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The effect of catchment data on project evaluation

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THE EFFECT OF CATCHMENT DATA ON PROJECT EVALUATION

THE IMPORTANCE OF RUNOFF RECORDS

In the assessment of a surface water source (including irrigation), the relationship between the reliability of supply from the source, the storage (if any) associated with the supply from the source, and the source yield is of great importance. The main factor governing this relationship is the variability of the surface flow. To take an extreme example, if all the riverflow occurred during 10 days and the rest of the year the river was dry, then storage would have to be provided to maintain the supply through the remaining 355 days. Conversely, if the riverflow remained constant throughout the year then theoretically no storage would be required.

The reliability of a source is partly related to the year to year variation of flows. Again taking a simple example, if the distribution of runoff between wet and dry seasons did not vary from year to year then the source would never fail and hence have 100% reliability.

Variability of river/stream is of great importance therefore and the only accurate way to estimate the effect of these variations is to analyse a long runoff record.

What constitutes a long record? This depends on a number of factors which include the variability of flow and the reliability of the supply.

In many situations 25 years of data would be considered adequate, however in very many countries including those of Africa this amount of data is rarely available.

METHODS WHERE DATA ARE SCARCE

Where the runoff record is short or non-existent, then attempts should be made to use other data available. A procedure for this is shown in Figure 1 and the rainfall/runoff model types mentioned in this figure are shown in Tables 1 and 2. It should be mentioned here that before the procedure in Figure 1 is followed the data used should be checked for errors. It is a difficult and sometimes expensive task to measure and collect hydrological data and in many cases the quality of this data is poor both in developing and developed countries. The most effective way of checking data is to visit the gauge on site if possible and then carry out checks with other data in the area if it exists (ref 1).

The list of rainfall/runoff methods given in tables 1 and 2 are by no means comprehensive but serve only to indicate the range of methods available. Many have been developed for specific areas and so are not strictly applicable to other catchments.

In order to high-light the problems of data when assessing surface water sources, two aspects are considered in further detail.

INFILLING DATA

In assessing meteorological data for hydrological purposes the situation is often encountered where a small number of stations have a comparatively long period of records, say thirty years, whilst there are many other stations in the same catchment or area with short term records. Additionally, many of such records are often found to be incomplete. The problem is to make the best use of such data. Consider say that annual rainfall is the parameter being utilised, then it would be possible to simply adjust the short record averages against the norms established by the long term records. However, this implies that the fluctuations of the long records are representative of the fluctuations in the short records, which may not be true. In cases where only a few, maybe incomplete, long records exist in the data the following method is a more reasonable way of establishing the average annual rainfall.

The stations are first grouped on say a geographical basis and the cross correlations of the available annual rainfalls computed. The bivariate correlations are examined and stations that are well correlated would be used for data infilling for those stations. No attempt is made here to define 'well correlated', but stations with say ten years common data that show a correlation coefficient greater than 0.8 would certainly be in this category.

Data infilling is then carried out by the normal ratio method. For each missing value in the particular record being infilled, the

corresponding value in each of the other (well correlated) records is reduced to its ratio to the norm for the common period of record. The missing value is then obtained by multiplying the norm for the incomplete data by the average ratio to the norm obtained from the complete records. In this way all incomplete records may be infilled, providing of course that at least one recorded value exists for each data point within each group of well correlated stations.

The following table shows the cross-correlation between a number of rainfall stations in the same country:

Station	1	2	3	4	5	6	7	8	9	10
1	1.00	0.81	0.87	0.59	0.52	0.78	0.70	0.23	0.17	0.12
2	0.81	1.00	0.72	0.56	0.49	0.79	0.68	0.36	0.27	0.29
3	0.87	0.72	1.00	0.60	0.80	0.80	0.87	0.49	0.07	0.17
4	0.59	0.56	0.60	1.00	0.21	0.74	0.85	0.39	0.04	0.18
5	0.52	0.49	0.80	0.21	1.00	0.56	0.63	0.42	0.37	0.38
6	0.78	0.79	0.80	0.74	0.56	1.00	0.87	0.37	0.40	0.26
7	0.70	0.68	0.87	0.85	0.63	0.87	1.00	0.34	0.33	0.17
8	0.23	0.36	0.49	0.39	0.42	0.37	0.34	1.00	0.88	0.82
9	0.17	0.27	0.07	0.04	0.37	0.40	0.33	0.88	1.00	0.91
10	0.12	0.29	0.17	0.18	0.38	0.26	0.17	0.82	0.91	1.00

In this case stations 3, 4 and 9 had thirty years of data and the remainder of the stations ten years. The grouping of well correlated stations for infilling data was selected as shown below:

Station	Stations used for infilling
1	2, 3, 6
2	1, 3, 6
3	records complete
4	records complete
5	3
6	7, 3, 2
7	4, 6
8	10, 9
9	8, 10
10	8, 9

Note that station 3 was not used to infill station 7 ($r = 0.87$) because the two are geographically separated and clearly in different catchments.

Consider as an example the following common data for four well correlated stations:

Taking the average ratio of rainfall to norm for the stations with records the infilled values for stations with missing values are hence:

1974 value = 361 x 0.77 = 278 mm
1976 value = 349 x 1.07 = 373 mm
1978 value = 331 x 0.90 = 298 mm.

For extending the records of the stations with only ten years data to the full thirty years, the procedure is as above except of course that each station is only compared to one other (ie with full 30 yrs record).

Year	rainfall (mm)			
1970	273	302	320	230
1971	382	367	387	335
1972	356	373	385	367
1973	417	432	440	402
1974	missing	288	285	228
1975	313	300	321	307
1976	398	missing	382	353
1977	481	452	484	475
1978	327	334	350	missing
1979	301	293	315	278
norm	361	349	367	331
1974/norm	-	0.83	0.78	0.69
1976/norm	1.10	-	1.04	1.07
1978/norm	0.91	0.84	0.95	-

RUNOFF WITH NO STREAMFLOW RECORDS

The United States Department of Agriculture soil conservation service have developed a method of predicting peak runoff from comparatively small rural catchments, where no runoff records exist. Sufficient rainfall records are required to decide on the design 24 hr rainfall. This rainfall is then applied to suitable profile, for frontal or convective rainfall standard profiles are used or alternatively any particular locally determined profile can be utilised. The original SCS method may easily be modified to yield the runoff hydrograph for the design storm. (16)

The method takes into account land use practice, soil type and ground condition in estimating runoff and hydrograph dimensions. Where appropriate allowance is made for channel losses and snowmelt base-flow. The following input parameters are necessary:

(i) Design 24 hr rainfall and profile
(ii) Surface runoff number C, derived from
  (a) antecedent rainfall conditions
  (b) crop cover and land preparation
  (c) hydrologic soil group
(iii) Catchment parameters
  (a) length of longest watercourse
  (b) area of catchment
  (c) gradient

The hydrologic soil group under section (ii) (c) is divided into the following categories:

Group A - high infiltration even when wet
Group B - moderate infiltration when thoroughly wet
Group C - slow infiltration when thoroughly wet
Group D - very slow infiltration when thoroughly wet.

Then depending on the crop cover and land preparation eg straight row crops, fallow, meadow etc, the curve number C (from 0-100) is found on a table (for average antecedent moisture conditions). This value is then modified if necessary for dry or wet antecedent conditions. The basic formula is:

$$Q = \frac{(P-I)^2}{(P-I)+S}$$

where Q = run-off
P = precipitation
I = initial losses
S = potential maximum retention.

If it is assumed that $I = 0.2S$,

then $Q = \frac{(P-0.2S)^2}{P+0.8S}$ in imperial units

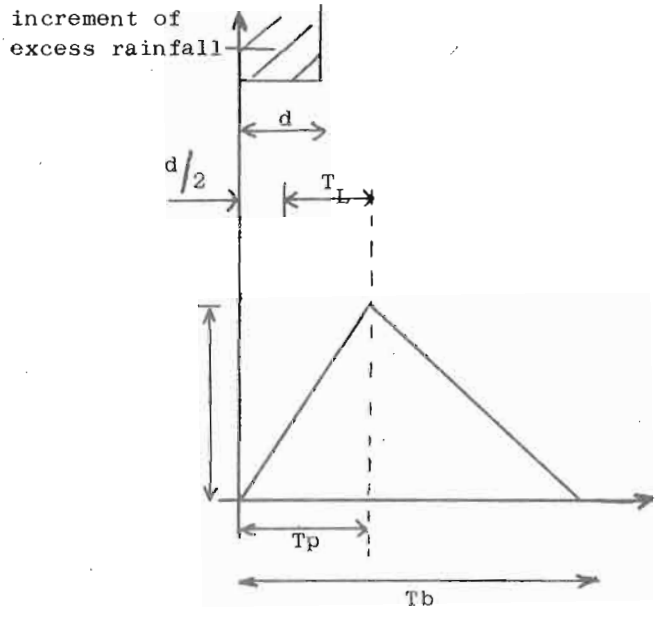
or $Q = \frac{(P-5.08S)^2}{(P+20.32S)}$ in metric units

The S parameter depends partly on the initial infiltration and surface storage but mainly on the infiltration after runoff has commenced. S is related to the curve number by the following relationship:

$$S = \frac{1000}{C} - 10$$

Thus knowing C, S can be determined.

A simple triangular hydrograph shape is assumed, the geometry of which is shown below.



$$q = \frac{A \times Q}{4.806 Tp}$$

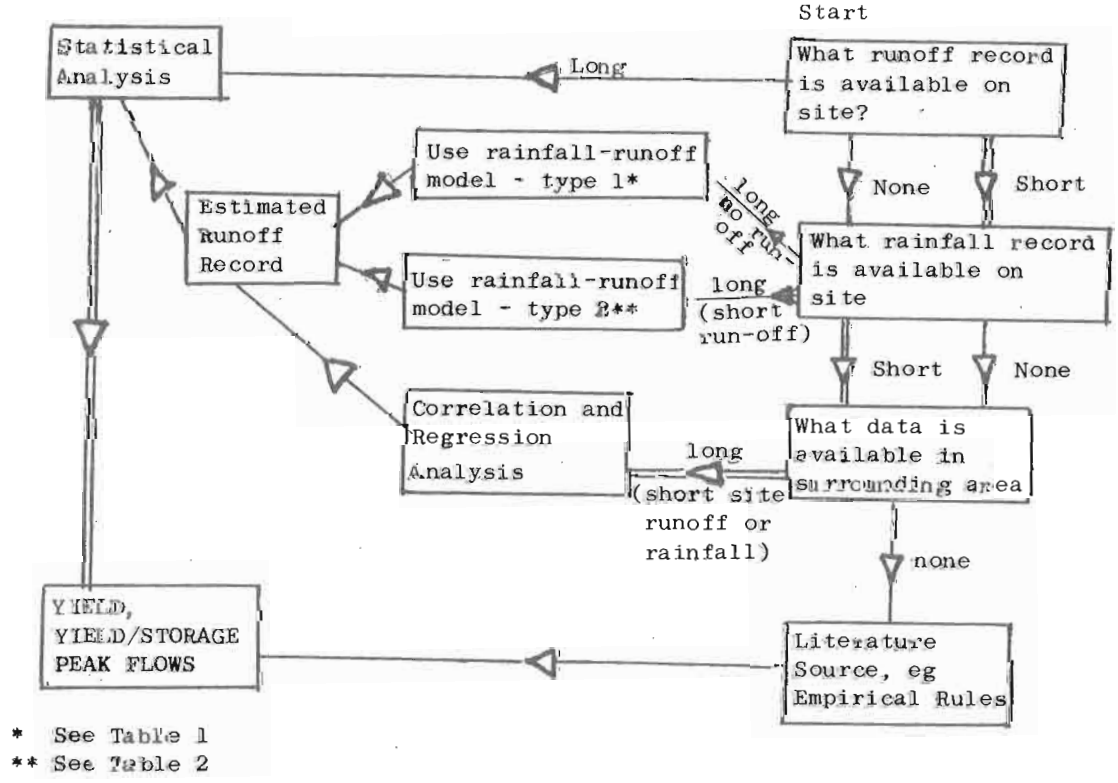
where q = hydrograph peak in m^3/s
Q = runoff in mm from storm increment d hours
A = catchment area in sq km
Tp = d/2 + L
Tb = 2.67 Tp
T_L = lag time in hours

$$T_L = \frac{(3281\ L)^{0.8} \times (S + 1)^{1.67}}{9000\ Y^{0.5}}$$

L = mainstream length in km
Y = slope of mainstream per cent.

The methodology is now to calculate the parameters of the unit hydrograph (ie 10 mm effective rainfall) for a suitable time increment. This unit hydrograph is then applied to the increments of effective rainfall for the corresponding time increment from 0 to 24 hurs. The resulting hydrographs are then convoluted to give the final runoff hydrograph.

Although originally developed for small agricultural catchments, the method has been found effective for ungauged catchments in excess of 10 km^2, but care is required in the assessment of the C number.



* See Table 1
** See Table 2

Fig 1

Table 1 - Rainfall-runoff methods
Type 1 - Long rainfall record, no runoff record

Flow type		
Low	Semi Empirical Methods eg Turcs rule (ref 2) Basin Climate Index (ref 3)	 Application to Limpopo River (ref 15) Application to Limpopo River (Ref 15)
	Runoff Coefficients (see notes) (from lit sources) eg Zambezi (ref 4) Nile (ref 4) Kafue (ref 5) Sokoto (ref 6)	) and other rivers)
High	Storm Runoff Coefficients (ref 7)	
	Synthetic Unit Hydrographs Nigeria (ref 8)) GB and used in other countries) (ref 9))	- derived from catchment characteristics
	Soil conservation service method	See later
	Richard's method (ref 10)	

Note 1. The catchment under consideration may not be found within the major catchments listed but it may be possible to use the runoff coefficients if the areas are hydrologically similar.

Table 2 - Rainfall-Runoff Methods
Type 2 - Long rainfall record, short runoff record

Flow type	Method	Remarks
Low	Water balance methods	(ref 12) Evaporation data required
	Regression analysis	
	'soil moisture reservoir' methods	eg applied in Botswana (ref 11)
	Black box methods	(ref 7) Mathematically based
	Comprehensive models Stanford Watershed model SAAR methods	(Ref 13) Will predice range of hydrological parameters. Computer required
High	Regression analysis	
	Unit hydrograph	(ref 8) Commonly used method
	Soil moisture reservoir	
	Black box and many others	(ref 14)

FINAL COMMENT

Assessment of surface water sources will never produce the 'right answer' to the yield/storage/reliability relationship or peak flow even with 100 years of data or more, since future flow variations cannot be predicted. All that can be expected is an estimate with an error which is related to the amount of data and the techniques used. Where much data are available many methods are available for solving the problem but where data are scarce the techniques available for estimation are equally scarce.

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