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HYDROLOGIC DESIGN OF SUKH BEAS DRAINAGE PROJECT

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1.0 BACKGROUND

A glance at the physiographic map of the Bari Doab located in the Punjab Province of Pakistan would conspicuously show a raised table-land or "bar" in the central and upper part which ends in a river-cut bluff or "Dhaya" and the remaining land at a lower level highly cut up by old river creeks and Nullahs. The most prominent and clearly defined of these channels, which now exist, is the Sukh (dried or Khushak) Beas which forms the boundary not only between North and South tehsils of Sahiwal district but also between irrigation systems based respectively on the Ravi and Sutlej rivers as shown in the location map given in Figure-1.

There are different versions about the Sukh Beas regarding its original existence; whether it was a continuation of Beas river, its tributary or simply a monsoon runoff Nullah. Some of the stories mentioned in the old historic documents are briefly narrated below for academic interest:-

The popular story used to be that till the end of the eighteenth century the Beas, instead of joining the Sutlej near Ferozepur, flowed down this Nullah and joined the Chenab river near Jalalpur Pirwala in Multan district. Lieutenant Elphinston (1858 A.D.) doubted the correctness of the story, on the ground that the Nullah could not carry the volume of water in the Beas which apparently appears to be a convincing reason.***(However, the possibility of gradual deterioration of channels section with persistent passing of decreasing discharges cannot be ruled out)*. The Moghal Emperor Akbar wrote in his autobiography Ain-i-Akbari that the Beas and Sutlej united 12 Keas *(about 15 statute miles)* near Ferozepur. This shows that upto the time of Emperor Akbar the confluence of the Sutlej and Beas rivers was almost at its present

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***Text in italics are the views of the authors* location upstream of Ferozepur and the above story may be dismissed as a fiction. The subsequent change in the point of junction is due to the Sutlej and not the Beas having shifted its course *(it is a geological fact that due to diurnal rotation of the earth all the rivers on the East of equator have a tendency to shift West-ward and according to this principle Sutlej could have shifted West-ward to join the Beas which could not have shifted East-ward to join the Sutlej);* still it is a fact that water came down this Nullah till a comparatively short time ago. The year 1750 A.D. is fixed as the day it ceased to flow. There seems no reason to doubt that the Nullah was a branch of the Beas; there is nothing to connect it with the Sutlej. In order to ascertain what it originally was it will be necessary to determine whether, when the Beas River ran under the Dhaya, it was at such a distance from this Nullah that both could have independent streams. A glance at the map will show that this might possibly have been the case in Sahiwal district. The question is, could it be in Lahore and Multan ? If so, the old Beas may be simply the continuation of the Kapurthala Bein, as the Sohag is of Phagwara Bein. The Nullah is nearly more than 200 ft. across; the depth is from 12-15 ft. and its carrying capacity is about3,400 Cft. per second (average annual flow of Beas river is about 13 MAF). A map shown in Figure-2 indicates the course of the bed of old Beas with respect to the Indus river system. This map also shows the bed of old Ghaghara a Hakara river which could have been the abandoned course of Sutlej river and may provide some food for thought about the shifting courses of these rivers.

The above versions are of more interest to a historian or an antiquarian but technically speaking the fact remains that the present depression running all along in the middle of Bari Doab called Sukh Beas Nullah and its tributaries used to provide natural drainage to its geographical catchment. With the cessation of flow in this river/ Nullah and passage of time a network of utility lines was constructed by the various builders for the development of the area but unmindful of the drainage discharges occasionally expected in this Nullah and omitted to provide proper cross-drainage works under the canal, road and railway embankments intercepting the Nullah. Cultivation in the bed and construction of water courses gradually choked up the bed with the result that the drain no longer performs its historic functions. Obviously, the reactivation of the old drainage lines, with the implementation of the Project, is essential for proper surface drainage in the Project Area. Accordingly, the Project Plan envisages reactivation of the abandoned channel into a regular main drain along with removal of all constrictions and blockages, short-cuttings of adverse bends, proper re-grading and reconstruction/ remodelling of crossing structures to suit the design discharge of the main drain.

2.0 DESCRIPTION OF THE PRESENT SUKH BEAS NULLAH

The Sukh Beas Nullah, as discussed above, popularly known as the abandoned course of the Beas River, during the ancient times used to flow in the middle of present Bari Doab having its junction with the Chenab River near Jalalpur Pirwala in Multan district. This Nullah originated from the heavy rainfall areas of Gurdaspur district (now in India) and used to serve as a surface drainage channel all along the length of Bari Doab. After the emergence of Pakistan as an independent state, this Nullah was truncated into two parts. The upper stem in the Indian territory used to bring huge flood discharges into the Pakistan territory and consequently, as a first measure of averting damage, this Nullah was diverted near the border (along the left bank of B.R.B.D.Link) to outfall into the Sutlej River upstream of Ferozepur Head Works. With this diversion the catchment of Sukh Beas Nullah in Pakistan now starts almost from the right bank of B.R.B.D. Link near Kasur and the Nullah following a highly tortuous course of 535 miles (measured along the zig-zag path from its present source to the outfall in Chenab River, the straight distance along the crow-line is only 208 miles) traverses the entire Bari Doab and outfalls into the Chenab River near Jalalpur Pirwala as shown in the Location Map given on Figure-1.

3.0 GEOGRAPHICAL LOCATION OF PROJECT

The Sukh Beas Drainage Project area which is almost the drainage basin of Sukh Beas Nullah is located in the Bari Doab region in the Punjab Province of Pakistan, between Longitudes (71^{o}-14') to (74^{o}-26') and Latitude (29^{o}-32') to (31^{o}-23'). The Ravi and Chenab Rivers flow on the North-West and the Sutlej on the South-East of this Region. The existing Sukh Beas Nullah is the main surface water drainage channel catering the entire Project with a catchment area of 5,180 square miles (which covers 40% of the total Doab area) and serves six major irrigation systems. The North-Western boundary of its catchment basin is formed by the Central Bari Doab Canal, the Lower Bari Doab Canal and the Haveli Canal and the South-Eastern boundary by the Dipalpur Canal, the Pakpattan Canal and the Mailsi Canal. The area in between is criss-crossed by innumerable branch canals, distributaries, minors, sub-minors and water courses which irrigate the entire catchment basin. The Sukh Beas Nullah follows the border line between the canal systems on its right and left along the lowest contours. The catchment area covers parts of the civil districts of Lahore, Kasur, Sahiwal, Vehari and Multan.

4.0 THE PROBLEMS OF INADEQUATE DRAINAGE

This Nullah is unable to remove the drainage water it receives from its catchment due to numerous functional deficiencies listed below:-

i) It has no proper outfall either into the Chenab or the Sutlej river with the result that the flow in the Nullah cannot find its way into any river, it spreads on the adjoining lands, collects in depressions and cannot be drained out.

ii) The existing insufficient drainage capacity of the Nullah is further restricted at numerous places by crossing structures along its route such as siphons under canals, aqueducts of water courses as well as bridges and culverts for roads. On the top of that, the Nullah follows a highly tortuous course with adverse bends and oxbow type of curves. Siltation on these bends coupled with weed growth has also blocked the waterway at innumerable places and rendered the Nullah ineffective in conveying the flood discharge that may reach its course.

iii) The shabby condition of the abandoned Nullah does not allow proper outfall conditions for the nine existing tributary drains which have proved unsuccessful in clearing the ponds.On the other hand the flood water of the Sukh Beas backs up into the tributary drains and thus the very purpose of their construction has been negated.

Besides the above-mentioned channel deficiencies of the Sukh Beas Main Stream vast areas, where ponding takes place during rain storms and excessive moisture depresses the yields of crops, have not been connected with the Nullah. Such areas cannot be drained out unless a proper system of tributary and branch drains is constructed to drain out the surplus water into the Spine Drain.

The unsatisfactory situation of drainage in the catchment basin of Sukh Beas Nullah, as described above,has a vital impact on the economy of the area which is suffering in many aspects as explained below:-

i) Vast areas of land cannot be cultivated due to the adverse effects of ponding and excessive moisture. It is estimated that an area of over 1,50,000 acres lies uncultivated every year due to ponding and excessive moisture. This area is commandable from the local irrigation channels and with proper drainage can be turned into a fertile tract of land.

ii) Additional to that, a huge area where cultivation is practised is partly affected by lack of drainage. The intensity of irrigation is low and the yield of crops sown is below normal as compared to the unaffected lands in the vicinity. It has been estimated that the cultivated area with depressed yield measures about 7,00,000 acres.

iii) Floods in this part of Pakistan are not uncommon. During the flood periods, breaches in the embankments of canals, railroads and highways, as well as damage to public utilities like public schools, dispensaries, bridges, telecommunication lines etc. has become a routine feature. Disruption of canal supplies due to breaches, increased transportation costs along detours on account of road breaches, less production in industrial units due to flood interference with the supply of materials and labour, evacuating and reoccupying the flood threatened areas and expenditure on flood restoration works etc. pose an unbearable burden for a country which is unable to feed and clothe its teaming millions.

It has been estimated that an annual damage of about 372 million rupees is caused on account of the abovementioned factors. The intangible damage on which no money value can be placed, is on the top of that. It includes such invisible factors as mental anguish and apprehension of floods (which discourages the farmer to work in the field with confidence), interference with the education of children, increased hazards of disease and many other allied problems which carry vital significance for the progress and prosperity of the area.

5.0 SCOPE OF THE PAPER

A complete Project Planning Report prepared by the authors (as a team work) for WAPDA, contains the solution of problems based on hydrologic studies of runoff, flood-routing and evolving the design of various components of the recommended plan, their cost estimates, implementation schedule and the economic analysis etc. A complete description of all these items is beyond the scope of this Paper which has only been confined to the hydrologic studies which are described in detail in the subsequent paragraphs for future reference and guidance of the professional engineers. The readers can refer to the comprehensive Project Planning Report for detailed information on the remaining project features.

6.0 HYDROLOGIC APPROACH FOR DETERMINATION OF RUN-OFF

6.1 Division of the Project Area into Sub-Catchments

As already mentioned in a previous paragraph the catchment area of the Sukh Beas Nullah is about 5,180 square miles which covers parts of the districts of Lahore, Kasur, Sahiwal, Vehari and Multan. The upper part of the area has a relatively higher rainfall (about 20") than the middle (about 10"). The lower part has still lesser precipitation (about 6") and high summer temperatures.

The catchment area is a well-developed crop land with flat topography. It is criss-crossed by a net-work of irrigation channels, roads and highways. The irrigation channels run on ridges to provide command to the areas on either sides. The road and railway embankments have also been set at higher elevations to guard against floods but create obstructions to the free over-land flow. These features divide the whole catchment into sub-catchments which would independently contribute run-off to the Sukh Beas Main Nullah. Eighty-seven such sub-catchments were delineated, being bounded by irrigation channels, roads and railway embankments and each one was independently analysed for computing run-off. The boundaries of these sub-catchments were marked on a detailed map in order to facilitate hydrologic analysis. This division of the entire drainage basin into sub-catchments is shown in Figures-3 and 4.

6.2 Discussion of Formulae Considered for Computing Run-off

It was initially proposed to consider the use of the Empirical formulae evolved by the Punjab Irrigation & Power Department, the Rational Formula and the Synthetic Unit Hydrograph Method (Snyder or Modified Snyder) for the purpose of comparison and supplementation of results by the modern scientific methods. The intention was to establish the trend and magnitude of comparative variation amongst the results of the various methods practised in Pakistan and abroad. After detailed consideration of the "Hydrologic Design Criteria" chalked out for this purpose, it was decided that only the scientific methods like Synthetic Unit-Hydrograph should be utilized instead of all the three methods mentioned above. Further, on the grounds of simplicity, the use of Synthetic Triangular Unit-Hydrograph instead of the Synthetic Snyder Unit-Hydrograph method was preferred. The remaining methods being Empirical and less accurate were dropped from the analysis. Hence this paper contains the application of Unit-Hydrograph method adopting the relations established by the Soil Conservation Service of the U.S.Bureau of Reclamation for estimating direct run-off from each sub-catchment.

6.3 Discussion of Factors Affecting Run-off from the Catchment Area

The important factors relating to the catchment of Sukh Beas Nullah and affecting the run-off are discussed below:-

6.3.1 Size Characteristics

The catchment area is about 5,180 sq.miles which is apparently very large and is prone to yield lesser run-off per square mile than the one having a small drainage area for the usual reason that the rainfall is seldom uniform in the entire area of a big catchment. Consequently,it may happen that the rainfall storms may confine to some sub-catchments while there may be scanty or no rainfall in the others.

6.3.2 Shape Factors

The length of the catchment is about 250 miles with an average width of 25 miles which is confined within Central Bari Doab, Lower Bari Doab Main Line and Haveli Canals on the right side and Dipalpur, Pakpattan and Mailsi Canals on the left side. Such a longitudinal narrow belt with a fern leaf arrangement of tributaries is bound to develop lesser run-off. As such, peaks from the tributaries shall not naturally reach the main stream at the same time. Therefore, both the size and the shape factors lead to the conclusion that the catchment being large with a corresponding longer channel, is less subject to extremes of flow and consequently uniformity in flow is more or less likely to prevail during floods.

6.3.3 Precipitation Features

The catchment is under the influence of well-known monsoon rainfall storms which sweep the Indo-Pakistan region for about 2-3 summer months with a rainfall often continuous in character over several days.

6.3.4 Topography and Surface Conditions

The area is flat and agriculturally developed crop-land fully covered with the various irrigation systems. It is mostly underained as only nine out of 87 proposed sub-catchments have drains which too insufficiently cover their individual basin's fetch. Therefore, the area; by virtue of having a top cover of vegetation, crops,forests, obstructions to run-off flow by irrigation channels,roads and railway embankments; is less favourable to production of run-off or flood conditions in the Sukh Beas Nullah and its tributaries unless a proper drainage network is provided for surface flow. It is, therefore, apparent that for achieving an optimum drainage of the area, the tributary drains are the most important part of the drainage system in order to convey the run-off from the various sub-catchments directly and quickly into the Sukh Beas Main Drain.

6.3.5 Temperature and Barometric Factors

The major part of the Sukh Beas catchment has an arid climate. The rain-storms causing floods occur in the monsoon period of summer months of June, July, August and September during which the temperature is very high. Such a higher temperature in relation to precipitation is favourable to heavy evaporation losses with a corresponding decrease in the flood quantum. The aridity of climate in the middle and lower parts of the catchment is also responsible for generation of wind movement which affects the run-off by causing excessive evaporation. Figure-5 indicates that track of the monsoon depressions after they enter Pakistan from the Indian side, lies parallel to the Sukh Beas with a direction of rain-storm parallel to the channel flow. Hence almost all the rain-storm pass along the Sukh Beas Nullah from source downwards causing the run-off not to accumulate at the same time. Such a condition tends to give lower flood peaks in the Sukh Beas Nullah.

6.3.6 Storage Conditions

The escarpment (locally known as 'Dhaya'); about 10-25 feet high, running parallel to the Sukh Beas course from its source near Kasur to Chichawatni (length about 150 miles), at an average distance of about 3-5 miles on the right side; has caused swamps over vast areas, at the foot of the 'Dhaya' with the sheet-flow washing down the colloidal clay and fine silt from the "bench land"through gully erosion along the 'Dhaya' slope . The top layer in the catchment area generally consists of pervious deposits of the coarse and moderately coarse soil. This type of soil extends over the central and lower portions of the catchment on both sides of the Sukh Beas and induces heavy percolation losses. Therefore, with the exception of some areas at the source or the upper part and some patches at the foot of the 'Dhaya', the run-off problem in the face of the relative predominance of such deep previous soils, is not considered grave. The existence of about 6 to 12-inch high dowels around all the fields, coupled with deep pervious soils, necessarily, leads to the enhancement of adequate for covering the time variations involved in a meteorological event according to the above statement.

6.5.4 Ground-Water Table Observation Record

The Project area is covered by a network of Irrigation channels (distributaries, minors and water-courses) as well as roads and railway embankments which tend to obstruct the natural drainage. Therefore, in order to ascertain the infiltration condition, behaviour of ground water movement, (cyclic trend of rise and fall, direction of ground water movement) or to locate water-logged patches and local water collecting depressions for providing relief to these areas, the water-table survey being carried out since long by the Irrigation & Power Department through the selected observation wells in which water levels are regularly measured twice annually over the area of every canal system, has been collected. This period of available observation record is from 1965 to 1975. This data is required for ascertaining the extent of water-logging which in turn is used for computation of run-off (as will be explained later) from each individual basin. Examination of data shows that there is water-logging only in a limited number of sub-catchments.

6.6 Frequency or Return Period of Floods and Rainfall Storms

6.6.1 Return Period of Floods to be Adopted

The cost of hydraulic structures is a function of the design flood to be passed. A liberal design though it provides better security against flood damages yet it leads to heavy investment. On the other hand, selection of lower design flood, is bound to have greater risk of failure.Thus only such a design will be economical which balances the cost of construction and the damages to be safeguarded. Another important point to be considered is that the return period of flood to be adopted for design of structures of a project should not be more than its useful or economic life. Keeping these factors in view classification of various hydraulic projects, based on recurrence interval of flood peaks as specified by various countries (for small catchments, of course), is indicated in Table-6 given below for guidance:-

TABLE -6

SELECTION OF RECURRENCE INTERVAL FOR DESIGN OF STRUCTURES AND CHANNELS

Sr. No.	*Structure/Project in a Small Basin*	*Design flood peak of a recurrence interval of N Years*
a.	*Spillway of small reservoir dams in the country-side not endangering other structures in case of failure ..*	*10 - 20*
b.	*As above but located so as to endanger other structures or urban residence in case of failure ..*	*50 - 100*
c.	*Channel improvement on small streams in open country where flooding is not desirable ..*	*3 - 5*
d.	*Channel improvement on small streams in areas threatening safety of buildings and urban residences ..*	*50 - 100*
e.	*Culverts and small bridges on less important highways or roads ..*	*30 - 50*

Source: Engineering Hydrology by NEMEC.

It is evident from the Table-6 that frequency analysis should be used to ascertain storms for design Return Period of 3,5,10,20,30,50 and 100 years.Therefore, for the project in hand, storms of frequencies 2,5,10,25 and 100 years were estimated.

All these stations are situated in and around the periphery and are well distributed over the main catchment. Of these, 27 stations with better and longer record were selected in such a manner that these are evenly spaced and distributed to facilitate plotting of isohyets. (Refer Table-3 at page 89).

6.5.2 Density of Rainfall Gauges

Twenty-seven gauges in the catchment area of 5,000 square miles give a density of 185 sq. miles ($\frac{5000}{27}$) per rain-gauge station. The density so obtained is quite close to the minimum value of 230-350 square miles per gauge prescribed by the World Meteorological Organization Standards for normal tolerance in respect of flat areas of temperate, mediterranean, and tropical zones (Refer Table-4 given below):-

TABLE-4

MINIMUM DENSITY OF PRECIPITATION NETWORK

Type of Region	Normal Tolerance (area for 1 station)	Tolerance under Difficulties (area for 1 station)
i) Flat areas of temperate, mediterranean & tropical zones	600-900 km^2 230-350 sq.miles	900-3000 km^2 350-1160 sq.miles
ii) Mountainous regions as above.	100-250 km^2 39-100 sq. miles	250-2000 km^2 100-770 sq.miles
iii) Small mountainous islands with irregular precipitation.	25 km^2 10 sq. miles	
iv) Arid and polar zones	1500-10000 km^2 580-3860 sq. miles	

The adopted value is slightly more dense and as such is preferable. A reference to Figure-9 reveals that reduction in the number of rain-gauges from 56 to 27 does not materially affect the accuracy of areal precipitation because the standard error with the adopted rain-gauge network density of 185 is 9.5 percent against a value of about 7.4 percent which is with respect to 56 number rain-gauges.

6.5.3 Length of the Precipitation Record

According to the standards of World Meteorological Organization laid down below as Table-5, the required length of precipitation record should be 40 years for the plains of tropical zones in order to give a stable frequency distribution:-

TABLE-5

NUMBER OF YEARS OF RECORD REQUIRED FOR VARIOUS LOCATIONS TO GIVE A STABLE FREQUENCY DISTRIBUTION

Climatic Element	Extra Tropical Regions				Tropical Regions			
	Islands	Coast	Plains	Mountains	Islands	Coast	Plains	Mountains
Temperature	10	15	15	25	5	8	10	15
Humidity	3	6	5	10	1	2	3	6
Precipitation	25	30	40	50	30	40	40	50
Cloudiness or Sunshine	4	4	8	12	2	3	4	6

The availability of data for such a long period is generally rare in most projects. However, in the case of Sukh Beas Drainage Project, the period of recorded rainfall ranges from 23 to 42 years (1934 to 1975) and is considered was computed for use in Snyder Unit Hydrograph method but later on Triangular Unit-Hydrograph was adopted for use which does not require this centroid parameter.

6.4.3 Slope

The channel slope (both in percent and ratio) of surface drainage channels on the land surface has been obtained from the G.T.S. topographic maps (scale 1" = 0.789 mile) by dividing the fall in elevation (termed as 'H') between the basin outlet and the most distant ridge. The channel length was divided into reaches and gradient of each reach was obtained by dividing the fall that occurs within the reach by the length of the reach. Where more than one slope exists, a mean slope by ordinary mean method was computed. The sudden free-fall wherever encountered as a result of escarpment ('Dhaya') has been subtracted from the value of H which is the difference in elevation between the basin source and the outlet.

6.4.4 Time of Concentration

This is the travel time of water from hydraulically most distant point of the watershed to the outlet point. From this a lag time has been obtained for hydrograph construction. Its evaluation has been done on the estimated velocities and channel lengths and also by the equation:

$$T_c = \left(\frac{11.9\ L^3}{H}\right)^{0.385} \qquad \ldots \qquad \text{(Eq-1)}$$

T_c = Time of concentration in hours

L = Length of longest surface drainage channel in miles

H = Elevation difference in feet (excluding sudden fall due to 'Dhaya')

The same empirical equation can also be expressed in the following two different forms by re-arrangement of parameters, exponents and changing the L into feet instead of miles:

$$T_c = \frac{L^{1.15}}{7700H^{0.385}}$$

OR

$$T_c = 0.000013 = \frac{L}{S^{0.385}}$$

where

T_c, L & H are same as defined above but L is in feet instead of miles.

S = Average slope of the sub-catchments in dimensionless ratio ($i = \frac{H}{L}$)

Since T_c based on the above mentioned equation works out to be higher in comparison to velocity estimates, it has been selected for use in the Unit Hydrograph Computations.

6.5 Historic Hydrologic Data

All the past available data with respect to rainfall and groundwater-table has been used to study the expected occurrence of hydrologic phenomenon in the future. The data with respect to occurrence of an intense and isolated rainfall storm event of a specific date and time over the basin (which is recorded by self-recording rain-gauges) is not available. On the other hand daily rainfall data for a sufficiently long period is available and has been used to determine the hydrologic elements through frequency studies. The basic data collected for this purpose is discussed as under:--

6.5.1 Rain Gauge Stations, Nature of Gauges and Data

There are sixty one (61) standard 'non-recording' rain-gauge stations maintained by the Punjab Irrigation & Power Department in the catchment area (Refer Table-2 at page 86) in addition to the three gauges of the Meteorological Department at Lahore, Sahiwal and Multan Cities. Data for only 56 out of 64 rain-gauge stations was available.

The rainfall is measured once a day at 8.00 A.M.

absorption losses. The net result is that flood peaks are reduced and the time-base of the hydrograph is prolonged.

6.3.7 Geology of Soil

The following types of land forms are present in the Project Area:-

a) Scalloped interfluve (S.I)
b) Covered Flood Plain (C.F.P.)
c) Active Flood Plain (A.F.P.)
d) Meander Flood Plain (M.F.P.)
e) Channel Levee Remnants (C.L.R)

As will be noticed from Figures-6 & 7 out of all these forms, the type C.F.P. predominates in the catchment. The soil consists of almost deep pervious deposits. Profiles having coarse to moderately coarse materials predominate with surface-materials ranging from coarse to medium size particles. Profiles consisting of layers of coarse to moderately coarse materials and layers of medium to moderately fine materials with textural classification ranging from moderately coarse to moderately fine materials, exist mostly as a secondary formation in combination with primary deposits mentioned above.

These deposits are relatively level in the valley resulting into a good condition for infiltration down to the sub-soil water for recharge of aquifer.

6.3.8 Unfavourable Conditions for Producing Extreme Flood Flow

As, a result of the above discussion about the various factors affecting run-off, it is evident that the prevailing conditions such as high summer temperature, moderate to severe wind movement, non-uniform precipitation, excessive vegetation, grass and forests, artificial obstructions to run-off, some marshy areas, flat slopes and previous deposits on the top, etc. should not lead to extremes of flow as is the case with the mountain fed basins having steep slopes and other factors favourable for production of higher run-off.

6.4 Drainage Basin Parameters for Calculation of Run-off

The main drainage basin has been divided into sub-drainage basins in such a manner that the land surface of each individual area within the limits of which the run-off can transport itself to one single outfall point, forms the drainage basin of that unit. The shape of the storm run-off as defined by a unit-hydrograph depends upon the geometry of land surface of the drainage basin. The geometric characteristics to be used in hydrologic analysis are size (area), slope, shape and the resultant time of concentration. The method of determination of these basin-parameters is briefly discussed hereunder. Table-1 given at the end of text (page 83) contains the dimensions of these parameters relating to each of the 87 sub-catchments of the Sukh Beas drainage basin. These parameters are defined and explained further in the following sub-paras.

6.4.1 Size of Area

This is the area in square miles above the point of outlet of the land surface which contributes run-off to the basin surface channels. For the Sukh Beas Project, it has been measured from G.T.S.Sheets scale 1 inch = 0.789 miles by locating the divide of each area and small scale maps prepared therefrom as Figures 3 & 4. The basin number and its area are given (as numerator and denominator respectively) on these figures in a circle in each of the 87 sub-catchments.

6.4.2 S h a p e

The shape of the basin is described by a shape factor which is the relationship of the distance of the outlet to the centroid of the area (termed as L_{ca}) to the total length along the main channel from the basin outlet to the most distant ridge (termed as L). A reference to Figure-8 would clarify these values. Centroid of any basin 'Ca' was found by vertically suspending a cardboard of basin shape successively from the two or more points and finding intersection of plumb lines from each point. This

6.6.2 Return Period for Design of Existing Sukh Beas Main and Tributary Drains

Drains are usually designed with a frequency of 5-10 years to provide full protection to agricultural lands against floods. For this purpose estimates of run-off were made for both 5 and 10 year frequencies. Table-6 above also prescribes a design return period of 3-5 years for channel improvement of small streams in the open countryside where flooding is not desirable. Sukh Beas with its tributary system of drains is exactly a project of this type. Accordingly, it was considered that the new drains should also have the same recurrence interval. Some-times mean annual storm which statistically approaches a return period of 2.33 years is also used but that is considered too small for this large project. The existing section of Sukh Beas Channel (excluding local constrictions) conforms to roughly 2,500 cusecs which incidentally coincides with the maximum flood run-off of 5-year return period. On the other hand, as is evident from Col. 9 of Table-14 (given at page 104) the flood computed from 10-year return period is likely to be more than twice the 5-year design discharge (i.e. in excess of 5,000 cusecs). As such the design flood based on 10-year frequency shall naturally be uneconomical on account of the increased cost of earthwork, land acquisition and much bigger structures. It is further viewed that drains with capacity based on 10-year return period apart from involving heavy investment are apt to deteriorate more for want of frequent flushing storms. Keeping all these factors in mind, 5-year return period as specified at S.No. (c) of the Table-6 has been adopted for fixing the capacity of all the proposed and existing drains.

6.6.3 Design Return period for Direct Inlets

Since the design of section of drains is based on a return-period of 5-years, the channel section cannot absorb floods of a higher intensity. Thus no benefits will be obtained in providing inlets of higher capacity. Therefore, it was considered desirable that inlets to be provided on the Sukh Beas Main Drain and tributary drains, should not have a design return period of more than 5-years.

6.6.4 Design Return Period for Bridges, Siphons and Aqueducts of Sukh Beas Main Drain

Serial No. (e) of the Table-6 specifies design return period of 30 to 50 years for culverts and small bridges on less important highways or roads. Generally, a return period of 50-100 years is used for moderately large permanent works. Even the magnitude of a 50-year flood as per computations, is too large to be accommodated in artificial channels which are designed for a 5-year frequency. Therefore, viewing from the angle that the catchment of Sukh Beas Nullah consists of contributing agricultural land with bunded fields and that the conveyance capacity of channels shall be limited, it has been proposed to have a normal waterway with pile-foundation treatment to cater for abnormal scour resulting from a 50-year storm which is expected to reach the structures of the main drain. Since it is not possible to pass high discharges through structures, breaching sections/gaps shall be left in the embankment on either side of the bridges in order to safeguard the structures during high emergencies.

6.6.5 Design Return Period for Bridges, Siphons & Aqueducts of Tributary & Branch Drains

In the light of sub-para 6.6.4 above normal waterway has been provided with open or well foundations safe against scour resulting from twice the design discharge based on a 5-year storm.

6.7 Precipitation and Frequency Analysis

The various aspects under this para are discussed hereunder:-

This method involves a lot of computational work and accordingly a computer programme was prepared, the results of which are abstracted in Table-8 for frequencies of 2,5,10,25,50 and 100 years. The average of computed points for 16 Nos. selected stations for each frequency is plotted on the probability paper against the recurrence interval in years or probability of non-exceedance, for 24 hours, 48 hours and 72 hours in order to get the desired information in connection with any other analysis as and when needed (Ref. Figure-10)

6.7.3 Procedure of Computation

Take all the selected maximum rainfall storms for 24, 48 and 72 hours as specified in sub-para-6.7.2 above for the full available record period. The various steps involved in the procedure are as below:-

a) Tabulate the year of storm in column(1).
b) Tabulate the maximum annual rainfall of 24 hours in column (2)
c) Re-arrange and compile rainfall variates of item (b) in the ascending order in column (3).
d) Take the logarithms of column (3) and enter in column (4).
e) Take the square of values in column (4) and enter in column (5).
f) Assign the order of magnitude to values in column (5) and enter them in column(6)
g) Compute probability of non-exceedance of values by the equation:

$$P_t = \frac{m}{n-1} \qquad \ldots \quad (Eq.3)$$

where

P_t = Probability of non-exceedance
m = Order of magnitude of the storms
n = Length of continuous record in years.

Put the results in column (7).

h) Compute the arithmetic mean ($\bar{x}$) and standard deviation (σ) of the logarithms of the variates respectively by the following equations:

$$\bar{x} = \frac{\Sigma x}{n} \quad \ldots \quad \text{(Eq.4)}$$

where

$\bar{x}$ = Arithmetic mean
x = Variate i.e. annual maxima
n = Total number of observations

$$\sigma = \left\{ \frac{(x-\bar{x})^2}{n-1} \right\}^{\frac{1}{2}} \text{ or } \left\{ \frac{n}{n-1} \quad (\bar{x^2} - \bar{x}^2) \right\}^{\frac{1}{2}} \quad .. \text{(Eq.5)}$$

where σ = Standard deviation

$$\bar{x^2} = \frac{\Sigma x^2}{n}$$

i) Use the required frequency factors from the Pearson type-III Distribution (Table-7) with respect to duration of storms and probability as shown below:

Flood Duration (days)	Probability of Non-Exceedance P_t (%) or Return Period T (Years): Pt / T	50 / 2	80 / 5	90 / 10	96 / 25	98 / 30	99 / 100
		Frequency Factors 'K'					
1.		0.01	0.9	1.27	1.80	2.13	2.30
2.		0.15	0.9	1.26	1.78	2.11	2.27
3.		0.02	0.9	1.25	1.76	2.08	2.24

j) After having known the values of K, σ and $\bar{x}$, compute x from the equations $x = \bar{x} + K\sigma$ and obtain the results in original units of the series by taking antilogarithms.

k) Repeat this process for storms of 48 and 72 hours in respect of each rain-gauge station.

6.8 Areal Rainfall

The point-rainfall can be applied in design to small water-sheds with area usually less than 2 square miles. As the area of all the 87 sub-catchments of the Sukh Beas catchment is far in excess of the limit of 2 square miles, it is apparent that the point and areal rainfall should be different. Accordingly it becomes necessary to determine the areal distribution over the whole catchment. The Theissen method which caters for a weight of each station proportionate to its area of influence has been adopted to determine the areal distribution of rainfall storms over each sub-catchment in preference to the Isohyetal method which involves laborious work of measurement of areas between successive isohyets against various storm frequencies. Theissen polygons for areal distribution of rainfall for the design storms of 5,10 and 50 year frequencies are shown in Figures-3 and 4 with the help of which Table-9 (given at page 93) is prepared which shows areal rainfall sub-catchment-wise. Isohyets to show maximum storms for 24, 48 and 72 hours are shown in Figures-11 through 14 separately for the adopted frequencies.

6.9 Determination of Direct Run-off from Precipitation

The run-off which shall be entering the channel, was estimated by the U.S.Soil Conservation method. The parameters which are used in this method and assumptions made in arriving at the 'Soil Cover Complex Numbers' of the sub-catchments are discussed below:-

6.9.1 Hydrologic Soil Group

The selection of the tentative 'Soil Group' has been based on 'Land-Form and Soil-Map' of the Canadian Soil Survey of 1954 (Refer Figures-6 and 7), the actual field conditions and on the basis of the Soil Associations which indicate both profile and field textural classifications. The soil in general all along the catchment is found to possess moderately coarse to moderately fine texture with a moderate rate of water transmission. The characteristics of the four Hydrologic Soil Groups used in the method applied are given in Table-10(at page 96) They differ mainly in their rate of infiltration depending on the texture of the soil.

Accordingly the soil of the Project area is assumed to belong to the group 'B' from source to tail.

6.9.2 Land-Use or Cover

The land-use class for the contributory area is 'row', 'small grains', 'closed seeded legumes', land lying vacant for rabi season and little range land. The land vacant for rabi by virtue of dense growth in the bunded fields during the monsoon period of summer season, has been classified as "Closed Seeded Legumes or Rotation Meadow".

6.9.3 Treatment Class

The 'Treatment Class'specifies the cultural or tilling practices in farming. In the Project Area the fields are small with dowels about 6-12 inches high all around them for holding up the irrigation waterings.Though the Table-11 (at page 97), giving Run-off curve Numbers (CN) for Hydrologic Soil cover complexes, does not specify such a classification in column 2, yet the practice of constructing dikes or bunds in the terraced and contoured fields for the purpose of controlling run-off and the practice of cutting of successive downstream bunds of fields by the cultivators in the event of excessive storms to achieve the drainage through overland flow, leads to the conclusion that the bunded fields can be reasonably assumed to behave as 'Contoured and Terraced'. This assumption should not cause error especially when it is seen that as per Table-11 'Contoured and Terraced' treatment classification also has the highest infiltration losses in comparison to the remaining classifications i.e. the 'straight-row' and 'The Contoured' as is indicated by the corresponding 'Soil Cover Complex Numbers'. Accordingly, a Contoured & Terraced (C&T) treatment has been adopted throughout for all sub-catchments for finding out the 'Soil Cover Complex Number'.

6.9.4 Hydrologic Conditions for Infiltration

The hydrologic condition of soil indicates the run-off producing potential in general terms and is classed as good or poor depending upon the permeability of soil, water-logging, salinity, or by both and other run-off control conditions. The presence of water-logging and salinity makes the hydrologic condition for infiltration poor. This is a temporary phase as with the advent of Salinity Control and Reclamation Projects (SCARPS) etc., the soil is bound to improve. However, where more than half the area of individual sub-catchment is affected by water-logging or salinity or by both,poor hydrologic condition has been assumed. Also in areas where the surface material is silty or clayey, poor condition has been adopted.

6.9.5 Antecedent Moisture Conditions

The amount of rainfall in a period of 5 days preceding a particular storm is referred as the 'Antecedent Rainfall' and the resulting condition of the basin in regard to potential run-off is referred as an "Antecedent Moisture Condition". The heavier an antecedent rainfall, the greater the direct run-off that occurs from a given storm. The rainfall limits to classify Antecedent Moisture Conditions as specified by the U.S.Soil Conservation Service for the storm period of Kharif Growing season have been adopted and are tabulated below:-

Antecedent Moisture Conditions		5-day total antecedent rainfall (inches)
I	...	Less than 1.4
II	...	1.4 to 2.1
III	...	Over 2.1

As per warabandi or rotational programme, irrigated area per day in a week would be 1/7th of 40 acres= 5.7 acres. Average area under irrigation over the 5 preceding days may be 28.5 acres. It is, therefore, obvious that a substantial area remains dry and the irrigation waterings do not have a material effect on the 'Antecedent Moisture Conditions'.

6.9.6 Weighting of 'Soil Cover Complex Number'

By estimating the ratio of each existing "land-use" or categories of crops grown in each sub-catchment, weights proportionate to the area have been arrived at for computing the weighted 'Soil Cover Complex Numbers'. Accordingly the following representative weighted 'Complex Numbers' (C.N) have been adopted for application to various sub-catchment:-

Land Use M	Land Treatment	Hydrologic condition for infiltration	Soil Group	C.n. for A.M.C. I	II	III
'Row', 'Small grains', 'Closed seeded legumes'	'Contoured and Terraced' (C&T)	Good	B	50	69	84
Rabi vacant Land, Range Land.		Poor	B	55	74	88

6.9.7 Status of Evaporation

Evaporation allowance has been neglected from the consideration that it is often too negligible to affect the rising limb of the Hydrograph and as such the peak value of the flood remains unaffected. It is felt that evaporation may be adverse during the recession limb thereby affecting alone the volume of run-off and not necessarily the peak rate.

6.9.8 Results of Run-off

After knowing the Land Use, Land Treatment Class, Hydrologic Condition, Soil Group and Antecedent Moisture Conditions, the Soil Cover Complex Number have been determined by the use of Table-11 (given at page 97).Since the storms last for several days, the run-off has been estimated on a daily basis changing Antecedent Moisture Conditions accordingly. CN for A.M.C.I or A.M.C.III has been converted from C.N.II by the use of Table-12(given at page 99).

The amount of direct run-off has been computed through the use of Figures 15 & 16 for the areal rainfall (in inches) of each sub-catchment. Results may be seen in Table-13 (given at page 101).

6.10 Use of Triangular Unit-Hydrograph

The method of Triangular Unit-Hydrograph is used for computing the run-off peaks and its time distribution of the ungauged water-sheds. A triangular Hydrograph for one inch run-off from the sub-catchment in question has been used for computing the peak discharges. It is assumed that the selected sub-catchments proposed to be drained shall, as far as possible, be covered by tributary drains of adequate length with respect to basin length.

Similarly, the sub-catchments with the existing established drainage channels, have been analysed more or less for the full physical length. Wherever such drains are much short of the basin lengths,channels of proper length have been assumed so as to assess the peak discharge that can develop from each individual sub-catchment under the application of Unit Hydrograph Method.

The relationships of peak discharge and L to other factors of the hydrograph are shown in Figure-17 and worked out in Table-14 (given at page 104).

6.10.1 Evaluation of Peak Time

Refer Figure-17 for understanding the terms defined below:-

$$T_p = \frac{D}{2} + L \qquad \text{... (Eq. 6)}$$

where

T_p = Time in hours from start of rainfall to Peak Rate.

L = Lag-time from centre of excess rainfall to time of peak, hours.

D = Duration of Excess Rainfall, hours

6.10.2 Evaluation of Lag Time (L)

$$L \doteq 0.6\ T_c \qquad \text{... (Eq.7)}$$

where

T_c = Time of concentration in hours (Travel time of water from the hydraulically most distant point of the water-shed to the water-shed outlet point)-Refer para 6.4.4 on Time of Concentration.

6.10.3 Evaluation of Time Base (T_b)

$$T_b = 2.67\ T_p \qquad \text{... (Eq.8)}$$

where

T_b = Time base of hydrograph in hours.

6.10.4 Evaluation of Peak Discharge

$$Q_p = \frac{484\ A\ Q}{\frac{D}{2} + L} = \frac{484\ A\ Q}{\frac{D}{2} + 0.6\ T_c} \qquad \text{..(Eq.9)}$$

$$= \frac{484\ A\ Q}{T_p}$$

where

Q_p = Discharge in Cusecs
Q = Total Run-off in inches
A = Area of sub-catchment in sq. miles.

6.10.5 Evaluation of Time of Concentration(T_c)

Refer equation-1 and its various forms which determine empirically the time of concentration in hours.

6.11 Storm Duration

In the absence of the 'recording' gauge data, the assessment of the magnitude of storm duration of the major and severe storms experienced in the past,is not possible. However, it is generally considered that the duration of rainfall in the 24-hour rainfall period may be equal to the average value of 50-60% i.e. 12-14 hours. But at the same time it often happens that the severe storms of the peculiar monsoons which are of non-uniform intensity, are continuous over 24 hours. The expected Unit-Hydrograph storm duration is indicated by the equation:-

$$D = 2\, T_c^{0.5} \qquad \text{... (Eq.10)}$$

where

D = Expected Unit hydrograph storm duration in hours.

T_c = Time of concentration in hours.

However, various expected storm durations like D=12 hrs, D=2 $T_c^{0.5}$ hrs, D=$\frac{T_c}{5}$ hrs, & D=24 hrs have been examined, and the one equal to 24 hours has been assumed in the computation of Unit-Hydrograph. It was proved earlier that extremes of flow are not likely to develop in the Sukh Beas Nullah. Under this assumption the storms of non-uniform intensity by extending over 24 hours shall evidently have reduced peaks through physical features and meteorological characteristics (as discussed in the aforementioned paras) thereby also incorporating the effect of bunded fields (para 6.3.6- Storage Conditions) by catering for any dissimilarity between 'bunded fields' and 'Contoured and Terraced' treatment assumed to be similar while computing the excess rainfall.

Increased discharge based on unit time $D=2\ T_c^{0.5}$ is also reflected in Table-17 (given at the end) and discussed in para-8.0.

6.12 Peak Flows

After computing Q_p, T_p and T_b for 1 inch run-off on the basis of equations, the equivalent peak rates of run-off in inches already determined for daily storms of 5,10 and 50 years return period from Soil-cover data etc. were converted into cusecs. By using these values simple hydrographs for the first, second and third day of the storm were plotted separately.

The total peak discharge has been obtained by graphical addition of simple hydrographs of each sub-catchment for rainfall storms of 5, 10 and 50 years frequency separately. The results are shown in Table-14 (given at page 104). The Triangular Hydrograph for sub-catchment No.2 is shown as an illustration in Figure-18 for the storm of 5-year frequency.

6.13 Extent of the Contributory Catchment Covered by 5-Year Frequency Storm Run-off

From Table-14, it is apparent that with a design storm of recurrence interval of 5-years for which the surface drainage system in the agriculture lands, is proposed to be designed, we get the peak discharge with the run-off factor varying from 6.9 to 1.2 cusecs per square mile only in the first 1-49 sub - catchments, it means that the storm rainfall is totally lost to infiltration in the remaining sub-catchments 50-87 of the lower reach and is, hence, unable to produce any run-off. It leads to the conclusion that the area beyond sub-catchment 49 does not need any drainage system under the circumstances of scanty rainfall and sandy nature of the soil. Therefore, instead of conveying the flood discharge a very long way down over a distance of about 100 miles in the old redundant channel of the Sukh Beas

Nullah, it is advisable that Sukh Beas should be diverted at some suitable point into Sutlej River close to sub-catchment No. 49. Fortunately there are two old and abandoned river creeks near sub-catchment No. 49 namely the Sukhnai Nullah, and the Vehari Nullah which can form links for diversion of Sukh Beas flows into the Sutlej river downstream of Islam Headworks. This proposal also provides a far better working head at the outfall point than that of the original outfall into Chenab River near Jalalpur Pirwala. (Refer Fig.3&4)

7.0 FLOOD ROUTING

7.1 General

The tributaries entering the Sukh Beas Main Stream were analysed to give flow hydrographs and peak rates on the basis of Synthetic Triangular Unit - Hydrograph. The flood wave resulting from the peaks has to enter the stream which has substantial storage volume. It is evident that the said flood wave shall considerably modify itself while passing through the successive reaches, thus reducing or changing the peaks of floods. It is necessary to investigate such flattening of the flood peak with respect to time and distance in the Sukh Beas drain by flood routing in order to determine the design discharge in various reaches and to work out hydraulic design accordingly. Time displacement of the flood wave, the reduction or change of the peak and the spreading out of the flood wave base are the fundamentals of the flood routing in a reservoir and in open channels. The solution of flood routing problem conforms to the law of continuity which states that in a given time interval, the difference between inflow and outflow is equal to change in storage.

7.2 Routing in Sukh Beas Main Channel by Muskingum Equation

The Muskingum method which expresses storage by a weightage to both inflow and outflow has been used considering that storage in a reach is composed of both prism storage (i.e. storage between line parallel to the stream bed) and wedge storage (i.e. storage between a line parallel to the bed and the actual profile).

The storage is expressed mathematically by Muskingum equation as follows:

$$S = K \{ X I + (1-X) O\} = KO + KX(I-O) \quad \text{..(Eq.11)}$$

where

S = Storage volume
I = Simultaneous inflow
O = Simultaneous outflow
K = Coefficient having a time dimension and is equal to the time of passage of centroid of the flood wave through the reach.

X = a dimensionless factor that defines the relative weights given to inflow and outflow in determining storage volume in the stream reach. It varies between 0 & 0.5.

X = 0 for a reservoir as the storage is solely a function of outflow.

X = 0.5 for uniform channels as equal weight is given to inflow and outflow.

Channel routing programme with a computer was chalked out using the parameters and assumptions as given below:-

i) Manning's Section was used for the earthen channel discharging flood at a velocity of 2.87 feet/second.

ii) Channel was divided into a number of reaches and flows were routed in the main channel with the intervening drainage flow added at the head of each reach.

iii) The rainfall storm has been assumed uniform over the whole catchment.

iv) The result was based on the drainage flow from the tributaries for a frequency of 5-year recurrence interval.

v) The storage and discharge record being not available, a value of 'X' equal to 0.25 was initially tried and was modified to 0.23 for the final results.

7.3 Routing with Pandoki Drainage System Outfalling into Sukh Beas

The results of hydrologic routing are set in Table-15 (given at page 107). The magnitude of flood likely to be produced from the movement of run-off through main and tributary drains is indicated in column 6 of Table-15. The storm is found to last for many days in the main drain with the flood discharge varying with respect to time and distance. After deducting absorption losses in the successive channel reaches, design capacity for the indicated channel improvement can be fixed within a reasonable accuracy. The adopted design capacity is shown in Column 8 of Table-15.

The summarised results are given below:-

S.No.	Reach	Design Discharges	Remarks
1.	1113+000 to 1027+000	1807 cusecs	
2.	1027+000 to 928+000	2104 cusecs	
3.	928+000 to 868+000	2437 cusecs)	Slope differs in the two reaches.
4.	868+000 to 801+000	2454 cusecs)	
5.	801+000 to 211+000	2457 cusecs)	
6.	211+000 to 0+000	2550 cusecs)	

7.4 Routing with Pandoki Drainage System Diverted Straight to Sutlej D/S of Ferozepur Headworks

It was concluded from the results of channel routing given above that the major portion of flood was contributed by the sub-catchments No.1 & 3 at the source of Sukh Beas Nullah, mainly the sub-catchment No. 2 drained by the Pandoki Drainage System. The evident cause is that the rainfall in the upper area near the source is comparatively higher with large run-off potential. The drainage area of the sub-catchment No.1 which is covered by the Pandoki Drainage System is also quite large i. e. 256 square miles. This huge discharge should not be allowed to spread misery all along the route of Sukh Beas over a distance of 211 miles to the proposed outfall of Sukhnai Diversion into the Sutlej river. The upper area is also highly saline and flood water from this area carries salts alongwith it to the lower reaches. It was, therefore, considered essential to divert the discharge from the sub-catchments No.1 and 3 through a 10 mile long leading channel of 2,000 cusec capacity, into the Sutlej river near Kasur and reduce the peak discharge in the lower reach of the Sukh Beas Main Drain.Accordingly routing on computer was done over again along the same flood path with the exception of run-off from sub-catchments No.1 and 3. The results of routing with modified conditions are contained in Table-16 (given at page 109) from which it is evident that the maximum peak likely to be produced after deducting conveyance losses is 1992 cs.. (say 2,000 cusecs) against a value of 2550 cusecs obtained without diverting the Pandoki System.The design section in the head reach after diverting Pandoki Drainage System is also considerably reduced over a long reach.Diversion of Pandoki Drainage System straight into Sutlej River would provide substantial benefits and would add a new dimension to the concept of Sukh Beas Drainage Project.

Under this proposal reachwise discharge peaks of the Sukh Beas Main are shown in column 7 of Table-16 (given at page 109). The summarised results are given below:-

S.No.	Reach	Adopted Design Capacity
1.	1053+000 to 989+000	600 cusecs
2.	989+000 to 929+000	1,200 cusecs
3.	929+000 to 851+000	1,400 cusecs
4.	851+000 to 730+000	1,600 cusecs
5.	730+000 to 0+000	2,000 cusecs

8.0 Conclusions

The adopted estimates of channel and structure capacity required for adequate drainage of the Sukh Beas sub-catchments are based on peak values from synthetic flood hydrographs assumed to be generated by non-uniform design storms occurring simultaneously over the entire drainage area. The design storms are assumed to be composed of a sequence of 24 hour increments of rainfall with each increment having a uniform intensity and the sequence having a recurrence interval of five years. The flood hydrograph is assumed to be a combination of triangular hydrographs generated by each 24-hour increment of rainfall from the design storm. Each tributary hydrograph is assumed to be contributed to the head of each reach of the main drain and the combined hydrograph will travel through the main drain at a rate of 2.50 feet per second (with Pandoki System separated from the Sukh Beas Main Drain).

There are, however, several recognized alternative methods and formulae available for estimating drain capacity which will give different results. Three of these alternative methods were tried and the required drain capacities estimated. A comparison of the results of the three methods are given in Table-17 (given at page 111).

The SCS Empirical Formula alternative is described in the Hand Book of the U.S.Soil Conservation Service and is based on the empirical formula:

$$Q_p = (14.75\ R_e + 16.39)\ A^{5/6} \quad \ldots(\text{Eq.}12)$$

where

Q_p = peak rate of run-off in cusecs

R_e = one-half of 48-hour direct run-off in inches.

A = catchment area in acres.

The SCS Empirical formula computes only the peak rate of run-off and does not give any other catchment and hydrograph parameters. It is necessary, therefore, to adopt parameters estimated for the triangular Unit-hydrograph (i.e. $T_p = T_c^{0.5}$ + T_b= 2.67 T_p) so that flood hydrograph routing can be accomplished for the Main Drain.

The Unit-time Duration alternative assumes a variable storm duration that is a function of the catchment's time of concentration as expressed by Equation-(10) i.e. $D=2\ T_c^{0.5}$.

It can be seen that this function will cause the 24-hour direct run-off to occur in a shorter period on smaller catchments and, hence, at a higher peak rate of run-off than that given by the adopted method in Table-14 (given at page 104).

Table-17 (given at page 111) shows that if alternative methods of determining the peak discharges are used, it would increase the required channel capacity of the Sukh Beas Main Drain below B.S.Link by 20 to 25 percent. This increase in the channel capacity would increase the excavation quantities by about 15% and the overall cost estimate by about 12%. This variation is acceptable as it only confirms the reults achieved from the adopted method.

Neither of the alternative methods described includes specific provisions for moderation of the peak rate of run-off by storage in surface depressions and bunded fields. The SCS Empirical Formula does, however, use only one-half of the 48-hour direct run-off for peak flow generation. This assumption embodies some catchment storage effect but, without actual run-off measurements, the adequacy of the assumption cannot be certain.

Although no adequate record of discharges in the Sukh Beas Nullah below B.S.Link Canal is available, miscellaneous stage observations carried out by our Field Staff indicated that discharges greater than 2,000 cusecs, seldom occur even with intense storms.An important feature of Monsoon storms also cannot be ignored that the storms are never so wide spread as to cover such large areas as the catchment of Sukh Beas Nullah. It is concluded, therefore, that the discharges shown in Tables-14 & 16 provide a reasonable basis for designing the Sukh Beas Drainage System.

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TABLE-1

BASIN PARAMETERS

Sub-catchment No.	Side Left or Right	Area of Miles	Length from Out-let to divide 'L' (Miles)	Fall 'H' (Feet)	Average Slope %	Average Slope 1 In	$T_c = \left(\frac{11.9 L^3}{H}\right)^{.385}$ (Hrs)	Remarks
1	2	3	4	5	6	7	8	9
1	R	256	40.00	56.0	.0418	2392	39.03	
2	R	97	15.50	26.0	.0416	2403	17.55	
3	L	58	24.00	25.0	.0204	4900	29.51	
4	R	20	3.00	10.0	.0340	2941	3.80	
5	R	48	18.50	38.0	.0270	3703	18.60	
6	R	49	33.00	48.0	.0397	2518	33.17	
7	R	33	12.00	25.0	.0395	2534	13.25	1000 cs inlet on B.S.Link
8	L	85	27.00	37.0	.0303	3300	29.07	
9.	R	9	4.50	7.0	.0333	3000	6.96	
10.	L	33	17.50	23.0	.0285	3500	21.16	
11.	L	04	3.75	3.0	.0152	6600	7.82	4000 cs.Inlet on B.S.Link
12.	L	81	38.00	36.0	.0200	5000	43.60	
13a.	L	116	26.75	47.0	.0250	4000	26.24	2000 cs.Inlet on B.S.Link
13b.	L	42	9.25	10.0	.0200	5000	13.96	
14.	L	7	3.75	7.0	.0350	2829	5.65	300 cs.Inlet on.B.S.Link.
15	L	39	19.50	26.0	.0250	3960	22.87	1000 cs Inlet on B.S.Link
16.	L	35	20.00	27.0	.0344	2911	23.21	- do -
17.	L	31	10.00	13.0	.0250	4062	13.81	- do -
18.	L	19	17.50	5.0	.0159	6300	24.63	
19	R	24	12.50	17.0	.0279	3580	16.11	
20	R	149	28.00	33.0	.0170	5882	31.69	
21	R	43	13.00	17.0	.0198	5050	16.86	
22	R	18	9.50	22.0	.0340	2941	10.63	
23	R	49	14.75	37.0	.0340	2941	14.18	
24	L	7	5.50	2.0	.0127	7900	14.23	
25	L	18	9.00	4.0	.0070	13250	19.25	
26	L	40	15.50	20.0	.0250	4000	19.40	
27	R	7	7.00	4.0	.0178	5600	14.40	
28	R	54	15.00	30.0	.0170	5882	15.99	
29	L	7	4.50	4.0	.0133	7500	8.64	
30	L	33	14.00	14.0	.0162	6200	19.79	

TABLE - 1

1	2	3	4	5	6	7	8	9
31	L	428	38.50	47.0	.0167	6000	39.95	
32	R	24	9.00	15.0	.0235	4250	11.57	
33	R	80	28.00	24.0	.0170	5882	35.82	
34	L	3	3.00	1.0	.0133	7500	9.22	
35	R	38	11.25	23.0	.0202	4950	12.70	
36	R	5	4.00	14.0	.0236	4237	4.66	
37	R	40	14.50	30.0	.0284	3521	15.37	
38	L	13	7.00	18.0	.0238	4200	8.07	
39	R	13	6.75	19.0	.0473	2114	17.57	
40	R	20	9.00	23.0	.0303	3300	9.82	
41	L	50	18.00	24.0	.0210	4550	21.50	
42	L	25	10.00	13.0	.0190	5250	13.81	
43	L	168	41,00	29.0	.0125	8000	51.74	
44	R	35	13.75	25.0	.0303	3300	15.51	
45	R	54	18.25	23.0	.0212	4716	22.21	
46	L	15	9.25	6.0	.0357	2800	16.99	
47	L	30	8.00	20.0	.0303	3300	9.04	
48	R	34	9.25	35.0	.0500	2000	8.62	
49	L	25	8.25	6.0	.0100	1000	14.89	
50	L	6	3.00	5.0	.0333	3000	4.96	
51	L	12	5.00	5.0	.0235	4250	8.95	
52	L	9	4.50	1.0	.0182	5500	14.71	
53	L	9	6.00	19.0	.0333	3000	6.61	
54	R	9	6.00	4.0	.0222	4500	12.05	
55	R	328	39.00	51.0	.0157	6370	39.30	
56	R	26	13.00	32.0	.0555	1800	13.21	
57	R	4	3.00	7.0	.0440	2263	4.36	85 cs.Inlet on S.M.Link
58	R	4	2.50	6.0	.0450	2200	3.75	50 cs.Inlet on S.M.Link

TABLE-1

1	2	3	4	5	6	7	8	9
59	R	78	16.00	15.0	.0180	5560	22.49	
60	R	27	15.50	27.0	.0330	3031	13.51	75 cs.Inlet on S.M.Link
61	R	33	14.00	33.0	.0450	2240	14.23	200 cs.Inlet on S.M.Link
62	R	354	47.00	62.0	.0208	4807	45.22	
63	R	38	12.50	9.0	.0204	4900	20.55	
64	L	48	20.25	20.0	.0190	5250	26.43	
65	L	7	3.00	3.0	.0200	5000	6.04	
66	L	22	9.50	9.0	.0139	7200	14.99	
67	R	75	21.00	49.0	.0308	3250	19.52	
68	R	5	3.50	21.0	.0667	1500	27.05	
69	L	10	3.00	6.0	.0333	3000	4.62	
70	L	19	5.00	5.0	.0250	4000	8.96	
71	R	27	11.00	10.0	.0217	4600	17.46	
72	R	231	34.00	56.0	.0204	4900	32.35	
73	R	74	20.00	28.0	.0278	3600	22.89	
74	L	21	8.50	9.0	.0156	6425	13.18	
75	L	160	37.00	39.0	.0244	4100	41.00	
76	R	22	9.00	10.0	.0167	6000	13.50	
77	R	44	13.00	18.0	.0262	3820	16.50	
78	R	566	60.00	70.0	.0222	4500	57.21	
79	R	143	30.00	37.0	.0222	4500	32.84	
80	L	70	18.25	23.0	.0239	4188	22.21	
81	L	56	13.25	11.0	.0163	6125	20.38	
82	R	267	28.00	29.0	.0217	4600	33.30	
83	R	22	15.00	10.0	.0147	6800	24.40	
84	L	19	12.75	11.0	.0132	7637	19.49	
85	L	23	10.75	8.0	.0136	7353	18.09	
86	L	17	10.00	10.0	.0210	4761	15.27	
87	R	74	28.00	19.0	.0208	4800	38.00	