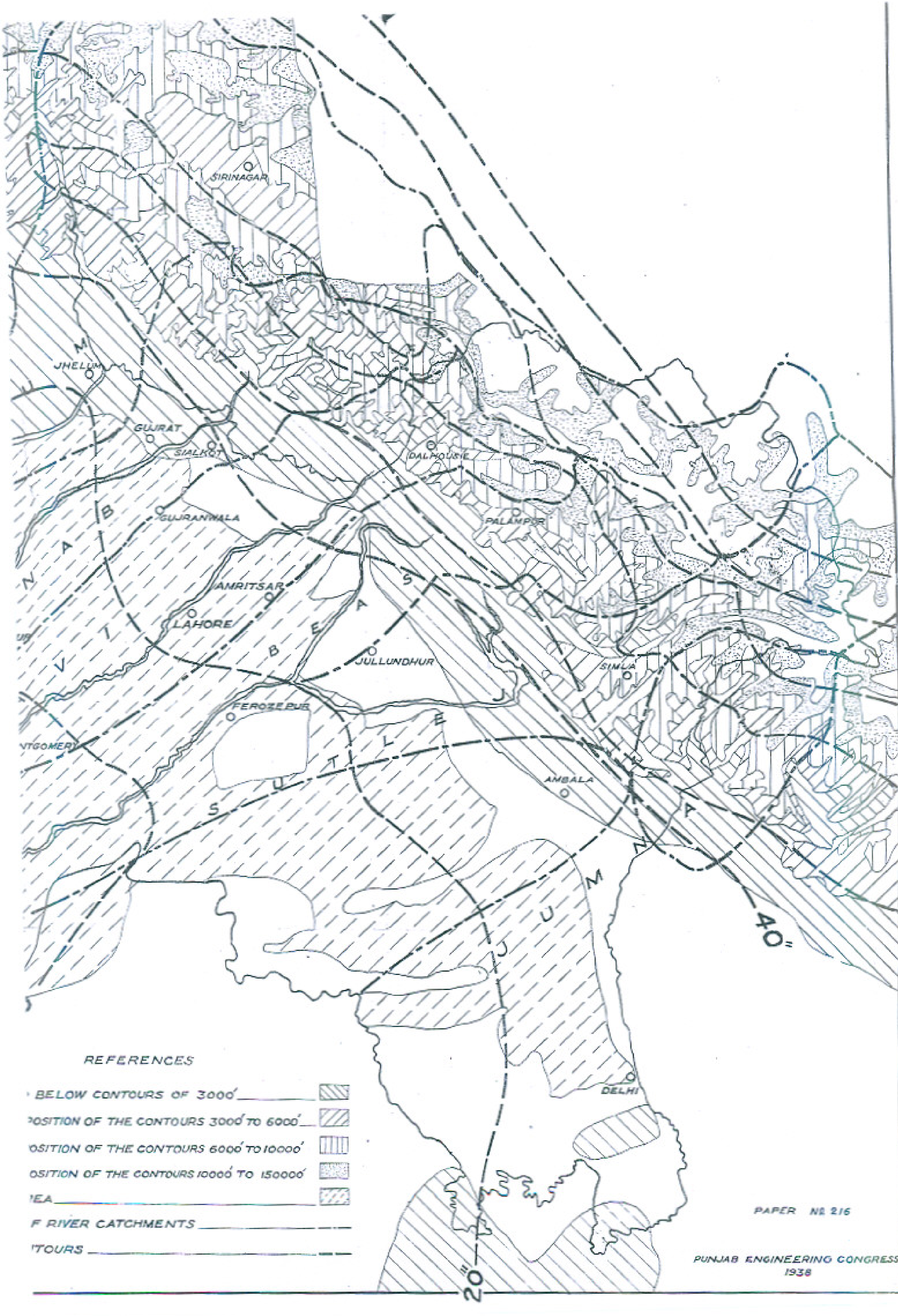
FIG. I
SOIL PROFILES





10
10
10
PESHAWAR
RAWALPINDI
SIRINAGAR
JHELUM
GUJRAT
SIALKOT
GUJRANWALA
AMRITSAR
LAHORE
LYALLPUR
DERA ISMAIL KHAN
MONTGOMERY
FEROZE
MULTAN
DERA GAZI KHAN
BAHAWALPUR
INDUS
JHELUM
CHENAB
RAVI
REFERENCES
SLOPING LAND BELOW CONTOURS OF 3000'
APPROXIMATE POSITION OF THE CONTOURS 3000' TO 600
APPROXIMATE POSITION OF THE CONTOURS 6000' TO 1000
APPROXIMATE POSITION OF THE CONTOURS 10000' TO 1500
IRRIGATED AREA
BOUNDARY OF RIVER CATCHMENTS
RAINFALL CONTOURS



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