



Regional Flood Frequency Curve For Some Internal Wadis in Saudi Arabia

Dr. Assaf A. Alhawas*

Abstract:

Saudi Arabia covers a vast area in the southwest Asia. It extends between latitudes 16°-33° N, and between longitudes 34°-56° E. Seldom-rainy events in Saudi Arabia, are driven by three mechanisms: Firstly, are the middle latitude winter cyclonic activities passing over the eastern Mediterranean coasts. Secondly, are the summer south-westerly monsoon winds blowing towards the seasonal central Asian low pressure. Thirdly, are the intense thunderstorms initiated by local thermal convections. Uncertainty associated with rainy events is intensified when reflected on ephemeral stream runoffs in the country. That is because runoff is not only dependent on rain incidents but on their anomalous magnitudes and intensities.

Floods, among all natural hazards, cause the highest percentage of deaths around the world (Cunderlik, Burn, 2003). In a rapidly growing country like Saudi Arabia flood data are essential for decision makers, following the vast horizontal growth of major cities and villages to cover areas that have never been populated before. It is also important for the increasing number of road building projects. For sustainable development, the need is certain for a fast and reliable method of estimating drainage basin runoff for un-gauged stations based on available data. As a step into that direction this paper's aim is developing flood regional curves for internal wadis of Saudi Arabia utilizing the available runoff records and using the standard procedures used by USGS, as outlined in Bulletin17B of Interagency committee on water resources. Five catchments for which systematic flood records were available for more than twenty years are investigated. A representative regional curve was developed, after checking for homogeneity, and correcting for outliers and zero values. The slope coefficient of the relationship between drainage area and mean annual flood was estimated to be 0.335.

* Associate Prof., Dept. of Geography, College of Arts, King Saud University, Riyadh, Saudi Arabia.

Introduction:

Since the initiation of the development plans in Saudi Arabia, many social, economic, urban, and transportation projects have been accomplished. The country is still rapidly growing, and various sectors are continuously developing. The expansion of cities over wadi basins that have never been urbanized, building of new highways and roads between cities and villages, necessitates the position of basic knowledge about drainage basins and their flooding magnitudes and behaviors. The flooding probabilities and the magnitudes of mean annual floods and varying flood frequencies are essential information for planners and engineers. Due to anomalous nature of rains in the country, the temporal and spatial coverage of gauging stations are inadequate and insufficient to provide specialists with the very basic knowledge needed for their projects. Problems posed by individual record shortness and variability of estimates are particularly acute in arid areas (Farquharson et al., 1992). Hydrologists usually deal with the situation by extrapolating data from a neighboring site, or by interpolating flood-data from nearby sites, or by developing a representative regional curve from available data within a hydrologically homogenous region. Regional flood frequency analysis (FFA) is a widely used method for the estimation of floods at sites where insufficient or no data are available. The method involves two steps: the identification of a group of hydrologically homogeneous catchments, and the application of a regional estimation method (GREHYS, 1996; Javelle, et al., 2002). The purpose of the regional estimation method is to infer flood magnitudes at a target site within the designated region using available data from elsewhere in the region.

The objective of this paper is to develop a regional flood curve for an internal area in Saudi Arabia. The available annual flood peak data for some internal basins will be analyzed and utilized in developing such curve. Once developed, the flood curve should allow the estimation of flood magnitudes of varying frequencies for ungauged sites. Further, the dimensionless regional flood frequency curve will not just provide means of estimating floods for ungauged sites, but will also help overcome the variability of site records (Farquharson et al., 1992).

2. Anomalous nature of rains in Arabia:

Floods in arid areas result from storm precipitation intensity exceeding soil infiltration capacity. Hence, flood curve similarities in different basins are more related to storm characteristics as opposed to basin physiography (Farquharson et al., 1992). To the best knowledge of the researcher there has been no analysis of the distributional nature of precipitation storms (DNPS) in Saudi Arabia. So it is important to describe the varying mechanisms driving DNPS. Covering a vast area in southwest Asia, extending between latitudes 16° - 33° N, and between longitudes 34° - 56° E., seldom-rainy events in Saudi Arabia, are driven by three mechanisms: Firstly are the middle latitude winter cyclonic activities passing over the eastern Mediterranean coasts. Secondly, are the summer southwesterly monsoon winds blowing towards the seasonal central Asian low pressure. The country is located in a marginal area with respect to both mechanisms. Thirdly, are the intense thunderstorms caused by local thermal convections, which are further, intensified by the release of latent heat due to condensation of water vapor.

A deep trough in the upper air circulation (jet stream trough), and may be a cut-off low; has to be present, for the cyclonic activities to extend their effects south toward the northern and central parts of the country. In this case the cyclonic system will be passing over the northern or central parts of Saudi Arabia. The extension of its fronts south, mostly the cold front, brings frontal rains to the central parts. The other type of cyclonic rain is caused by deep and strong dynamic low pressure systems passing to the north of Saudi Arabia, and associated with long cold frontal arm extending south as far as the central parts of the country.

Monsoons are mostly limited to the southwestern parts of the country. And they are rarely able to penetrate north as far as the central and northern parts of the country. Regionally, the depth of the Indian thermal low, and the thermal low over the Empty Quarter, may be considered helping factors in predicting how far north the monsoon will go into the country. Globally, monsoon circulation is shown to be

strongly coupled to the El-Nino Southern oscillation, and to the advancement and retreat of ice sheets in high latitudes and their effect on ITCZ (Inter Tropical Convergence Zone) migration into the northern hemisphere (Bodo et al., 2005). However, it is not clear whether monsoon responds to high latitude changes via teleconnections or they pass abrupt changes from El-Nino/Southern Oscillation (ENSO) through the northern hemisphere (Wang et al., 2004). Nevertheless, monsoon rains in Arabia are of orographic nature, and are mostly limited to the windward side of Asir Mountains.

Cyclonic rains are longer in their durations (3days- one week), but may be less in their hourly rates than monsoon showers. However, they fall in cool temperature days when evaporation and evapotranspiration rates are minimal. These waters hit a gently sloping sandy fine-grained land surface, in average. Monsoon showers occur in high evaporation rate warm months. They, mostly, hit rough highly relieved coarsely grained mountainous areas. Solid impermeable igneous or metamorphic bedrocks are exposed at several locations in every drainage basin in the southwestern part. Or at best, impervious bedrocks are only covered with thin layers of coarsely grained rock fragments.

3. Rainfall-runoff relations:

The relationship between rainfall and runoff is linked to several storm and basin characteristics. Flood regime is a resultant reflection of a composite catchment's hydrologic response to flood producing processes (Cunderlik, Burn, 2002). However, Nouh (1987) stated that storm rainfalls in Arabia have to exceed a threshold of about 20mm for any substantial surface runoff to take place. Such figure must be taken with great deal of skepticism bearing in mind:

- 1 - The complexity of the runoff generation processes. Runoff generation, beside rainfall intensity and duration is related to soil moisture contents, infiltration capacity, vegetation cover and interception, evaporation and slope.
- 2 - The great spatial variability in basin characteristics throughout the country of Saudi Arabia. Relief, texture and composition of

ground materials are significantly different between basins in Arabian shield than those in Arabian shelf.

Aljerash (1986) in studying wadi Baysh on the western side of Asir heights (Arabian shield) has calculated a runoff-rainfall ratios standing at an annual average of 0.44 for wadi Baysh and 0.33 for wadi Bishah. Albaroudi (1986) estimated the same variable ratios for wadi Fatima between 20-60 percent increasing downstream. Nouh (1987) on the other hand, estimated annual runoff coefficients fluctuating between 0.133 and 0.185, with an overall average of 0.158. Uncertainty associated with rainy events is intensified when reflected on ephemeral stream runoffs in the country. That is because runoff is not only dependent on rain incidents but on their anomalous magnitudes.

4. Runoff data:

Given the anomalous nature of rains and the long dry periods separating runoff events, stream channel gauging deserves more attention. The earliest gauging stations were mounted in the south western region in 1966. But, as expected, most of the records are not continuous. The spatial coverage all over the country is very sparse too. The greatly growing demand for water to supply agricultural, industrial, and municipal activities; and the need to ease the drawdown of fossil deep aquifer waters forced water agencies to consider and utilize other sources of water supply. More attention is being waged to surface water runoff. Hopefully more and more gauging stations will be installed reducing the scarcity of the spatial coverage. Such information is needed for the design and operation of many water resources systems, including dam allocation and management. Monitoring drainage basins runoff and flooding is also important for many engineering purposes. Floods, among all natural hazards, cause the highest percentage of deaths around the world (Cunderlik and Burn, 2003) In a rapidly growing country like Saudi Arabia such data is essential for decision makers, following the vast horizontal growth of major cities and villages to cover areas that have never been populated before. It is also important for the increasing number of road building projects. For sustainable development the need is certain for a fast and reliable method of estimating

drainage basin runoff for un-gauged stations based on available data. As a step into that direction this paper's aim is developing flood regional curves for central Saudi Arabia utilizing the available runoff records. Five catchments for which flood records are available for more than twenty years are investigated (Fig. 1).

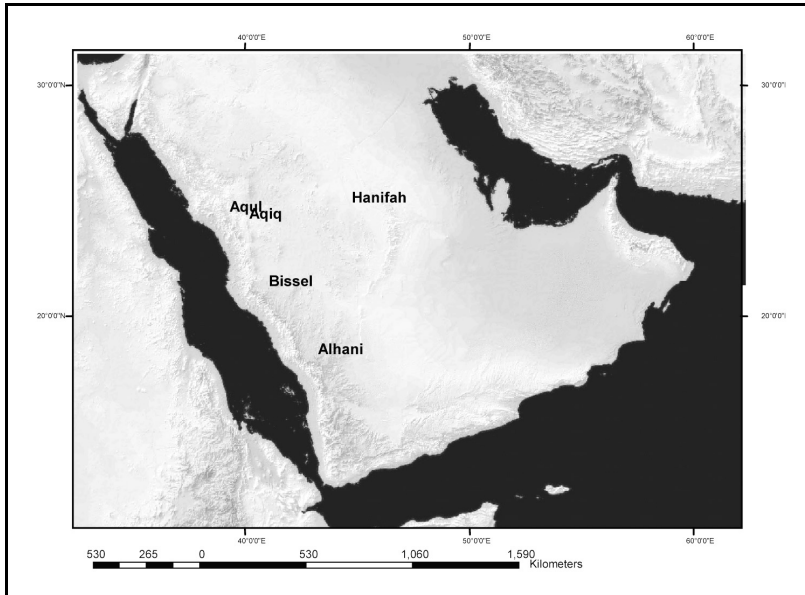


Fig. 1: Relative locations of gauging stations

5. Regional curves:

Simultaneous reduction of the impact of flooding both on people and their properties will ultimately improve the quality of life (Bernholz, 2002). This is best accomplished by making flood control and management part of a nation's development plans (UN Economic Comm., 1999). Recurrence and duration curves are the basis of planning river channels and valley floors. They are required for engineering design, planning flood insurance schemes and land use zoning of flood prone areas (Dunne & Leopold, 1978). Estimation of flooding potentials is often required for watersheds with non-existent or insufficient hydro-metric information. Such estimates can be obtained by simple

extrapolation from nearest gauged site (Wharton et al., 1989). But in situations where there are no gauged sites in the proximity, or if the catchments are different in size and characteristics, regional curves provide prompt and reliable method for estimating flood discharges of particular recurrence interval for a specific site. A regional frequency analysis method utilizes information from nearby stations exhibiting similar statistical behaviour as at the site under consideration to obtain more reliable estimates of ungauged site design floods (Kjeldsen, et. al., 2002). Their development is based on the assumption that in large regions of meteorologically and physiographically homogenous conditions, individual basins have flood frequency curves of approximately the same slope. If the regional curve is determined by using average parameters of a homogenous region, at site parameter deviations from the regional average it should be small (Hosking and Wallis, 1997). Regional analysis, usually, involves two major steps: the identification of a group or groups of homogenous catchments, and the application of a regional estimation method within the delineated homogenous region (Javelle, et al., 2002). In Saudi Arabia single station FFA are subject to large errors because of the immense variability in flood occurrences and magnitudes, and due to the insufficient temporal and spatial data coverage. By combining peak flood records from many gauged sites in a region flood analysis (RFA), such errors may be reduced. Floods in ungauged basins can be estimated on the basis of correlating flood-frequencies to basin characteristics.

6. Methodology:

One of the foremost goals of contemporary hydrology is improving techniques of flood frequency estimation (Cunderlik and Burn, 2002). Such goal cannot be accomplished unless techniques are applied in varying environments. RFA involves verification of the homogeneity of the catchments at hand. And it also, requires the estimation of the upper end of a probability distribution function (PDF) of peak flows either from annual or partial duration series.

For the question of homogeneity two methods will be used. Kruskal-Wallis statistical test for 3 or more independent groups, will

be used to test whether the flood data samples are from the same population. Traditional Dalrymple homogeneity test is to be used to verify the overall hydrologic homogeneity of catchments.

Estimation of the parameters of the presumed PDF depends on the researchers ability to find and use the most robust method of parameter estimation for a given sample size (Witold, et al., 2002). The standard procedures used by USGS to calculate recurrence intervals, and to estimate regional curves are used here. Plotting positions for annual peaks are calculated using standard Weibull equation. Weibull formula deals with ordinal scale data, and does not account for the sample size, as opposed to Gringorten methods; however the former is adopted by USGS and is more widely used by many researchers. T-year flood–peak discharges at gauging stations are calculated using the guidelines of Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). Each flood peak (Q_p) value is standardized by division by the mean annual flood (2.33 yr. flood) for the given station record period. Mean annual flood (MAF) can either be statistically calculated or defined graphically. The resulting dimensionless ratio (Q_p/MAF) is then plotted against recurrence intervals. The regional curve is traditionally defined as the median ratio for values of each recurrence interval.

Because of prevailing aridity, the systematic records have 0 flows for some years in the record. So, the threshold value for the flow was set to be zero (flood base Q_0). And the probabilities of having a flow of more than zero (P_0) were calculated first then the total probabilities were the product of the exceedance probability by $P\{\small 0$. Bulletin 17B specifies dealing with below threshold outliers in the following equation:

$$W = \frac{H - N_{HP} - N_{HO}}{N_S - N_{HO}} \quad (1)$$

Where:

W = the weight to be given to systematic peaks N_S .

H = historic period which includes systematic record period (S_p).

N_{HP} = number of historic peaks.

N_{HO} = number of high outliers.

The effective number of peaks N_e above Q_0 is

$$N_e = N_{HP} + N_{HO} + W(N_S - N_{HO} - N_{BB}) = H - W(N_{BB}) \quad (2)$$

Where:

N_{BB} = Number of peaks equal or below Q_0 .

If no historic peaks are utilized, $H = S_p$.

P_0 then can be estimated from:

$$P_0 = \frac{N_e}{S_p} \quad (3)$$

Though, there is no obvious base of judgment on which distribution to fit maximum discharge data to, the choice is seemingly dependent on data fitness. This is a question of great importance in any FFA. A special case of gamma function: the Pearson Type III distribution, in its logarithmic form Log Pearson III (LPIII) is more widely adopted as the standard method for FFA (Viessman et. al., 1977). The first three moments of the annual flood peak series, in specific the first three product moments, which are mean annual flood (MAF), coefficient of variation (CV), and coefficient of skewness (CS) are used. MAF was estimated graphically. CV and CS were calculated for the logarithmic equivalents of data at hand using the following relations (Merz and Blöschl, 2005):

$$CV = \frac{S}{\ln MAF} \quad (4)$$

Where:

$$S = \sqrt{\frac{\sum_{j=1}^n (\ln Q_j - \ln MAF)^2}{n - 1}} \quad (5)$$

$$CS = \frac{n \sum_{j=1}^n (\ln Q_j - \ln MAF)^3}{(n - 1)(n - 2)S^3} \quad (6)$$

Where:

Q_j Is the specific peak-flood discharge for year j . n is the number of years in the flood record. S is the standard deviation.

$$X = \bar{X} + K\sigma_x \quad (7)$$

Where:

X = a flood specified probability.

\bar{X} = The mean of the flood series.

σ_x = The standard deviation of the series.

The general form proposed by Chow (1951), for most frequency functions (eq. 7), is used to estimate fitting values for flood magnitudes as follows:

$$\ln Q_{RI} = \ln MAF + S_{\ln Q} \cdot K_{CS,RI} \quad (8)$$

Where:

$$\ln MAF = \frac{\sum_{i=1}^n \ln Q_i}{n}$$

RI = recurrence interval.

Looking at the general form presented in equation (8), K is merely a frequency factor representing the number of standard deviations the probability point of interest is above or below the mean. It is synonymous to z-scores in the normal distribution. K varies with probability or its equivalent in frequency analysis RI , and with CS in skewed distributions. It can also be greatly affected by the number of years of record (Viessman, et al., 1977).

The final step in building a regional flood curve is to establish some measure of a relationship between one or more of the basins physiographic characteristics in the region and T-year floods (Adamowski, 2000), which takes the general form:

$$Q_{RI} = aA^b \varepsilon \quad (9)$$

Where Q_{RI} is the flood of return period RI , A is the drainage area

and a, b are coefficients to be estimated and ε is the error term. Usually nonlinear regression relationship is calculated between *MAF* and basin area. Others may use basin shape or other variables along with the basin area in multiple regression analysis. Nonlinear model forms are shown to give more accurate estimates of quantiles from ungauged sites (Pandey, Nguyen, 1999).

7. Flood Record Problems in Arabia:

Sparse spatial coverage, improperly located stations and record discontinuity, are very common problems in arid areas flood records (Al-Turbak, 1996). But, two main problems were faced in handling this research data set. These problems may not be limited to Arabia, but probably are present in all arid lands in the same latitudes. The first is related to heterogeneity of the flood populations and the second is related to severe aridity and frequent zero flood records.

Annual maximum flood discharge series in central Saudi Arabia may be subject to seasonality factors (winter cyclones, spring local convections and summer monsoons). This may produce non-identically distributed hydrologic flood data, which may invalidate the basic assumption of identical distribution that the conventional methods rely upon (Singh, Wang and Zhang, In Press). However, unavailability of detailed data precludes seasonal analysis. Such a question is left bending for future investigations.

A zero flood record means dryness in that year, and no sufficient runoff happened at the sight that was detectable by the stage recorder. That is not a missing value to be interpolated from records at hand. Zero floods require special care in the analysis in three occasions. It affects calculating the mean annual flood (*MAF*), calculations of probabilities, and the most problematic the logarithmic transformation of the data set to reduce skewness.

In order to avoid the effect zero annual peak discharge values may have on the calculation of *MAF* Farquharson, et al. (1992) suggested using the 5-year flood as a scaling factor. The use of a flood with designed RI is very helpful in avoiding such problem. But, the use of 2.33-year flood is seen here to be more appropriate for two reasons: first, is

overcoming the statistical mean sensitivity to outliers. Second is enabling comparability with results from other parts of the world reported in the literature, since 2.33-year flood is widely accepted as a representative of the MAF. Graphical estimation of MAF was done to avoid the effect of outliers on arithmetic mean calculations. MAF was chosen as the flood with 2.33 years recurrence, as widely adopted in the literature. The probability of having a flood above zero was first calculated, then the probability for a specific flood value being equalled or exceeded is the product of the probabilities of its conditional occurrence multiplied by the probability of having a peak above zero. A more serious problem is encountered with the zero peak values when transforming to logarithmic equivalents. Excluding these values from the transformation and consequently from the analysis will alter the distributional characteristics of the data. Since a zero value does not necessarily mean totally dry runoff as much as meaning no flow was sufficient enough to be detected by the stage recorder at sight, it is arguably valid to assign very minimal values in lieu of zero values in the record, prior to taking the logarithms. However, in this research the method recommended by Interagency Advisory committee on Water Data as outlined in Bulletin 17B (1982) was used. The procedure starts by calculating MAF_0 , S_0 and CS_0 for all above zero peaks from each station. Then a logarithmic Pearson Type III curve was fitted to $\ln Q_p$, p is the probability of being equalled or exceeded. Special care must be paid to obtaining the tabular values of K , as they are a function of both CS and p . By solving the set of the following three simultaneous equations for the three unknowns (MAF , S and CS):

$$\ln Q_{0.5} = \ln MAF + S_{\ln Q} \cdot K_{CS,50} \quad (10)$$

$$\ln Q_{0.10} = \ln MAF + S_{\ln Q} \cdot K_{CS,10} \quad (11)$$

$$\ln Q_{0.01} = \ln MAF + S_{\ln Q} \cdot K_{CS,01} \quad (12)$$

A frequency curve can be fitted for $\ln Q_p$ when zero values are present.

8. Homogeneity Test:

One of the most important stages in regional frequency analysis, and subject to a great deal of slanted judgement is the identification of homogenous regions. It is quite a controversial issue to delineate a homogenous region for the purpose of FFA. Regions delineated on geographical basis are often found not to be hydrologically comparable (Adamowski, 2000). Regions are assumed to be homogenous according to flood related variables (Meunier, 2001). Homogeneity tests are an important component of many regional analyses, particularly RFA (Fill, et. Al., 1995). Several methods are used in the literature to delineate homogenous regions. The residual method (RM) and Fuzzy c-mean method (FC) are used whenever there are good number of sites to divide to homogenous groups. For the limited number of catchments involved here, the traditional Dalrymple homogeneity test is employed. Dalrymple’s test has been widely used in hydrologic practice for more than 30 years (Fill, et. Al., 1995). Steps followed are outlined in table (1). The results are shown in figure (2). Results indicate acceptable degree of homogeneity between sites.

Table (1)
Homogeneity test

Basin	$Q_{2.33}$	Q_{10}	$X = Q_{10}/Q_{2.33}$	$Q_{2.33} * \tilde{X}$	RI (yrs)	Period of record
Bissel	65.6	358	5.46	394.65	8	23
Aqul	2.16	17.5	8.102	12.995	5.75	21
Aqiq	1.14	5.4	4.737	6.858	11.5	22
Alhani	31.28	218	6.97	188.18	7.33	22
Hanifa	86.13	414	4.81	518.158	11.5	22
Mean (\tilde{X})			6.016			

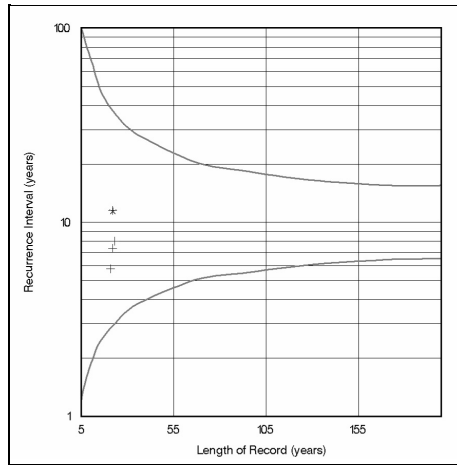


Figure 2: Dalrymple Homogeneity Test

9. Results and discussions

The main assumption regional curve fitting relies upon, is the homogeneity of the aerial basins. Such a characteristic, though must be tested, should be noticeable from similarity in slope of flood-frequency curves for individual basins in the region, covering a wide range of drainage areas (fig. 3). Figure (3) shows flood-frequency curves for the five catchments used in this article (table 2), plotted on Gumbel Type III paper.

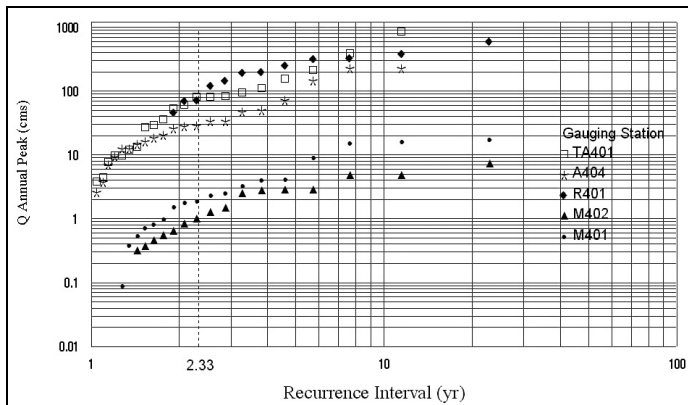


Figure 3: Flood Recurrence Interval

Table (2)
Wadi basins and gauging stations used in the analysis.

Wadi	Bissel	Aqul	Aqiq	Alhani	Hanifah
Gauging station ID	TA401	M401	M402	A404	R401
Station Catchment's Area (km ²)	236	3300	3100	146	1675
Station length of record (years)	23	21	22	22	22
Station longitude ^o	40.72	39.73	39.58	42.52	46.62
Station latitude ^o	21.20	24.50	24.45	18.24	24.67
Station altitude (m)	1525	625	620	2145	625

Where *MAF* for each basin can be read from figure 3 at *RI* of 2.33 years as shown. Fitted curves for annual maximum flood values above the flood base (Q_0), are shown in figure (4). *K* values were obtained from Viessman, et. al. (1977), appendix C, table C2, PP 682-684.

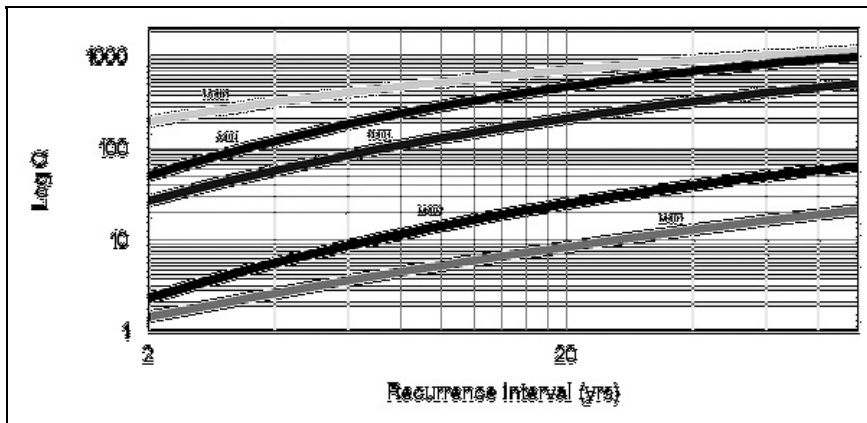
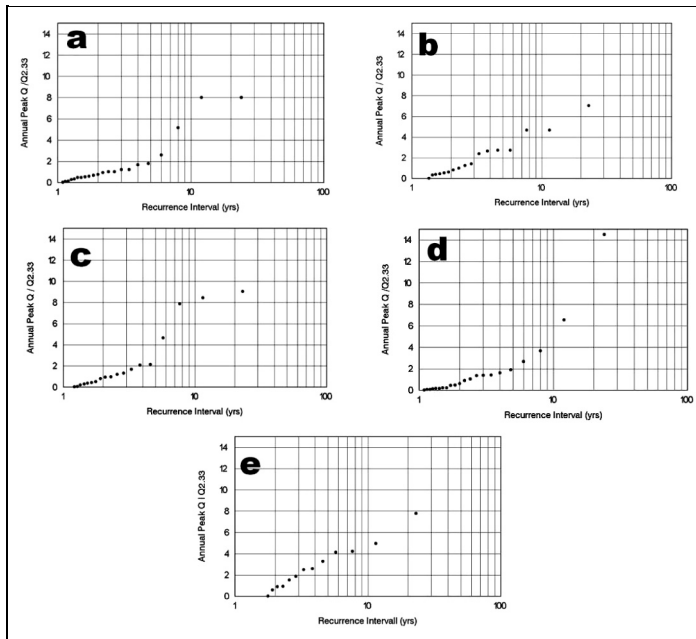


Figure 4: Above Q base Curves

Recurrence intervals against the ratio of annual maximum Q to $MAF (Q_{2.3})$, for the five catchments are shown in fig (5). The jump in ratio magnitude between 5-7 years *RI* is noticeable in all catchments. This may imply different mechanism and probably different distribution governing high magnitude floods.



a: Wadi Alhani, b: Wadi Aqiq, d: Wadi Bissel c: Wadi aqul and e: Wadi Hanifah

Figure 5: Plotting Positions for Annual Peak Ratios

The ratios of T-year floods to *MAF* are shown in table (\ref{eq2}). In fig (6) those ratios are plotted on the ordinate against *RI* on the abscissa.

Table (3)
T-year flood ratios to MAF for the catchments.

Ratios to mean annual flood						Median
	Bissel	Aqul	Aqiq	Alhani	Hanifa	
1.5yr flood	0.15	0.278	0.263	0.51	0.14	0.263
5yr. flood	2.13	3.148	2.719	2.24	3.6	2.719
10yr. flood	5.46	8.102	4.737	6.97	4.81	5.46
20yr. flood	12.5	8.935	6.579	7.99	7.26	7.99

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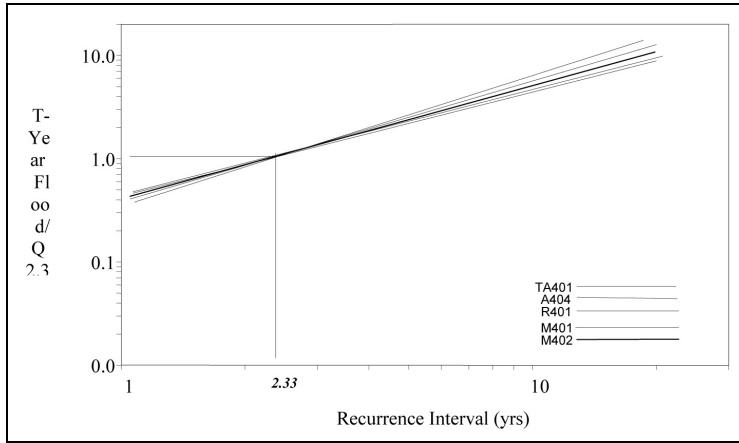


Figure 6: Relationship between Q/MAF and RI

Note that all lines intersect at MAF . The regional curve is defined to be the median of the five curves representing the five catchments at hand. The median value for each row from the first five columns in table (3), are presented in the last column right in the same table. The regional curve is plotted in fig. (4), from the median values aforementioned.

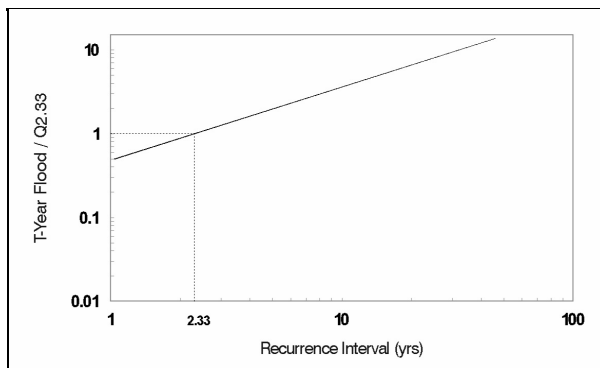


Figure 7: Regional Curve for Central Saudi Arabia

For the region defined, the value of an index flood must be related to catchment's characteristics (Jingyi and Hall, 2004). Power regres-

sion relationship between *MAF* and drainage basin area was calculated for the region. Results are shown in equation (9):

$$Q_{2.33} = aA^{0.335} \quad (13)$$

The regression line was forced through the origin for obvious reasons. Consequently, *a* will have the value of unity. It is worth note that the value of *b* in equation 13 is a measure of elasticity of *Q* on *A*, as the values are logarithmically transformed. Farquharson, et. al. (1992), have estimated the value of *b* for 30 stations in western Saudi Arabia and Yemen to be 0.701, and for 6 stations in Jordan to be 0.427. Pitlick (1994) suggested that variation in flood frequency distributions reflects largely the variability in precipitation amount and intensity rather than physiographic differences. The poor relation ship noted between physiography or drainage area and floods of designated recurrence in Saudi Arabia and probably in many arid areas is related to storm driving mechanism. Most surface runoff producing storms are thunder storms caused by local thermal convections. Those storms have a very narrow spatial coverage, that they may not cover the whole catchment's area. So relating flood magnitudes to the whole drainage area may not be meaningful.

10. Conclusion:

The analysis of data from the five internal drainage basins showed that they are hydrologically homogenous. Hence, their flooding characteristics can be regionally presented by a single regional curve. Such curve can be used to estimate magnitudes of floods of a specific recurrence interval. The curve is applicable to all catchments within the region via the relationship between *MAF* and drainage area, the parameters of which are estimated by regression analysis. The regression line intercept was forced to unity, and the line slope (β) = 0.335. In Saudi Arabia where the gauging net coverage is very poor, adopting indirect means of flood magnitude estimations is becoming increasingly important. The regional curve shown in this research was a reliable and economic method to overcome the data problem. However, the demand for establishing more gauging stations is legitimate and urgent.

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