CHAPTER-6 CONCLUSIONS AND FURTHER RESEARCH

6.1 General.

Since a limited amount of data have been analysed it is not possible to draw firm conclusions from this study alone.Data used in this research are data collected by various hydrological institutions for their routine purposes and not for research work.The following general conclusions can be made through this study.

6.2 Synthetic unit hydrographs.

The SCS and Williams' unit hydrographs are very promising for further study.Since the Williams' unit hydrograph is an instantaneous unit hydrograph, unit hydrographs of any duration can be determined easily.For the SCS unit hydrograph this may not be easily possible always,since the unit rainfall duration is fixed by the time of concentration.The Williams' instantaneous unit hydrograph method is more adaptable to computer methods than the SCS unit hydrograph.

6.3 US Soil Conservation Service method.

This study shows that the SCS method can be employed easily and successfully to estimate runoff caused by storms.Since this method requires only total rainfalls and a curvenumber;the runoff can be computed easily even with an ordinary pocket calculator.The runoff curvenumber is used to determine the rainfall excess (or surface runoff).

There is no difficulty in getting the total rainfall which is usually the only type of data available for small catchments.The estimation of the SCS curvenumber requires one's judgenment.The method adopted in this research to compute the SCS curvenumber though not a standard one,seems to be a satisfactory method for large Sri Lankan catchments where observed hydrographs are available.Since this method does not require the catchment characteristics such as the soil cover ,the application of this method is easy.In small catchments where runoff data are not available it would be necessary to use the standard method of estimation of the curvenumber.

It is interesting to see that the runoff curvenumbers estimated from observed hydrographs are reasonably consistent.These curvenumbers remain resonably consistent even after adjustment to match the peakflow.The average runoff curvenumber for Attanagalu Oya under AMC II (The average condotion) is taken to be in the region of 65.

If the curvenumber is estimated using the standard method,assuming that the type of land use or cover is "woodlands" and the hydrologic soil group is B (Refer table 2.5),the curvenumber would be around 60 for fair hydrologic conditions which further strengthens the validity of the result already obtained.The Survey Depertment's land use maps would be very useful in this respect.

In summing up it can be concluded that the SCS method of estimating runoff is easy to use and yields resonably satisfactory results.This method is specially suited for Sri Lankan catchments where the only reliable type of data available are total rainfalls.For the computation of hydrographs the variations of rainfall with time can be easily measured using a cylindrical container. In flood studies it would be best to select events in AMC III where the variation of the curvenumber is less.

6.4 Runoff hydrographs.

Computed peak flows tally well with the observed peakflows, whereas the computed baselengths and times to peak did not tally satisfactorily.The possible reasons may be the spatial variation of rainfall over a large catchment and the continuation of the small intermittent storms ,as discussed in chapter 5.

6.5 Further research.

Before embarking on further research it should be said pointedly that a programme should be launched to collect suitable data at least for a few catchments in Sri Lanka.A few isolated storms and the corresponding hydrographs should be measured accurately.The most needed data are the cumulative rainfall chart and the observed hydrographs.

The validity of the SCS method should be checked for Sri Lankan catchments.The SCS curvenumbers should be estimated from the observed hydrographs and the standard method. The SCS curvenumbers thus obtained should be used to estimate runoff and the results should be compared with the observed values using the SCS unit hydrograph and the Williams's instantaneous unit hydrograph.This should be tested for a range of catchments.

For very large catchments these methods can be applied by dividing the main catchment into several smaller sub-catchments.For each sub-catchment depending on its properties, SCS curvenumbers and runoff hydrographs should be estimated.To get the resultant hydrograph these sub-hydrographs should be routed in sequence while being added.

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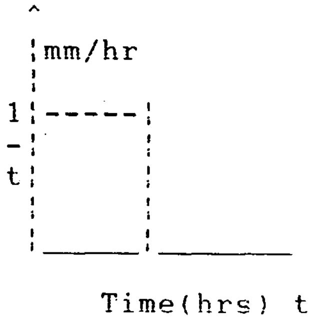
Appendix A

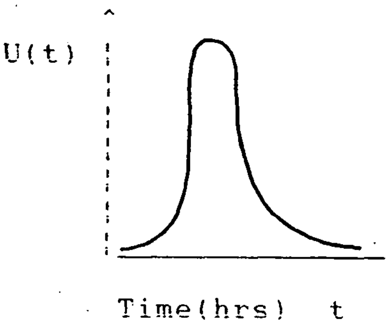
Derivation of the equation for the first segment. of the Williams' instantaneous unit hydrograph

(After Dooge(1959) and Nash(1959))

The equation for the first segment of the Williams' unit hydrograph is derived on the basis of the concept of unit impulse function and the convolution integral.The unit impulse function can be considered as the instantaneous inflow that consists of a burst of rainfall of constant intensity acting only during an infinitesimally small period of time so that the period of duration and intensity is 1 mm of rainfall.The instantaneous hydrograph is considered as the impulsive response to the watershed to an instantaneous inflow as shown below.



Instantaneous
inflow



Instantaneous
unit hydrograph

The convolution integral is used to determine the response or hydrograph Q(t) of the system of any arbitary excitation of rainfall excesses i(t) if the unit impulsive response is known.

$$Q(t) = \int_{0}^{t} i(z)\ u(t-z)dz \text{ ------------ } (1)$$

in which the z represrnts the time and is the dummy variable of integration.For a 1 mm rainfall excess of constant intensity and of duration D,the excitation is

$$i(t) = \frac{1}{D} \text{ ------------} (2)$$

Equation 1 becomes $U(D,t) = \frac{1}{D}\int_{0}^{t} u(t-z)dz \text{----------} (3)$

which is the unit hydrograph of duration D.If an instantaneous inflow i(0) is applied the time t, approaches Δt then the equation 1 yields the instantaneous hydrograph q(t)

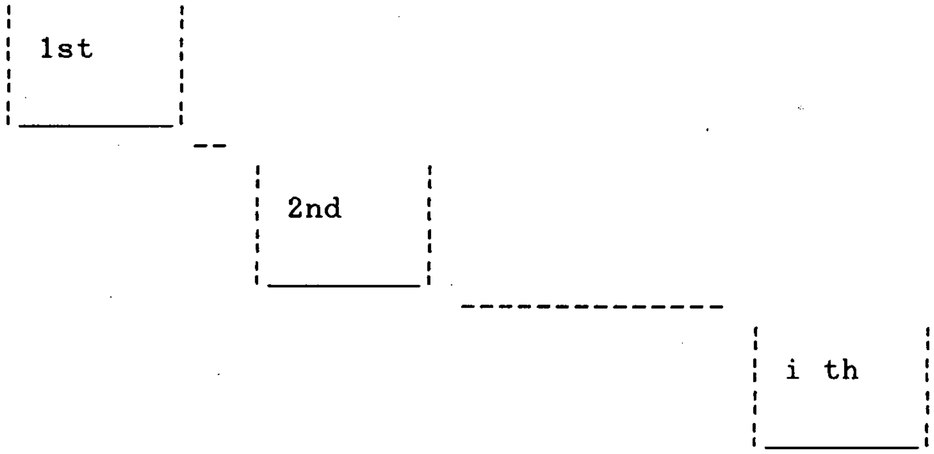
$$q(t) = i(0)\ \Delta t\ u(t) = Pe\ u(t) \text{ ------------------} (4)$$

Expressions for the instantaneous hydrograph is derived with the assumption that an instantaneous inflow is applied to n equel linear reservoirs with the same storage coefficient k

For a linear reservoir the storage S is related to the outflow q by

$$S = kq \text{-----------------} (5)$$

A system of linear reservoirs



Consider the i th tank

By the continuity equation $I - O = \frac{ds}{dt}$

$$\frac{ds_i}{dt} = q_{i-1} - q_i$$

At time t=0 there will be no inflow

at i=1

$$\frac{ds}{dt} = 0 - q_1 = \frac{S}{k}$$

$$S_1 = Ae^{-t/k}$$

at t = 0 S = 1 therefore A= 1

$$S = e^{-t/k}$$

$$q = \frac{e^{-t/k}}{k}$$

At i = 2 the change in storage is given by

$$\frac{ds}{dt} = q_1 - q_2$$

$$\frac{ds}{dt} + \frac{S}{k} = \frac{1}{k} e^{-t/k}$$

Take the intergrating factor $V(t) = e^{-1/kdt} = e^{-t/k}.X(t)$

$S_2 = X(t).V(t) = e^{-t/k}$ on differentiation

$$\frac{dS_2}{dt} = -1/ke^{-t/k}.X(t) + e^{-t/k/}\;X(t) + 1/k.e^{-t/k}.X(t)$$

$$= -t/k.X'(t) = 1/k$$

$$X(t) = (t/k+C)$$

$$S = (t/k + C)\, e^{-t/k}$$

When t=0 $S_2 = 0$ $C = 0$

$$S_2 = t/k\ e^{-t/k}$$

$$q_2 = t/k^2\ e^{-t/k}$$

$$q_i = \frac{1}{k(i-1)!}\,(t/k)^{i-1}\ e^{t/k}$$

For an instantaneous inflow the outflow from a linear reservoir is

$$q = V/k\ e^{-t/k}$$

in which V = A.Pe where Pe is the total volume of runoff from the basin of area A.Then for a number of n equel linear reservoirs in series with the same storage coefficient k the outflow is

$$q = \frac{V}{k(n-1)!}\,(t/k)^{n-1}\ e^{t/k}$$

This may be modified on the introduction of the Gamma functuon instead of the factorial.

V= 1 for a unit hydrograph

$$q = \frac{1}{k\Gamma(n)} (t/k)^{n-1} e^{t/k} \quad \text{----------------------}(6)$$

$\Gamma(n)$ represents the Gamma Function.

For a given delay time the effect of varying the value of n on the outflow hydrograph may be found by taking the first derivation of equation (6) with respect to time setting dq/dt=0 and

$$t_p = (n-1)k$$

t_p is the time to peak

If X= t/k

R = Depth of runoff in mm

A.R = V

$$\frac{qt_p}{A.R} = \frac{(n-1)\, X^{(n-1)}\, e^{-X}}{\Gamma(n)} \quad \text{----------------------}(7)$$

in which

$$X = t/k = \frac{t}{t_p}(n-1)$$

If $t = t_p$ and $q = q_p$ then the equation (7) becomes

$$\frac{q_p . t_p}{A.R} = \frac{(n-1)}{\Gamma(n)} X^{(n-1)} e^{-X}$$

in which X= (n-1)

Therefore

$$\boxed{q = q_p(t/t_p)^{(n-1)} e^{(1-n).(t/t_p -1)}}$$

This is the equation of the first segment of the hydrograph.

APPENDIX - B COMPUTER PROGRAMMES

Programme to open a rainfall file

Programme listing

```
10  HOME
20  INVERSE : PRINT "STORING A MASS RAIN CURVE": NORMAL
30  PRINT : INPUT "HOW MANY ENTRIES?            ";N
40  PRINT : INPUT "TIME INTERVAL(Hrs)?    ";DT
50  HOME
60  DIM Q(300),PE(300)
70  FOR J = 1 TO N
80  PRINT J;: INPUT "  CUMULATIVE RAINFALL(mm)   ";PE(J)
90  REM PRINT
100  IF K = 1 THEN 130
110  NEXT J
120  PRINT : PRINT : PRINT
130  INPUT "ANY MISTAKE Y OR N  ";G$: PRINT : PRINT : PRINT
140  IF G$ = "N" THEN 170
150  PRINT : PRINT : PRINT
160 K = 1: INPUT "NAME OF THE WRONG ENTRY? ";J: HOME : GOTO 80
170  HOME
180  PRINT "FILE NAME SHOULD BE AS RAIN-1,RAIN-2...1,2..REACH NO.": PRINT : PRINT : PRINT
19   INPUT "NAME OF THE FILE   ";DF$
200  PRINT : PRINT : PRINT
210  PRINT  CHR$ (4);"OPEN" + DF$
220  PRINT  CHR$ (4);"DELETE" + DF$
230  PRINT  CHR$ (4);"OPEN" + DF$
240  PRINT  CHR$ (4);"WRITE " + DF$
250  PRINT N
260  PRINT DT
270  FOR J = 1 TO N
280  PRINT PE(J)
290  NEXT J
300  PRINT  CHR$ (4);"CLOSE " + DF$
310  HOME
320  VTAB 9: INVERSE : INPUT "WANT TO STORE ONE MORE CURVE?";H$: NORMAL
330  IF H$ = "N" THEN 350
340  CLEAR : GOTO 10
350  HOME : END
```

Programme to compute runoff hydrographs based on Williams' method

Programme Listing

```
10  CLEAR
20  HOME
30  DIM Y(310),T(310),C(300)
40  INVERSE : PRINT "COMPUTING A HYDROGRAPH": NORMAL
50  INVERSE : PRINT "PROGRAMME->COMPHYD": NORMAL : PRINT
60 WRITE = 49568
70  PRINT : PRINT : PRINT
80  INVERSE : PRINT "######INPUT DATA######": NORMAL : PRINT
90  INPUT "(1) CATCHMENT AREA(SqKm)?      ";A: PRINT
100  INPUT "(2) CATCHMENT HEIGHT(m)?       ";H: PRINT
110  INPUT "(3) LONGEST STREAM LENGTH(Km)? ";L: PRINT
120  INPUT "(4) RUNOFF CURVE NUMBER?       ";CN: PRINT
130  INPUT "(5) RAINFALL FILE NAME?        ";DF$: PRINT
140  HOME : VTAB (15): HTAB (9)
150  INVERSE : PRINT "READING THE RAINFALL FILE": NORMAL
160  PRINT  CHR$ (4);"OPEN" + DF$
170  PRINT  CHR$ (4);"READ" + DF$
180  INPUT J: INPUT DT
190  DIM PE(J),PR(J),Z(J)
200  FOR I = 1 TO J: INPUT PE(I): NEXT I
210  PRINT  CHR$ (4);"CLOSE" + DF$
220  HOME : VTAB (15): HTAB (1)
230  INVERSE : PRINT "COMPUTATION OF TIME TO PEAK AND RUN OFF": NORMAL
240 W1 = L * L / A
250 K = 5.95 * (A) ^ 0.231 * (H / L) ^ - 0.777 * (W1) ^ 0.124
260 TP = 1.44 * (A) ^ .422 * (H / L) ^ - .460 * (W1) ^ .133
270 R1 = 0
280 S = 1000 / CN - 10
290  FOR I = 2 TO J
300 PR(I) = PR(I) / 25.4
310  IF PR(I) > 0.2 * S THEN 350
320 Z(I) = 0
330 R1 = 0
340  GOTO 380
350 R2 = (PR(I) - .2 * S) ^ 2 / (PR(I) + .8 * S)
360 Z(I) = (R2 - R1)
370 R1 = R2
380  NEXT I
390  HOME : VTAB (15): HTAB (1)
400  INVERSE : PRINT "COMPUTATION  OF  WATERSHED PARAMETER ANDSHAPE CONSTANT- (PLEASE  WAIT A  LITTLE)": NORMAL
410 N = 5:R = K / TP
420  FOR I = 1 TO 100
430 T = (1 + (1 / (N - 1)) ^ .5)
440 N1 = 0.05 / (R * ( LOG (T / (T + 0.05)) + 0.05)) + 1
450  IF  ABS (N1 - N) < 0.001 THEN 470
460 N = N1: NEXT I
470 T0 = (1 + (1 / (N - 1)) ^ .5) * TP
480 D = T / 200
490 X1 = N - 1
500 X2 = 1 - N
```

```
510 T1 = 0
520  FOR I = 2 TO 201
530 T1 = T1 + D
540 C(I) = (T1 ^ X1) *  EXP (X2 * (T1 - 1))
550  NEXT I
560 S = C(201) / 2
570  FOR I = 2 TO 200
580 S = S + C(I)
590  NEXT I
600 C1 = S * D
610 C2 = C(201)
620 E =  EXP ( - 2)
630 B = 645.333 / (C1 + C2 * (E * (1 - E) + E * (3 * K / TP)))
640  HOME
650 QP = B * A / (2.5888 * TP)
660  PRINT : PRINT : PRINT : PRINT : PRINT : HTAB (7): VTAB (15): INVERSE : PRINT "WANT PRINTED INPUT DATA?": NORMAL
670  PRINT : PRINT : HTAB (8): INPUT "YES-Y OR NO-N   ";V$
680  IF V$ = "Y" THEN 700
690  GOTO 750
700  PR# 1
710  CALL WRITE:"CATCHMENT AREA    =",A;F5.2,"SQKM", CHR$ (13):
720  CALL WRITE:"CATCHMENT HEIGHT  =",H;F5.2,"M", CHR$ (13):
730  CALL WRITE:"MAINSTREAM LENGTH =",L;F5.2,"KM", CHR$ (13):
740  CALL WRITE:"RUNOFF CURVENUMBER=",CN;F5.2, CHR$ (13):
750  PR# 0: REM  UNIT HYDROGRAPH
760  HOME : HTAB (1): VTAB (15): INVERSE : PRINT "UNIT HYDROGRAPH COMPUTATION-PLEASE STAY": NORMAL
770 C(1) = 0
780 T(1) = 0
790 Q0 = QP * ((T0 / TP) ^ (N - 1)) *  EXP ((1 - N) * (T0 / TP - 1))
800  FOR I = 2 TO 300
810 T(I) = T(I - 1) + DT
820  IF T(I) > T0 THEN 840
830 C(I) = QP * ((T(I) / TP) ^ (N - 1)) *  EXP ((1 - N) * (T(I) / TP - 1)): GOTO 900
840  IF T(I) > T0 + 2 * K THEN 860
850 C(I) = Q0 *  EXP ((T0 - T(I)) / K): GOTO 900
860 C(I) = Q0 *  EXP ((T0 - T(I) - 4 * K) / (3 * K))
870  IF C(I) > 1.5 THEN 900
880 L1 = I
890  GOTO 910
900  NEXT I
910  REM    STORM HYDROGRAPH
920  HOME : VTAB (15): HTAB (1)
930  INVERSE : PRINT "COMPUTATION  OF  STORM  HYDROGRAPH  ONLAGGING  AND  ADDING  UNITHYDROGRAPHS": NORMAL
940 I = 300
950 I = L1
960  FOR M = 2 TO J
970 N1 = M + L1 - 2
980  IF N1 > 300 THEN 1000
990  GOTO 1010
1000 N1 = 300
1010 G = M
1020 I = 2
```

```
1030  FOR H = G TO N1
1040 Y(H) = Y(H) + Z(M) * C(I)
1050 I = I + 1
1060  NEXT H
1070  NEXT M
1080 W = H - 1
1090 RO = 0
1100 PF = 0
1110  FOR I = 1 TO W
1120 RO = RO + Y(I)
1130  NEXT I
1140  FOR I = 1 TO W
1150  IF Y(I) > Y(I + 1) THEN  GOTO 1170
1160  NEXT I
1170 PF = Y(I) * 0.028
1180 W = I
1190 RO = RO * DT * 0.1008 / A
1200 T(1) = 0
1210  FOR I = 2 TO N1
1220 T(I) = (I - 1) * DT
1230  NEXT I
1240  PR# 0
1250  HOME : VTAB (10): INVERSE : PRINT " WANT PRINTS OF GAMMA STORM HYDROGRAPH ?": PRINT : PRINT : NORMAL : HTAB (16)
   : INPUT "Y OR N   ";V$
1260  IF V$ = "Y" THEN 1280
1270  GOTO 1400
1280  PR# 1: PRINT  CHR$ (15): PRINT "RUNOFF  HYDROGRAPH BASED ON TWO PARAMETER GAMMA DISTRIBUTION"
1290  PRINT "RAINFALL FILE ";DF$: PRINT
1300  PRINT "   RANK      TIME          DISCHARGE     DISCHARGE"
1310  PRINT "             HRS          CUSECS        CUMECS    "
1320  FOR I = 1 TO N1
1330  IF I = 1 THEN 1360
1340  IF Y(I - 1) =  < Y(I) THEN 1360
1350  IF Y(I) < 350 THEN 1380
1360  CALL WRITE:"  ",I;I3,"    ",T(I);F5.2,"    ",Y(I);F9.2,"    ",Y(I) * 0.028;F5.2, CHR$ (13):
1370  NEXT I
1380  CALL WRITE:"RUNOFF=",RO;F5.2,"mm", CHR$ (13):
1390  CALL WRITE:"PEAKFLOW=",PF;F5.2,"Cumecs", CHR$ (15):
1400  PR# 0
1410  HTAB 1: VTAB 10
1420  INVERSE : PRINT "BEFORE COMPUTING THE  NEXT HYDROGRAPH STORE THIS HYDROGRAP IN A  FILE": NORMAL : PRINT : PRINT

1430  INPUT "WANT TO STORE?   'Y' OR 'N'  ";V$
1440  IF V$ = "N" THEN 1550
1450  PRINT : PRINT : PRINT
1460  INPUT "HYDROGRAPH FILE NAME?     ";DF$: PRINT
1470  PRINT  CHR$ (4);"OPEN" + DF$
1480  PRINT  CHR$ (4);"DELETE" + DF$
1490  PRINT  CHR$ (4);"WRITE" + DF$
1500  PRINT N1
1510  FOR I = 1 TO N1
```

```
1520  PRINT T(I): PRINT Y(I)
1530  NEXT I
1540  PRINT  CHR$ (4);"CLOSE" + DF$
1550  HOME
1560  INPUT "WANT TO COMPUTE ANOTHER HYDROGRAPH";V$
1570  IF V$ = "Y" THEN 10
1580  HOME
1590  PRINT "    THANK YOU!  "
1600  END
```