CHAPTER TWO SURVEY OF LITERATURE

2.1 Introduction

Researches on the characteristics of infiltration have been undertaken widely by soil conservationists, goemorphologists, hydrologists or agriculturists. In this chapter, some of the previous works shall be referred to in order to present a proper perspective and context for the present study.

The references cited are mainly focussed on the theory and practice of measuring infiltration, on the factors affecting infiltration and the determination of infiltration using various types of infiltrometers.

2.2 Infiltration Equation and the Mechanics of Infiltration

Infiltration is usually conceptualized by theoretical approaches for most boundary and initial conditions of interests. These approaches provide consistent means of physical quantification governing measurements of water and air. These elaborate procedures are rarely used in practice to describe the infiltration process because of the large number of computations required to operationalise the numerous calculations.

These are usually time - consuming and complicated procedures while at the same time there are no guarantees of success through their application. A brief review of the equations presented in this chapter indicate that a sizeable number of parameters are required to be determined in each one of them before they can be utilized.

A more severe limitation, however, has been the difficulty of obtaining the necessary soil property data because soil properties vary both with depth and from point to point in the field (or vary spatially and temporally).

This time and space variation of the infiltration process is already well-known by those involved especially in irrigation works. Attempts to characterize infiltration for field applications have usually involved simplified concepts which permit the infiltration rate or cumulative volume to be expressed algebrically in terms of time and certain soil parameters.

The most obvious characteristic of the process is that the rate decreases rapidly with time during the early part of the infiltration event. A number of different formulae for the infiltration process have been proposed. Several admirable summaries of these formulae exist and only the barest summary is presented here.

Green and Ampt (1911) proposed a model for infiltration under ponded water conditions. They regarded water moving through the soil as an advancing water front at which the pressure, H is negative because suction is a constant characteristic of the soil. The equation is expressed as :

$i = k_{sat}\ (H_0 + 1 - H_f)/1$ .... (2.1) where,

i = infiltration rate

k_{sat} = saturated hydraulic conductivity

H_0 = depth of ponded water

1 = vertical depth of saturated zone

H_f = capillary pressure at wetting point

Green and Ampt (op.cit), envisaged a sharp reduction of soil moisture content in the water front whereas recent works have suggested that there is a transition zone rather than an abrupt zone (Morel-Seytoux ,1977).

Gerrard (1981), quoted Kostiokov who introduced an emperical formulae in the following form :

$(f) = f_0 t_{-0}$ .... (2.2) where,

(f) = instantaneous infiltration rate at time t

f_0 = minimum infiltration capacity at t = 0

o = constant

t = time

This implies that (f) must become zero after a sufficient time and contrary to experience and to theory based on physical principles.

A very similar formula to that of Kostiokov was suggested by Horton (1940). The formula is as follows:

$(f) = f_c + (f_0 - f_c)e^{-ct}$ .... (2.3) where,

(f) = instantaneous infiltration rate at time t

f_c = minimum infiltration capacity at t ->

f_0 = minimum infiltration capacity at t=0

c = constant for the soil

t = time, minute

e = exponential

This equation seems to fit infiltration rate well, but requires three parameters whose values must be obtained from results of field experiments. This equation was developed as part of a wider conceptual model of overland flow and surface erosion and assumes unimpeded movement of water into the soil. However it gives poor results for short-term infiltration rates.

Skaags et.al (1969), reviewing Philip's equation on infiltration rate in the form of :

F = at + bt............................(2.4) where,

F = Cumulative depth, in cm

t = time, in seconds

a = a constant close to the hydraulic conductivity value at the surface for t = 0

b = a sorptivity value obtained from the rate of penetration of the wetting front

The first factor, a, is generally thought to represent conductivity flow under gravity by unimpeded laminar flow through a continous network of large pores. The second term, b, is a diffusion term representing the filling up of the smaller pores by diffusion from one pore space to the next. The Philip's equation overestimates initial infiltration rates but is a remarkedly good fit otherwise.

2.3 Practical Methods of Measuring Infiltration

Because of the complexity of the infiltration phenomena and the fact that many factors affect the process, the measurements of infiltration rates and volumes are usually accomplished under varied field conditions. Butler (1959), stated that owing to the great number of the variables involved in the infiltration process, it cannot be predicted with much accuracy unless predictions are based on field measurements of infiltration under various conditions.

Various methods have been used in an attempt to quantify infiltration. These methods have differed in accordance with different purposes for which they are established and according to available facilities.

To the extent that soil structure largely controls the rate of infiltration, measurements are usually conducted upon soil in place (Musgrave and Holtan,1964). Laboratory or other determinations of infiltration of soils of modified structures are undertaken largely to give results differing widely from those that occur in the field.

Among the various methods that have been used to obtain comparative results are listed by Sherman and Musgrave (1949), as follows:

1. Measurement of the rate of intake of water in areas defined by concentric rings of various sizes.

2. Measurement of the rate of water intake in areas defined by tubes with different techniques by different researchers.

3. Measurement of the rate of intake of water defined by irrigation practises, particularly flooding.

4. Measurement of runoff of water applied to small sample areas by rainfall simulators of various kinds.

5. Measurement of precipitation compared with surface runoff.

Landon (1984), summarized the methods of measuring infiltration based on the flooded basin infiltration. This involved the use of basins with areas usually between 3 and 10 meters. The soil surface is prepared in a manner similar to that to be used when the land is developed, and a number of graduated measuring staffs are located within the basin.

After the construction of a bund of suitable height around the basin, water is introduced and the rate of intake into the soil is calculated from readings on the measuring staffs.

In some circumstances, it may be desirable to maintain a constant head of water in which case the infiltration rate is obtained by relating the rate of water inflow to the surface area of the plot.

The most practical and simplest method for the soil surveyor is the cylinder or ring infiltration. This method of measuring infiltration rate uses either a single or a double ring infiltrometer, but the latter method is preferred because it reduces errors due to effects at the edges of the inner ring (Sherman and Musgrave,1949). The measurement is usually performed in triplicate at any given site and the three stations, not less than 10m apart, should be located according to a described soil profile. Sherman and Musgrave also stated that at each pre-wetted station, a large and a small diameter steel cylinder were hammered concentrically into the ground to a depth of 15 cm and levelled. Each ring was filled to an equal height about 15-20 cm above the surface of the ground. The height of water in the inner ring was allowed to fall about 5-15 cm between refills up to it original level, and the height of water in the outer ring was adjusted throughout to follow these changes. Rates of flow are established from measurements of the water levels at predetermined time intervals. In practice, the rate of inflow diminished with time and the experiment is terminated when the rate becomes constant, which is normally after 3 to 5 hours of infiltration, depending on the soil.

The infiltration rate may also be determined by passing water down a furrow of known length and wetted cross-sections and then measuring the inflow and outflow rates (Chow,1967). In describing this, he stated that the flow rates may be obtained empirically or by the use of a "V" notch or rectangular weir sections associated with standard formulae.

The use of a rainfall simulator in determining infiltration rate has been widely known. Chow (op.cit) stated that rainfall simulators of various types have recently been used to determine infiltration rates on sample areas lying within and representing larger areas about which information is desired.

Various sizes of plots had been tested, ranging from one square-foot to 40.4 square-meter areas. Artificial rainfall is supplied under standardized procedures, so that, in addition to a known rate of application, there is some control of the pattern of distribution, the drop sizes and the height of fall. The rate of runoff and rainfall is then determined and the hydrograph plotted and analysed.

In determining the infiltration rate using such methods as described above, Lutz and Chandler (1957), stated that two categories of techniques may be recognised - infiltration is regarded as equivalent to the water applied when runoff is prevented or infiltration is regarded as equivalent to the difference between water applied and runoff when the latter is permitted.

This concept is further explained by Bertrand (1965), who stated the difference between the rates of application and surface runoff is usually taken as the rate of water intake. The rate of application is measured continously by a rain gauge in the plot area, or by a small trough across the plot to collect rainfall and carry it to a recording device.

Even though there are many methods used in the determination of infiltration rates in the field, there seem to be a general acceptance of a problem associated with it. The problem of determining infiltration rates is well summed by Miller (1977). He stated that it is not possible to predict infiltration rates from a knowledge of the physical properties of the soil even though notable progress is being made.

Difficulty has also arisen in making valid projections from measurements made on one square-foot or 1.84 square-meter of soil surface to infiltration performance on a 23-hactare field or a 25 square-km watershed.

The use of artificial rainfall by means of various kinds of rainfall simulators to determine the infiltration rate has so far been accepted because of its efficiency in representing natural rainfall, especially the type F or FA rainfall simulator (Chow,1964). However, a difficulty would arise when one considers using the preferred type F or FA rainfall simulator due to the fact that the spray rig is rather elaborate and an expensive piece of equipment and it demands a rather large water supply. In this study, the simulator is clearly unsuitable in the steep, inaccessible terrain of some parts of the study areas.

Marston (1982), also claimed that his rainfall simulator (operating with the 1.5 H30 nozzle, 2 metres above the ground at 70kPa pressure and disk rotating at 60 rpm with a 30 degree aperture) can satisfactorily produce rainfall closely identical to natural rainfall. A comparison of natural rainfall and simulated rainfall in his study is summarised in Table 2.1.

Table 2.1 Natural Rainfall vs Simulated Rainfall

Characteristics	natural rainfall	simulated rainfall
Intensity	10 cm/hr	11.5 cm/hr
Median drop	2.6	2.6
Terminal velocity of median drop, m/s	7.4	7.0
KE (J/m/mm)	30	33

However, this simulator is only portable by means of a tractor, which means it cannot operate in rugged terrain and inaccessible areas.

A portable, compact, light-weight, simple and more affordable rainfall simulator has been innovated to ease the problem in infiltration determination. The main advantage of a rainfall simulator infiltrometer is that it gives some indication of the rate of infiltration of rainfall as opposed to the ponded water condition of cylinders. But, as stated by Holmes, Taylor and Richards (1967), even the sprinkler infiltrometer cannot perform well in field conditions. They found that the drop size distribution is not similar as it is in rains.

Many simple rainfall simulators adopt a falling height of just 1 or 1.5 metre above the surface (Tricker,1979). But, that will not resemble natural rainfall in many aspects. Lal (1977) and Hudson (1976), stated that for 5.0mm diameter drop size and terminal velocity of 9.1 m/sec, the fall needed to reach 95% of terminal velocity is 7.6m. In terms of kinetic energy, the drops produced by simple rainfall simulators also do not resemble that of natural rainfall (Brandt,1990;Rhiezebos and Epema,1985).

However, by careful manipulation and under strict precautions, a simple rainfall simulator can produce a relatively satisfactory drop-size distribution, but the disadvantage of an inadequate fall height and a too-small simulated area still remains (Imeson,1977).

Unger (1992), used a rotating-disc type rainfall simulator to determine the infiltration rate. With his simulator, the kinetic energy of natural rainfall for intensities of up to 50 mm/hr are closely simulated. Infiltration measurements are made on 1.5m areas enclosed by metal frames that are designed to permit measurement of runoff. The frames extended about 10 cm above the soil surface and about 15 cm into the soil. The wetted area under the simulator is about 2.5m diameter and splash into and out of the test area is considered equal. Infiltration rate is calculated as the difference between measured runoff and the water application rate.

Keren (1990), investigated the effects of water drops kinetic energy of on infiltration in Sodium-Calcium-Magnesium soil. He used two types of rainfall simulators. The first one was a drip-type rainfall simulator with a closed water chamber that generated rainfall through a net of hypodermic needles which formed a fix known droplet size. The rainfall intensity of 33.1 mm/hr was controlled by a peristaltic pump. The second one was a nozzle type with rainfall intensity of 37.4 mm/hr.

2.4 Infiltration Measurements in the Field

In Malaysia, several studies on infiltration measurements were carried out in the field of agriculture. Maene et.al (1978), used a flooding type infiltrometer which consisted of a double-ring infiltrometer to evaluate the rate of infiltration in oil palm plantations. This type of infiltrometer is only suitable for use in flat areas and on ground with no gravel and coarse sand . (Brechtel,1976).

A study conducted by Baharuddin (1987), using a drip-type rainfall simulator in a forested area, revealed that infiltration rates varied between 9.8 cm/hr and 15.6 cm/hr on slopes of 25% and 30%, respectively. Table 2.2 shows several measurements of infiltration rates conducted by some researchers using cylinder and rainfall simulator infiltrometers.

Table 2.2 Infiltration Rate Measurement Under Various Landuses

Source	Type of infiltrometer	Type of landuse	IR, imme'dt cm/hr	IR, aver cm/hr
Maene et.al (1978)	double ring	oil palm (track)	17.6	0.9
	"	(dried frond)	205	43
Lapitan (1984)	"	coconut	195	-
Baharuddin (1987)	rainfall simulator	forest plantation	15.6	10

Field measurements of infiltration were conducted by Erh and Wong (1977) on the Dunlop Sagil Estate, where over 3000 acres of cocoa at different stages grew; using a double ring infiltrometer. They found that steady state infiltration was established after 6-7 hours. Table 2.3 indicated the characteristics of the infiltration process in the cocoa plantation at Dunlop Sagil Estate.

Table 2.3 Measured and Calculated Cumulative Infiltration (cm), Under Cocoa, Dunlop Sagil Estate

Soil series	Wet period		Dry period	
	measured	calculated	measured	calculated
Prang	141	135	85	79
Munchong	162	158	114	110
Bungor	61	59	56	56
Bt.Temiang	153	137	307	-

Infiltration rate determination of soil of various landuses has been conducted by some researchers worldwide. The purpose varied from one case to another, depending on the focus and areas of interests of the studies.

Roth et.al (quoted by Meek et.al,1990), in their study revealed that in two tillage systems, a 100% residue cover on the soil led to the complete infiltration of a 60mm rainfall, whereas only 20% of applied rainfall infiltrated when the soil was bare. Sherman and Musgrave (1949), examined the effect of landuses on the infiltration rate as summarized in Table 2.4.

Table 2.4 Effect of Landuse on IR

Landuse	Total Infiltration (cm/hr)	Average Infiltration (cm/hr)
Pine	7.75	0.76
Bare	1.12	0.28

Kirkby (1976), showed that grain size, moisture content and ground cover all have influence on infiltration rates, as summarized in Table 2.5, Table 2.6 and Table 2.7.

Table 2.5 Effect of Grain Size on Infiltration on Soil Without Vegetation Cover

Grain size	IR (cm/hr)
Clays	0 - 4
Silts	2 - 8
Sands	3 - 12

Table 2.6 Influence of Moisture Content on Infiltration Rate or Illinois Clay-pan (mm/hr)

Initial moisture content	Good grass	cover	poor
	Top soil >33cm	Top soil <33cm	
0 - 4	17	19	6
14 - 24	7	7	4
> 24	4	4	3

Table 2.7 Influence of Ground Cover for Cecil, Medison and Durham Soils on Infiltration Rate

Ground cover	Infiltration Rate (mm/hr)
Old permanent pasture	57
Old permanent pasture moderately grazed	19
Old permanent pasture heavily grazed	13
Weed and grain	9
Clean tilled	7
Bare ground crusted	6

Dooge (1988), summarized his studies on influence of successive vegetation and forest management on infiltration rate in Table 2.8 and Table 2.9, respectively.

Table 2.8 Potential Infiltration Rate for Successive Vegetation

Nature of vegetation	Potential IR, mm/hr
Old pasture	43
30-year pine forest	75
60-year pine forest	63
Oak hickory forest	76

Table 2.9 Effect on Infiltration Rate of Forest Management

Nature of surface	Potential IR, mm/hr
Undisturbed forest floor	60
Without humus, litter	49
Unimproved pasture	24

A change in infiltration values was also noted by Miller (1977), as shown in Table 2.10.

Table 2.10 Infiltration Changes During Ecological Plant Succession

	Mean rate over 5 hour (mm/hr)		Mean rate in last hour (mm/hr)	
Soil series	Blue grass pasture	Corn	Blue grass pasture	Corn
Muscatine (rich organic matter)	27	7	15	3
Berwick (intermediate organic matter)	18	6	8	3
Viola (low organic matter)	4	7	4	2

Note: IR under silt-loam soil under pasture and corn, under simulated rainfall of 45 mm/hr.

Rodda, Richards and Low (1967), investigated the effect of soil compaction on the infiltration rate of soil of various landuses as indicated in Table 2.11.

Gerrad (1981), investigated the effect of antecedent soil moisture content on the infiltration rate. Table 2.12 showed that on the second run of infiltration, which is carried out 24 hours after the first run with the soil still wet, the fall-off of infiltration with time is clear, while data of the second run emphasizes the importance of antecedent soil moisture content.

Table 2.11 Infiltrometer Results for Soils in the Bristol Area (mm/hr)

Soil series	Site characteristics	Inf. capacity (summer)
Worcester	orchards, bare ground, compaction by vehicle	9
	part bare, compaction by vehicle	29
Nibley	vegetated, compaction by cattle	11
	light pasture	115
Evesham	heavy pasture, compaction by cattle	164
Charlton Bank	heavy pasture (compacted)	55
	woodland	383
	light pasture	366

Table 2.12 Infiltration Rate on Different Soil Types in the U.S

Soil type		IR, mm/hr 1st qtr.	2nd qtr	3rd qtr
Honeoye gravelly silt loam	1.	478	306	224
	2.	230	177	163
Austin clay	1.	208	85	69
	2.	134	48	45

Biot (1990), related the infiltration rate of soil under canopy and unshaded condition to some soil physical properties, as shown in Table 2.13.

Table 2.13 Average Infiltration Capacity, Ground Cover, Organic Matter Content and Bulk Density Under Tree Canopy and in Unshaded Areas

	IR min/cm	Ground cover,%	Organic matter content,%	Bulk density,%
Canopy	36	27	1.07	1.34
Unshaded	162	15	0.62	1.64

Greenland (1977), investigated the effect of some soil conditions of Iwo and Oba on infiltration rate, as shown in Table 2.14.

Table 2.14 Equillibrium Infiltration Capacity and Rate of Water Entry (mm/hr) into Crust-free Iwo and Oba Soils in Bush Fallow and After 2 Subsequent Years of Annual Crops, (corn)

	Iwo		Oba	
Soil condition	Inf.capacity	IR	Inf.capacity	IR
Bush fallow	118.9	21.1	107.7	25.4
Corn, after 1st crop year	44.7	20.5	48.8	25.1
Corn, after 2nd crop year	49.5	22.4	21.6	9.1

Lal (1977), investigated the effect of some soil surface treatments on infiltration rates as shown in Table 2.15.

Table 2.15 Effects of Soil Surface Treatments on Infiltration Rate

Soil surface treatment	Max. IR (cm/hr)
Bare soil	
Undisturbed	1.27
Hoed at fortnightly intervals	2.29
Hoed after every storm	3.05
Mulches	
Dead grass	12.7
Groundnut shell	> 12.7
Shorgum stalks	> 12.7

2.5 Infiltration Rate in Soil Relation to Physical and Biological Properties

Ghuman, Lal and Shearer (1991), stated that land clearing affects physical properties of soils such as its bulk density, total porosity, aggregate stability and infiltration rate. The process of forest clearing using machines affect these properties due to soil structure deterioration and removal of top soil that contains most of the soil's organic matter.

In their study, the bulk density and infiltration rate were measured approximately 3 months after forest clearing. Bulk density is measured on undisturbed cores taken from 0 - 10cm, 10 - 20cm, and 20 - 30 cm layers at 3 points per plot using 100 cm cubic cores. The infiltration rate is measured at three places per plot using double ring infiltrometers with inner and outer rings of 20 and 28 cm diameter, respectively.

In their investigation, they found that soil bulk density of the upper layer was affected significantly by land clearing. In the 0 to 10 cm layer, bulk density was increased by 22% over that of the forested control, while in the 10 to 20 cm layer, the bulk density increased by 29%.

In the forested control, the 1-hour infiltration rate was 89 cm/hr. The compaction caused by the clearing technique decreased the infiltration rate, but after 2 years of cropping, the total 1-hour infiltration rate increased to 47 cm/hr. This was due to:

1. Biological activity that disappeared immediately after clearing due to soil exposure, reappeared under the different landuse system during cropping, and loosened the soil to a certain extent.
2. The roots of shrubs and trees probably decomposed with time, and consequently left root channels in the soil profile.

Dunne, Zhang and Aubry (1991), studied the relationship between vegetation as well as microtopography and the infiltration rate. They noted that the theory of how vegetation affects infiltration has not been well developed and there was no relationship between vegetation cover density and infiltration measured with infiltrometers.

However, study conducted by Leopold (1974), documented large changes in infiltration with only modest changes in vegetation density. In his study, plots measuring 5 metres in length and 1.2 metres in with were used. A single nozzle moved rapidly along a tract 3 metres above the plots, and generated drops with median diameters of 2mm at rainfall intensities between 5.2 - 8.5 cm/hr.

Rainfall was measured at 20 - 30 minutes interval at 24 places on the plot, and runoff was measured every 2 minutes. Apparent infiltration declined rapidly to a constant value within 5 - 30 minutes of the onset of rainfall, and curiously, he found that the density of the vegetation had no discernible effect on infiltration rate.

Sherman and Musgrave (1949), in their study on infiltration on several types of landuses concluded that the commonly observed higher infiltration and lower runoff occured in virgin soils, and areas under native grass and forest, in contrast to intensively cultivated land. They also found that a higher content of organic matter caused rapid movement of soil water. In this case, they showed that the rate of infiltration was significantly associated with the content of organic matter.

Vegetation increases the infiltration rate by mounting a thicker soil cover, better soil texture and by breaking the impact of raindrops on the soil surface. Its effect on soil structure is mainly through the build-up of an organic-rich A horizon with a relatively open pore structures and high permeability. Vegetation therefore has a controlling influence on 'Horton overland flow' by increasing both initial depression storage and the infiltration rate, so that, where dense cover is established, 'Horton overland flow' is very unlikely (Kirkby,1976).

Dunne (1976), said that in certain forest situation, there appear to be a complete absence of rainfall excess on the surface. Ward (1967), stated that vegetation cover tend to increase infiltration in comparison with areas of bare soil. Soil cover shielding the soil surface from the direct impacts of raindrops, thereby reducing surface sealing. In the case of woodlands, he said that the presence of a layer of ground litter normally has a more pronounced effect on infiltration rates than the main vegetation itself.

Linsley (1950), stated that porosity of the soil determines storage capacity and also affects resistance to flow. Thus, infiltration tends to increase with porosity. It was also noted that an increase in organic matter also resulted in increased infiltration capacity which was largely caused by a corresponding change in porosity.

Wilson (1983), said that the infiltration rate appears to be largely controlled by the surface pores. Exposed soil can be rendered almost impermeable by the compacting impact of large drops coupled with the tendency to wash very fine particles into the voids.

Compaction due to man and animals treading the surface or a vehicular traffic, can severely reduce the infiltration rate. Dense vegetal cover such as grass or forest tends to promote high values of infiltration rates. The dense root systems, all providing ingress (power of entrance) to the subsoil, the layer of organic debris furrowing sponge-like surfaces, the cover preventing compaction and the vegetation transpiration removing soil moisture, all tend to help the infiltration process.

2.6 Conclusion

The determination of infiltration rates based on the various methods as suggested by the literature, helps in many ways the understanding of the infiltration prosess, but there is no guarantee of their usefulness, considering the existance of a great variability of infiltration characteristics both spatially and temporally.

It is therefore necessary for the determination of the infiltration rate to be conducted upon soil in the field. Infiltration rates can be determined through the use of various types of infiltrometers, ranging from the simplest double-ring infiltrometer to the more sophisticated F-type infiltrometer (which was claimed to have succesfully produced artificial rainfall of the same quality as the natural one).

The determination of infiltration rates of soils of various landuses and conditions, cited in this chapter, revealed that infiltration rates are greater in densely vegetated soils and on soils of better physical properties, in contrast to the lower rates of soils lacking in vegetation.