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HYDROLOGIC SOIL CLASSIFICATION

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SUMMARY

Hydrologic soil classification refers to a group of soil series that can be considered homogeneous in respect of soil characteristics. Hydrologic soil classification is useful for estimation of runoff. The soil characteristics of the watershed play an important role in the hydrologic soil classification. The various elements namely surface runoff, infiltration, percolation, soil moisture are influenced by the soil characteristics of the watershed which plays an important role in soil classification. The surface characteristics of the soil are defined by infiltration capacity and subsurface characteristics by percolation rate at which the water moves through the soil.

This review note gives in detail the history of soil classification system,statistical approaches which can be used for soil classification, hydrological parameters used for soil classification, soil classification based on SCS, soil classification based on All India Soil and Land Use Survey Organisation and classification of irrigation soils in Denver,U.S.A.

The main parameters for hydrologic soil classification considered in this review report are effective soil depth,soil texture in the surface and subsurface layer,clay content,soil structure,infiltration rate, soil permeability and soil drainability. Soil Conservation Service of the Unites States Department of Agriculture has classified the soils into four hydrologic soil groups namely Group A,B,C and Group D respectively in the increasing order of runoff potential. To use

the soil classification list, it is necessary to know only the names of the soil on the watershed. To estimate the runoff the area of each soil must be known.

1.0 INTRODUCTION

Soil classification is largely a 20th century concept although work in this area started in the preceding century. In the U.S. for example efforts were made during the 19th century to classify the soils of a few states. The purpose of classification is to organize the members of a large population of objects (soils) into groups or classes of objects so that the relationship between the objects can be more easily understood (R.J.Arkley,1976).

There are a number of different ways in which soil can be classified. Prerequisite to the classification of soils is the concept that the soil mantle consists of natural geographic bodies with their own genesis. Such a concept became possible after the science of geology was born, even though the first theory of soil genesis as rock weathering was found inadequate later. Proposed systems of soil classifications have all relfected the concepts of soil and theories of genesis.

Hydrologic soil classification refers to a group of soil series that can be considered homogeneous in respect of soil characteristics that influence the runoff. Soil characteristics of the watershed play an important role in its runoff potential. The surface runoff, soil moisture storage and deep percolation due to infiltration from a storm are influenced by the soil characteristics of the watershed. Such response is affected by the characteristics of soils both on the surface and sub-surface horizons. The characteristic of the soils on the surface is the infiltration capacity and characteristic of the soil in the subsurface is the percolation or transmission rate.

In this report an attempt has been made to review the hydrologic soil classification system. Also application of statistical approaches in soil classification system has been reviewed briefly. The main emphasis has been given on hydrological properties of the soils such as soil profile, soil structure, soil texture, infiltration rate, soil permeability, soil drainability etc.

2.0 REVIEW

Numerous systems of soil classification have been developed and many are in use in various parts of the world. The engineer classifies soil on the basis of those characteristics which determine how a soil will behave as an engineering construction material. Some of the characteristics of soils which are important in determining the engineering properties are particle size,shape,density and consistency. The soil scientist or pedologist is concerned with the surface mantle of material subject to the force of weather and climate. The hydrologist is concerned with the surface layers as well as deeper soil layers that can transmit water. Also the soil classification system vary from country to country. Most systems have a number of points in common with the classifications used in the United States.

2.1 History of Soil Classification

The first systematic soil survey was launched in 1899 in the United States before any method for classification of soils was developed. The kinds of soils shown on the earliest maps were called soil types and no effort was made at first to relate the types of one survey area to those of another. Within the first 10 years of the program,however, a classification consisting of three categories namely physiographic region, the soil series and the soil type were proposed. The early system of classification was a direct reflection of the prevailing concept of soil as the weathered mantle of rock, and the prevailing theory of soil genesis as rock weathering in place or as the deposition of weathered rock. The system was followed in U.S. with little change for about 30 years. Despite this frame of reference for the classification of soils, however, attention was given to soil profile characteristics that were not directly related to weathering or to source rocks. Those characteristics were being introduced as series criteria within the first 10 years of the century, well before a different approach had been proposed (Simonson,1964).

The second system of soil classification was based on a proposal by Marbut(1927,1935) in the U.S.A. The emphasis has been given to soil profile characteristics. The characteristics spelled out by Marbut in 1922 were still in use as class criteria 30 years later (Whiteside,1954). A skelton outlines of the scheme developed by Marbut is given in Table 1. The categories , their bases and their names are listed without the individual classes. Names of some great soils groups were carried over when the scheme devised by Marbut was modified a few years after it was published (Baldwin et al,1938). The modified version gradually came into use although it did not fully replace the initial scheme.

Table 1- Categories in the Scheme of Marbut with brief Descriptions and the Names

Category*	Description	Names
VI	Solum* Composition groups	Orders
V	Inorganic Composition groups	Suborders
IV	Broad environment groups	Great Soil groups
III	Local environment groups	Families
II	Soil type groups	Soil series
I	Soil units	Soil types

* A category is a set of classes of the same rank

** Solum is the upper and most weathered part of the soil profile.

The revised version also consisted of six categories called orders,suborders, great soil groups,families,soil series and soil types. The names of the caregories were the same as those introduced by Marbut in 1935 (as shown in Table 1). The system had 3 orders, 6 suborders and 36 great soil groups as shown in Table 2. At that time approximately 2000 series had been recognized in the U.S. but these were not grouped into families and great soil groups. From the time, the second system was introduced in 1938 until it was replaced in the soil survey program in 1965, a number of changes were made in the list of great soil groups but not in the structure as a whole. The concept of soil and the theories of genesis reflected in the second system of classification are greatly different from those expressed in the initial system. Rather than being considered the weathered rock mantle, soil was looked upon as an organized natural body closely related to but differing from weathered rock.

In 1950, efforts were begun to revise the entire system rather than try to improve individual segments. The work of revising the classification system was carried forward through a sequence of approximations. This sytem has also six categories as shown Table 1. The soil type is now considered a kind of phase within a series. This system has been completed by defining all classes in all categories and by grouping all soil series of the U.S. into classes of higher rank. Thus in 1975, the system consisted of 10 orders, 47 sub-orders,185 great groups,900 subgroups,4500 families and 10,500 series (Soil Survey Staff Report,1975). A new nomenclature was

Table 2 - Order, suborder, and great soil groups of the system outlined in 1983

Orders	Suborders	Great soil groups
Zonal soils	Soils of the cold zone Light-Colored soils of arid regions	Tundra soils, Desert soils, Red desert soils, Brown soils
	Dark - colored soils of semi arid, subhumid and humid grasslands	Prairie soils, Reddish prairie soils
	Soils of the forest-grassland transition	Nonclacic brown soils
	Lateritic soils of forested warm temperature and tropical regions	Yellowish brown lateritic soils, Reddish brown lateritic soils, Laterite soils
Intrazonal soils	Saline and Alkali soils of imperfectly drained arid regions	Solonchak soils Solonetz soils
	Hydromorphic soils of marches, swamps, seep areas and flats	Meadow soils, Alpine meadow soils, Ground Water laterite soils
	Calcimorphic soils	Brown forest soils
Azonal soils	(No suborder)	Alluvial soils, Dry sands

developed for classes in the top four categories of the system, mostly from Latin and Greek morphemes. The nomenclature is designed so that every class name identifies its rank in the system. Moreover, each name of each class in the three categories below the order identifies the class or classes into which the named one is placed at higher levels. Thus all names of orders end in ' Sols'. For example Alfisols,Entisols,Mollisols,Spodosols etc. All names of suborders consist of two syllables and each ends in a syllable taken from the name of the appropriate order. For example, the name Aquod ends in the letter of indicating that it is a suborder of spodosols. All names of great groups have three or four syllables and were constructed by adding a prefix to the name of the appropriate suborder thus Haplaquod. All names of subgroups consist of two words,as for example,Typic Haplaquod.

This system of classification does not reflect a substantial departure from previous theories. A large number of properties were ignored. Later on, a large number of soil properties not mentioned so far were considered in the classification of soils, like soil profile, characteristics of horizons,soil texture,soil structure etc.

2.1.1 Soil profile

Much emphasis in describing soils and in defining soil series is given to the soil profile. The sequence and arrangement of horizons within a profile and their characteristics are keys to the concepts and descriptions of soil series. Horizons are layers parallel to the soil surface and range in thickness from a few millemeters to as much as 1.5 m. The nature of the individual horizon is due to the additions, losses,transfers and transformations that have affected a profile in the past.

A hypothetical soil profile with all horizons are shown in Figure 1. All horizons are seldom present in a single profile but part of the full set always is there.

Major horizons in profiles are identified by the letters,A,B, and C. In addition, the letters O and R are also used in defining the horizons in a profile. The letter O refers to organic matter on the soil surface whereas R is used to label rock beneath the soil. The O horizon is a surface layer consisting of organic debris in some stage of decomposition. On the basis of the stage of decay, the horizon is subdivided into O1 and O2 horizons. The O1 horizon consists of leaves, twigs,and other litter which is just beginning to decay. The O2 horizon consists of organic residues that have decomposed enough so that plant structures are no longer identifiable. The O horizon is most common in soils under forest cover in humid climate. Many mineral soils,however,lack O horizons.

The A horizon occurs at or near the soil surface. In most soils, it is reached first by the falling rain and by solar radiation. The A horizons is also highest in organic matter and humus with few exceptions. The immediate surface layer highest in organic matter is also the darkest one in profile and it is designated by the A1 horizon. In well drained soils , its thickness ranges from 3 cm or less to 30 cm in the various parts of the United States. A 1 horizon are present in profiles of a great majority of the soils of the world.

01	Loose leaves and organic debris,largely undecomposed.
02	Organic debris,partially decomposed.
A1	A dark-colored horizon of mixed mineral and organic matter and with much biological activity.
A2	A light-colored horizon cf maximum eluviation.
A3	Transitional to B but more like A than B
B1	Transitional to A but more like B than A
B2	Maximum accumulation of silicate clay minerals maximum expression of blocky or prismatic structure ; or both
B3	Transitional to C but more like B than C
C	Weathered parent material,occasionally absent; formation of horizons may follow weathering so closely that the A or B horizon rests on consolidated rock.
R	Layer of consolidated rock beneath the soil.

FIRUTE -1 A hypothetical soil profile showing all principal horizons and layers.

Where the A 1 horizon is thin, the second layer is usually paler in color and lower in organic matter, bases(like calcium) etc. This layer is called an A 2 horizon. A 2 horizons are commonly present in soils under forest cover in humid climates and are as commonly lacking in soils under prairie vegetation in subhumid and semiarid regions.

The B horizon is a subsurface layer into which organic matter and silicate clays have been transferred in suspension, solution or both. B horizons also have blocky or prismatic structure. Such B horizons occur in humid and wet dry tropics. In many soils, especially in those of grasslands, the B horizon is a subsurface layer with distinct blocky or prismatic structure as the chief evidence of alternation of the original weathered rock material. Many of the criteria for defining and differentiating classes in upper categories of the current system in the U.S. are keyed to B horizons. They are less subject to modification than A horizons, which means that placements of soils can be more stable. The A and B horizons, taken together, are called the solum, meaning that they are the principal genetic horizons. They are sometime called the 'true soil' because these two horizons are the principal reflections of soil genesis.

The C horizon is a subsurface layer of weathered materials, commonly presumed to be like those from which the A and B horizons were developed. This horizons, like the A and B horizons may be absent with one of the other two resting directly on rock. Conventions have been developed to label C horizons that clearly consist of material different from those in the A and B horizons. In some stratified deposits the A, B and C horizons all differ in their lithology. Consequently, many C horizons are simply the weathered materials below the A or B horizons. The letter R is used to flag a layer of consolidated rock beneath the soil profile.

2.1.2 Characterization of horizons

Soil horizons are described in terms of properties such as thickness, color,texture,structure,consistence,porosity, mineralogy,chemical composition etc. These characteristics are in turn the basis for determining whether a given horizon or combination of horizons qualifies as a diagnostic feature for a class in one of the upper categories of the current system. Such characteristics are also the basis for placments of soils into families and series.

2.1.3 Texture

Soil texture depends on the relative proportions of different size groups of mineral particles below 2 mm in diameter in a small mass of soil material. The size groups are called soil seprates; their names and limits are given in Table 3.

Table 3. Size Limits of Soil Seprates in Scheme of U.S.Department of Agriculture

Name of Seprate	Diameter range (mm)
Very coarse sand	2.0 - 1.0
Coarse Sand	1.0 - 0.5
Medium Sand	0.5 - 0.25
Fine Sand	0.25 -0.10
Very fine sand	0.10 -0.05
Silt	0.05 -0.002
Clay	Below-0.002

Soil texture classes are defined largely on the basis of relative proportions of seprates of different sizes. Permissible proportions of clay (below 0.002 mm), silt (0.002 to 0.05 mm) and sand (0.05 to 2.0 mm) in the basic texture classes are shown in Figure 2.

Subdivisions are made of some of the basic texture classes as shown in Figure 2, according to the relative proportion of the soil seprates. For example coarse sand and fine sand,loamy fine sand, loamy very fine sand, and coarse sandy loam and fine sandy loam.

The texture of a horizon is a rather permanent property, more so than are structure , porosity and consistence. All of these properties can,for example, be altered by tillage,, whereas much more needs to be done to change texture. Soil texture was a characteristic used to distinguish soil types in the earliest soil surveys in the U.S.because Whitney(1892) believed it to be the best available index to conditions of soil moisture and temperature.

Textures of horizons are considered in defining soil series and in subdividing them. Texture of the surface layer is used to define and distinguish soil types within a series. The textures of the B and C horizons (consists of silicate clay minerals and organic matter) are different. Particle size distribution in a part of the profile is one basis for differentiating and defining soil families.

2.1.4 Structure

Soil structure is the natural clustering of primary

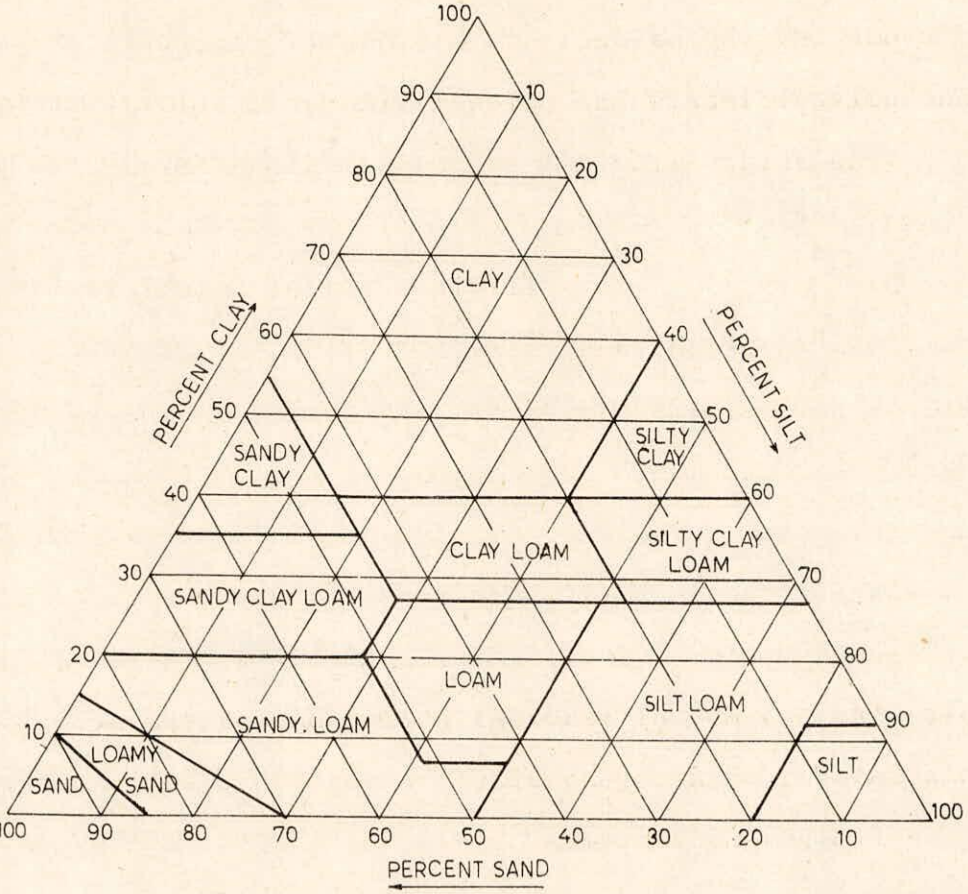

FIGURE 2 - Triangular graph showing the proportions of clay (below 0.002 mm), silt (0.05 to 0.002 mm), and sand (2.0 to 0.05 mm) in the basic classes of soil texture.

particles into groups that are seprated by surfaces of weakness. A single natural cluster is called a ped. Among soils of the world, peds have a variety of shapes and sizes as well as a wide range in distinctness. Classes for shapes and sizes of peds are given in Table 4 (Soil Survey Manual;1951). Distinctness of peds is called structure grade and is normally described as weak,moderate,or strong. Provisions has been made for subdivision of each of the weak and strong grades by adding the modifier very or moderately. The four principal types of structure are;granular,platy,blocky and prismatic as shown in Table 4.

2.2 Statistical Methods in Soil Classification

Soil classification in the past has been primarily hierarchical in nature,with one or more criteria used at each categorical level to divide soils into mutually exclusive classes. Such a classification is helpful in the understanding of relationships among soils, but some relationships may be seriously distorted. This occurs when a group of soils which is relatively similar in all other respects, is subdivided into two groups at all lower categorical levels by small difference in a particular differentiating characteristic. Avery(1968) points out that a successful hierarchical classsification can be made only if the differentiating criteria can be ordered in accordance with the number of other attributes associated with them. He points out further that soil variation is not of this character,presumably because soil characteristics result from the interaction of several factors. This is the major problem in

Table 4 - Principal Types (Shapes) and size classes of soil structure

Platy Structure	Prismlike structure	Block Structure	Granular Structure
Very fine platy < 1 mm	Very fine prismatic < 10 mm	Very fine blocky < 5 mm	Very fine granular < 1 mm
Fine platy 1 - 2 mm	Fine prismatic 10 - 20 mm	Fine blocky 5 - 10 mm	Fine granular 1 - 2 mm
Medium platy 2 - 5 mm	Medium Prismatic 20 - 50 mm	Medium blocky 10 - 20 mm	Medium 2 - 5 mm
Coarse platy 5 - 10 mm	Coarse Prismatic 50 - 100 mm	Coarse blocky 20 - 50 mm	Coarse granular 5 - 10 mm
Very Coarse platy > 10 mm	Very coarse prismatic > 100 mm	Very coarse blocky > 50 mm	Very coarse Granular > 10 mm

soil classification. Experience has shown that soils may occur as discrete, relatively homogeneous bodies when considered only within a local area. But as investigations extended to broader areas, more and more soils of intermediate character are encountered which bridge the gaps between the original discrete soil bodies. This leads to problem in soil correlation.

Avery (1968) argues forcefully that a coordinate system of classification is more appropriate for soil than a hierarchical system. The advantage to a coordinate system being that each differentiating criterion is given equal weight at least a priori.

In the statistical method of soil classification, it is observed that the soils (mainly soil profiles) fall into natural clusters or groups which can then be ordered into a classification. Although little work has been done toward the development of a coordinate classification scheme, however, some of the statistical methods described can be used effectively for this purpose assuming that soil characteristics vary in such a way as to form a continuum through the whole population of soils. A method is suggested by which soils can be classified using a set of well-separated centroids and classes formed on the basis of the general affinity of real soils to the centroids.

2.2.1 Cluster analysis of soils

Cluster analysis of soils is defined (Sneath and Sokal, 1973) as the grouping of soils by numerical methods on the basis of their character states, i.e. texture ,structure, soil profile etc. Groupings are formed using the following general procedures: First, data for a number of units, such as soil profiles are assembled including a sizeable number of selected variable properties for each unit. The data are commonly arranged into a matrix consisting of soils by columns and soil properties by rows. Next an overall estimate of resemblance is obtained between pairs of soils by some mathematical function of all differences between the values for each property of the two soils. After numerical values for the estimate of resemblance between all paris of soils are obtained, the matrix value is subjected to a sorting strategy which forms groups of similar soils. The nature of the groups formed and their relationship can be presented in various ways; these may include dendograms, recorded matrices, ordination, or simply tables of coordinates.

2.2.2 Data selection

The choice of soils to be included in the data should be such that the number of soils is large and the general kinds of soils included are well represented. For example if the soils included are mainly well drained and without evidence of wetness, then the inclusion of a very few poorly drained soils may interfere with the analysis because those soil properties associated with wetness may not be representative of the range of variation in those properties.

The selection of soil properties is even more important than the selection of soils for soil classification. Although all kinds of both field and laboratory data can be used, there are certain kinds that should be excluded or that need special treatment. Some soil properties such as field moisture content are generally irrelevant to soil classification and should be excluded. Logically correlated properties, such ad dry and moist colors, are generally so highly covariant that one or other should be included. Particle size distribution for sand,silt and clay always add up to 100% and so one of the three should be eliminated from the data. The inclusion of large numbers of logically related properties should be avoided, as they tend to create an inadvertent extra weight to such a group of properties in the classification.

Soil data obtained from laboratory analysis are always continuous variables as are a number of field measurements such as thickness and depths of recognizable characters. Field observations such as soil texture,structure and consistency are usually discrete or multistate variables and need to be treated with special care. Data of this kind should be coded in such a way as to reflect their proper rank order reflecting their importance to soil behaviour. For example, soil texture classes might be coded in order of their relative clay content or water retention characteristics.

Structure is a particularly difficult soil property to code as a ranked multistate variable. For surface soils, an appropriate order of structure type might be single grained, massive,platy,crumb,granular,subangular blocky and angular blocky; for subsoil layers the order might be single grained, massive, platy,granular,subangular blocky,angular blocky,prismatic and columnar. The system suggested is only one of many possible ways that soil structure might be treated.

2.2.3 Ordination of soils

Another approach to the examination of taxonomic structure is through ordination, which is normally used when the distribution of individuals tends to continuous rather than in distinct clusters.

Two kinds of ordination have been used in soil studies. Q-type ordination or analysis of objects operates on a similarity matrix of objects and examines the distribution of objects in object space to find the dimensions along which the objects are distributed. R-type ordination or analysis of variables operates on the covariance matrix variables to find dimensions in variable - space. These dimensions are formed by clusters of covariant variables.

2.2.4 Q-type ordination

Ordination of this type was used in one of the first attempts at numerical classification of soils by Hole and Hironaka (1960) and Bidwell and Hole (1964).

The method or principal coordinates analysis (PCO) developed by Gower (1966) operates best on a Euclidean distance matrix (dissimilarity coefficients) but may be used with other similarity coefficients.

The first use of this approach was by Rayner(1966) who utilized the method of Gower (1966). Norris and Dale (1971) used a slightly modified form of PCO as part of procedure for comparing the classification derived from two sets of data on the same soils and found a high degree of correlation between the two sets of data.

2.2.5 R-type ordination

Principal component analysis

The most commonly used R-type procedure is the Principal Components Analysis (PCA) which operates on the matrix of correlation coefficients(r) between all pair of variables. Principal components analysis provides an accurate representation of the relationship between major groups and clusters. The analysis has been used in a number of soil studies. Barkham and Norris (1970) used principal components analysis on the vegetation and soils and examined the relationships between the two by comparing the first two vegetative components with four soil components and various soil variables. Cipra et al.(1970) used PCA together with cluster analysis to study the relationships between different type of soils. They considered this a meaningful method of visualizing relationships between soils.

Cuanalo and Webster (1970) also used both principal components with projection of individuals on the first two dimensions together with clustering methods. They concluded, that soil data be first examined by ordination by principal components before attempting a classification of a set of soils.

Norris (1971a) applied PCA to two groups of soils using two sets of data: laboratory and field data for each group. From the analysis, he concluded that the variation of soils can be characterized by the variation of a relatively few properties, and that there is a considerable correspondence between groupings based upon field and laboratory data separately. Norris (1972) applied the results derived above to applied the problems in soil mapping and classification and as an aid in understanding the causes for soil variation.

Principal factor analysis

Principal Factor Analysis (PFA) has been used much less frequently than principal components analysis in soil studies. PFA differs from PCA in that in principal component analysis, the diagonals of the correlation matrix of variables are filled with unities whereas in principal factor analysis the unities are replaced by so-called communalities, the percentage of variation due to the common factors. In PCA the axes are orthogonal, whereas in factor analysis they can be rotated and can be correlated. This is particularly suited to soil data which are often highly intercorrelated.

Arkely (1971) used this approach to analyse six different sets of soil data and found that five dimensions accounted for 85 percent of the squared raw correlations in 220 California soils, 87 percent in 620 California soils, and 72.1 percent in 59 different type of soils; seven dimensions accounted for 75.5 percent of the squared raw correlation in 148 Ohio soils, and 80.9 percent in 86 different type of soils. In every case only about three or four variables were required for each dimension. They concluded that 20 to 25 variables are sufficient for soil classification.

2.2.6 Soil as an anisotropic entity

Soil description and analytical data have been treated in several different ways in an attempt to solve the problem of homology, i.e.the comparisons of profiles,layers or horizons, should be compared between soils with different sets of horizons designated in the conventional way by soil scientists.

Soil profile as an array of soil properties

Soil properties such as the color and structure of the A 1 and B 2 horizons, texture of the A 1 ,B 2 and C, and difference between maximum clay in the B and minimum clay in the A horizon have been used. The use of soil profile data or soil horizon data has been criticized on the grounds that it is subject to the human error even when the designation of horizons follows defined rules.

Soil data by layers or horizons

Soil samples taken at specified depth and compared directly have been used by Barkahm and Norris (1970),Norris and Loveday (1971), and Webster and Burrough(1972). This method is appropriate only over small areas where the samples depth taken can reasonably be expected to sample comparable portions of the soil profile.

The choice of variables to be used in soil classification will depend upon the nature of the data available or the purpose of the classification. However, for a general classification,Arkley;1971 suggest that a minimal set of soil properties should include at least one or several measurements representing the following dimensions:

1) Soil reaction such as surface and subsoil pH, exchangeable sodium etc.

2) Texture or contents of clay and sand or clay and silt and gravel content.

3) Thickness of surface layer

4) Soil wetness

5) Degree of profile differentiation such as difference in clay content between the A and B horizon

6) Solum thickness

Most of these are properties measurable in the field. Since the purpose of soil classification is related mainly to land use or plant growth in the field, it is relevant only to soil distributions that are mapped by field methods.

2.3 Soils Classification based on Hydrologic Soil Properties

Hydrologic soil classification is essential for the evaluation of runoff. The main parameters used commonly in hydrologic soil classification are:

1. Effective soil depth,
2. Soil texture/average clay content in the surface and subsurface layers
3. Soil structure in the surface and subsurface layers
4. Infiltration rate, and
5. Soil permeability and drainability

2.3.1 Effective soil depth

The depth of soil that can be effectively exploited by the plant roots is an important criterion in selecting land for for irrigation. Effective depth includes the solum thickness plus adjusted or corrected thickness of the disintegrated and weathered permeable rock material where the soil rests on such a material. In case of soils with hard pan, the effective depth is the thickness of soil overlying such a layer. When the soils are lying over disintegrated and weathered rock material, the effective soil depth will consist of soil depth plus the percentage soil equivalent of the weathered substratum. The adjusted and corrected thickness for such a disintegrated layer can be calculated by multiplying thickness of this layer with the per cent soil material contained in it. For example, if the disintegrated substratum is 50 cm thick and contains about 30 per cent soils material, the adjusted thickness would be 50 x 0.30 = 15 cm. If this substratum is overlain by a soil solum of 30 cm., then the effective depth will be 30 + 15 = 45cm. In case of soils with hard pans, indurated or permanently saturated moisture zone that prevents the entry of water through it, the effective depth signifies the thickness of the soil overlying such layer. The significance of effective soil depth to runoff potential is given in Table 5.

Table 5 : Relationship between effective soil depth and runoff potential

Thickness, cm	Soil depth class*	Runoff potential
above 100	d5	Low
51-100	d4	Moderately low
26-50	d3	Moderately high
11-25	d2	High
0-10	d1	High

*As used by the All India Soil and Land Use Survey Organisation

2.3.2 Soil texture/average clay content

Soil texture refers to relative proportion of various soil separates in a soil material and is related to soil water interrelationships. On the basis of relative proportion of this basic separates, as shown in Table 3, various soil textural groups are recognized. Clay, being the most active and reactive fraction, is used as a single factor index in deciding hydrologic group of a series. Clay content of the surface layer and the average clay content of the whole profile are considered for this purpose. In order to compute average clay content of the profile, the clay content of each of the soil horizon is multiplied by its respective thickness and the summation of these is divided by the total thickness of the profile.

Clay content of the surface layer is more important with respect to infiltration. The relationship between clay content, textural class and runoff potential are given in Table 6.

Table 6 - Relationship between clay content and runoff potential

Clay content (%)	Qualifying Textural class	Runoff potential
0 - 8	Sand, loamy sand	Low
9 - 25	Sandy loam, Silt	Low to moderately low
26- 40	Silt, sandy clay loam, clay loam, silty clay loam	Moderately high to high
> 41	Sandy clay, Silty clay, clay	High

2.3. 3 Soil structure

Soil structure refers to the arrangement of soil particles in the soil profile. Soil structure governs the moisture and air regimes in the soil. The movement of water in the soil and its transmission is affected by soil structure and texture. The influence of structure on runoff potential is given in Table 7.

Table 7 - Soil structure and runoff potential

Soil structure	Runoff potential
1. Single grain	Low
2. Grannular,Crumb	Moderately low to low
3. Subgrannular blocky Columnar	Moderately low to moderately high
4. Strong angular blocky prismatic	Moderately high to high
5. Strong platy compact massive	High

2.3. 4 Infiltration

Infiltration is the term applied to the process of water entry into the soil,generally by downward flow through all part of the soil surface. The rate of this process determines how much water will enter the root zone and how much, if any, will runoff. The infiltration rate is defined as the volume flux of water flowing into the soil profile per unit of soil surface area. The maximum rate at which the soil can absorb water through the soil surface is termed as infiltration capacity. This is a function of soil moisture condition. At saturation,infiltration capacity is minimum and is the characteristics of the soil i.e. texture, structure,organic matter content, type of clay mineral, antecedent soil moisture etc. The relationship between infiltration classes and runoff potential is given in Table 8 as per the studies conducted by All India Soil and Land Use Survey Organisation of Ministry of Agriculture.

Table - 8 Infiltration rate and runoff potential

Infiltration Class	Basic Infiltration rate cm/hr	Runoff Potential
1. Very high	< 8.0	Low
2. High	5.01 - 8.0	Low to moderately low
3. Medium	3.11 - 5.0	Moderate low to moderately high
4. Low	1.60 - 3.1	Moderately high to high
5. Very low	< 1.6	High

2.3.5 Soil permeability

Soil permeability refers to the ease with which water can move in the soil profile. Its a measure of drainability of the soil in cm/hour or cm/day. Soil properties such as texture, structure,management practices, land cover, land use all controls the total water intake in a soil profile at a given time. The relative classes of soil permeability and their interpreted runoff potential are shown in Table 9.

Table 9 - Permeability and Runoff potential

Permeability Class	Water intake rate, cm/hr.	Runoff Potential
Very slow	< .13	High
Slow	0.13 - 0.5	High
Moderately slow	0.51 - 2.0	Moderately high
Moderate	2.01 - 5.0	Moderately high to moderately low
Moderately rapid	5.01 - 13.0	Moderately low
Rapid	13.01 - 25.0	Low
Very rapid	> 25.0	Low

2.4 Hydrologic Soil Groups Classification based on SCS

Soil conservation service of the U.S.Department of Agriculture has classified the soils into four hydrologic soil groups namely Group A,B,C and Group D respectively in the increasing order of runoff potential. All the four groups alongwith their grouping criterion and descriptions are given in Table 10.

2.4.1 Hydrologic soil group - A (low runoff potential)

Soil having high infiltration rates even when thoroughly wetted and consisting chiefly of deep to very deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission throughout the profile and ground water table is usually below 5 meters.

2.4.2 Hydrologic soil group - B (moderately low runoff potential)

Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to weel drained soils with moderately fine to moderately corase textures. These soils have a moderate rate of water transmission throughout the profile. The depth of ground water table is usually 3 to 5 meters or more.

2.4.3 Hydrologic soil group - C (moderately high runoff potential)

Soil having low infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water or soils with moderately fine to fine textures. These soils have a slow rate of water transmission. The depth of water table is usually 1.5 to 3.0 meters or more.

2.4.4 Hydrologic soil group - D (high runoff potential)

Soil having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils (vertisols and vertic subgroups) with a high swelling potential, soils with a permanent high watertable,soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Table 10 - Hydrologic soil classification based on soil conservation service

Soil character	HYDROLOGIC SOIL GROUP			
	A	B	C	D
Effective depth, cm	> 100	51 - 100	26 - 50	≤ 25
Texture	S, LS	SL, Sil, L	Si, SCL, CL SiCL	SC, SiC, C
Clay percentage	0 - 8	9 - 25	26 - 40	> 40
Structure	Simple grained, granular crumb	Granular crumb, sub angular blocky	Sub angular blocky, columnar prismatic	Platy, massive
Infiltration rate cm/hr	> 8.0	5.1 - 8.0	1.6 - 5.0	< 1.6
Permeability cm/hr	High > 13	Mod.High 2 - 13	Mod.low to Mod.high 0.5 - 2	Low < 0.5

S-sand, LS-loamy Sand, SL-Sandy Loam, Sil-Silty Loam, L-Loam, Si-Silt, SCL-Sandy Clay Loam, CL-Clay Loam, SiC-Silty Clay, C-Clay, SiCL- Silty Clay Loam

The SCS soil group can be identified at a site using one of the three ways:-

1. Soil Characteristics
2. Soil Survey, and
3. Minimum infiltration rate.

The soil characteristics associated with each group are presented in Table 10. Soil survey gives a detailed description of the soils at a given location. These surveys are usually the best means of identifying the soil group. Soil analysis can be used to predict the minimum infiltration rates, which can be used to classify the soil into various hydrologic soil groups. The SCS cover complex classification consists of three factors namely, land use, treatment or practice and hydrologic condition. There are approximately fifteen different land uses that are identified for estimating curve number. Agricultural land use are often subdivided by treatment or practices, such as contoured or straight row. The hydrologic condition reflects the level of land management and it is classified into three classes, namely poor, fair and good.

The SCS developed an index which is termed as the runoff curve number (CN), to represent the combined hydrologic effect of soil, land use, agricultural land atreatment classes,hydrologic condition and antecedent soil moisture. These factors can be assessed from soil surveys, site investigation, and land use maps.

2.5 Hydrologic Soil Grouping by All India Soil and Land Use Survey Organisation

All India Soil and Land Use Survey Organisation has been carrying out soil surveys since 1958 in various parts of Andhra Pradesh,Bihar,Gujarat,Himachal Pradesh,Madhya Pradesh, Maharashtra,Orissa,West Bengal. The survey were done in the catchments of selected River Valley Projects namely,Sutlej, Chambal,Ramganga,Mayurakshe,Damodar Valley,Kangsabati,Machkund, Mahanadi,Ghod,Dantiwada,Tungbhadra and Kunda. Some of the non-river valley project areas have also been surveyed. So far more than 12 million hectares area have been surveyed by this organisation and about 4500 soil series have been recognised by them.

All India Soil and Land Use Survey Organisation has also attempted the classification of the soil series into hydrologic soil groups. The important soil characteristics like effective depth,average clay in the profile, soil structure,infiltration rate,permeability were considered in soil classification. The important characteristics of these soil series, their hydrologic soil groups, area mapped under the soil series and their location with regard to state,district,river valley project or non-river valley project have been estimated and presented in the report published in 1984.

2.6 Irrigated soil classification in Colorado,U.S.A.

All major irrigated soils in the Colorado State are listed and assigned to a design group. Each design group is then listed with an assigned cylinder infiltrometer intake family and a brief general soil description. This description includes a depth range, a permeability range, nature of sub-stratum, available water holding capacity range, a surface texture and other pertinent data. The assigned intake families are based on ring infiltrometer data, which applies to borders or other controlled flooding methods where an entire surface is flooded.

The irrigated soils in Colorado are classified into 17 design groups according to cylinder infiltrometer intake families and available water holding capacities. The intake families represented in Colorado are : 0.1,0.3,0.5,1.0,1.5,2.0 and 3.0. They are related to intake rates in inches per hour. The available water holding capacities are : very low (2 to 3 inches), low (3 to 6 inches),moderate (6 to 9 inches) and high (over 9 inches). The available water holding capacity is the amount of water stored in the soil profile, or the amount stored to a depth of 5 feet, whichever is appropriate.

The details of the various design group are :

Group 1. Deep and moderately deep,very slow or slowly permeable soils with modrate (5 to 7.5 inch) water capacity. The surface texture is of clay,clay loams and loams. (Intake family 0.1).

Group 2. Deep,slowly permeable soils with low (2.5 - 5 inch) water capacity with loamy sand surface textures. (intake family 0.1)

Group 3. Deep,very slowly permeable soils with high water capacity (> 7.5 inch) with surface textures of silty clays and clay loams. (Intake family 0.1)

Group 4. Deep and moderately deep slowly permeable soils with low (2.5 to 5 inch) water capacities and with surface texture of clay,clay loam,loam and sandy loam (Intake family 0.3)

Group 5. Deep,slowly permeable soils with high(> 7.5 inch) water capacity. Surface texture is of loam,silty clay loam, clay loam,sandy loam and loamy sand (Intake family 0.3)

Group 6. Shallow,moderately slowly permeable soils with very low (< 2.5 inch) water capacity. Surface textures

is of silty clay,silty clay loam and clay loam.
(Intake family 0.5)

Group 7. Deep and moderately deep,slowly permeable soils with moderate (5 - 7.5 inch) water capacity. Surface texture is of loam,sandy loam,clay loam and silty clay loam
(Intake family 0.5)

Group 8. Deep well drained soils with high (>7.5 inch)water capacity with surface texture of loam,silt loam, clay loam,silty clay loam,and gravelly clay loam.
(Intake family 0.5)

Group 9. Shallow soils with very low (< 2.5 inch) water capacity and loam surface texture
(Intake family 1.0)

Group 10. Deep and moderately deep soils with low (2.5 - 5 inch) water capacity. Surface textures is of stony and cobbly loams and clay loams
(Intake family 1.0)

Group 11. Deep and moderately deep,moderately permeable soils with moderate (5 - 7.5 inch) water capacity. Surface soils range from clay loam to sandy loam
(Intake family 1.0)

Group 12. Deep moderately permeable soils with high (>7.5 inch) water capacity and surface soils varies from loam, clay loams, and sandy loam surface textures.
(Intake family 1.0)

Group 13. Deep soils with moderately rapid permeability and low (2.5 - 5 inch) water capacities. Surface textures is of cobbly and gravelly loams and sandy loams
(Intake family 1.5)

Group 14. Deep soils with moderate (5.0 - 7.5 inch) water capacity. Surface texture range from loamy sands, sandy loams, sandy clay loams, and loams
(Intake family 1.5)

Group 15. Deep and moderately deep soils with low (2.5 - 5.0 inch) water capacities. Surface texture is of loamy sands, sandy loams and gravelly sandy loams
(Intake family 2.0)

Group 16. Deep soils with moderate (5 to 7.5 inch) available water capacity. Surface texture varies from loam, sandy loam to loamy sands
(Intake family 2. 0)

Group 17. Deep soils with low (2.5 - 5.0 inch) water capacities. Surface texture is of sands, loamy sands, gravelly loamy sands, and gravelly and cobbly sandy loam
(Intake family 3.0)

3.0 REMARKS

Hydrologic soil classification are essential for accurate estimation of runoff. The main soil parameters generally considered for analysis are effective soil depth, soil texture, clay contents in surface and subsurface layers, soil structure in surface and sub surface layers, infiltration rate, soil permeability and soil drainability.

This review note gives in detail the history of soil classification system, statistical approaches which can be used for soil classification, hydrological parameters used for soil classification, soil classification based on SCS, soil classification based on All India Soil and Land Use Survey Organisation and classification of irrigation soils in Denver, U.S.A.

The existing methods of hydrologic soil classification do not include all the possible parameters of importance. Generally it is not possible to establish the importance of the individual parameters in hydrologic soil classification by conventional methods like contribution of soil texture, soil structure, infiltration rate in Group A, B, C and D respectively. All India Soil and Land Use Survey Organisation has classified the soils into different hydrologic soil groups based on effective depth, percentage of clay, soil structure, infiltration rate, permeability. The percentage contribution of each variable in different hydrologic soil groups are not yet estimated. Therefore, an alternative means of establishing inter relationship and importance of various parameters should be evolved. The Principal Component Analysis a multivariate statistical techniques could be one of effective means of determining the importance of individual soil parameters and their contribution in soil classification system. For example soil texture, structure, infiltration rate, permeability, effective soil depth are the various soil parameters which effects runoff. It could be possible to determine the percentage contribution of each parameters apart from establishing inter relationship between them.

Generally the soils are classified in Group A,B,C and D depending upon the effective soil depths, soil texture, soil structure, infiltration rate and permeability as shown in Table 10. It is rather difficult to say in this classification which parameter is having more importance as compared to other parameters. This can be determined by statistical techniques like Principal Component Analysis.

Also some time one or two groups predominates in a catchment, others covering only a small part of the catchment. For example, in a catchment area, 85 percent of the soils is in A group, 10 percent is in C group and 5 percent is in D group. The contribution of runoff coming from C and D groups will be more and putting all soils into the A group will cause under estimation of runoff.

Also reclassification of soils must be done from time to time. Some of the soils are placed in D group due to high water table that creates a drainage problem. Once these soils are i.e. effectively drained they can be placed in higher group.

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