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Hydrology-Based Method of Environmental Flow Assessment (Case study: Karoon River, Iran)

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ABSTRACT

Background: According to the importance of environmental aspects of river, several methods have been developed to assess environmental flow. In this paper, desktop hydrological-based environmental flow assessment method has been applied for Karoon River, Iran. **Objective:** Flow duration curve technique was used to evaluate environmental flow for daily, 7-daily mean and 30-daily mean classification. Two approaches were used for three mentioned group. In the first method, discharge of probability of exceedance 95%, Q95, was calculated corresponding to three mentioned classification. In the second method, flow duration curves were extracted for various return periods using Weibul plotting position formula. Then, flow discharge corresponding to probability of exceedance 95% was determined using linear trendline equation for above three classification. **Results**: It was indicated that hydrology-based of environmental flow assessment represent a necessary first step in planning for environmental allocation in developing countries. It is shown that use can be made of complementary features of existing environmental flow assessment technique to arrive at justified estimates of environmental flows even in the conditions of limited basin-specific eco-hydrological knowledge. **Conclusion**: Results showed that the first method has reasonable outputs as regards to frequency analysis of dry-period of Karoon River. The amount of environmental flow was calculated as 244.36 $m^3.s^{-1}$.

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INTRODUCTION

The availability of water is one of the most basic conditions for sustainable development. The accessibility of freshwater per person is constantly decreasing, mainly due to population growth nowhere is the problem more urgent than in developing countries, particularly in arid climates where the population already relies on very limited water resources. Human links to river ecosystem services are also strongest in these countries (Stikker, 1998)

Many of the countries that experience river degradation know that environmental protection must be part of their aquatic resources management (King *et al*, 2003; Mazvimavi, 2007; Hughes & Hannart, 2003).

Internationally the importance of maintaining sustainable river basins, by reserving some water along the river, is growing (King *et al*, 2003; Mazvimavi, 2007; Hughes & Hannart, 2003).

Environmental Flow Assessments (EFAs) produce one or more descriptions of possible modified flow regimes for the river, thus the Environmental Flow Requirements (EFRs), connected to a predetermined recommended ecological status. There is no single best way to do an environmental flow assessment. The choice of methodology depends on the availability of resources, i.e. data, time, funds etc. The major criteria for determining environmental flows should include the conservation of the variability of the natural flow.The timing of the environmental flows is complicated by the lack of understanding of the relationship between river flows and river ecology as well as uncertainties in the estimation of the hydrology. A database of various methodologies for environmental flow assessment, established in 2003, contains useful information on 134 methodologies with key references. This database is a valuable source of different environmental methodologies. The methodologies can be sorted by type, region or country where they have been applied. There are four categories of environmental flow methodologies, which are recognized by most scientists in the environmental flow field. Hydrological (desktop estimates) is one of the categories. Hydrological methodologies are generally used for the planning level and have been applied widely, both in developed and developing countries. The most simple environmental flow methodologies are the hydrological methods. They are often referred to as desktop models and rely primarily on the use of hydrological data, usually in the form of historical

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flow records, for making EFRs.The results are often presented as a minimum required flow to maintain the ecological status at some acceptable level There are numerous methodologies used in Southern Africa; Desktop Estimate, Rapid Reserve Determination, Flow Duration Curves percentiles (FDCs), Range of Variability approach (RVA), VHI, BWE, Ecotype-based Modified Tennant Method (Tharme, 2003)

Flow duration curve (FDC) is a common hydrological methodology. It is a convenient way of summarizing the hydrological frequency characteristics of river flow. It provides information on the probability that a flow is equaled or exceeded and is driven by portioning the flow hydrograph (generally as mean daily flows), ranking the flows in descending order and sorting by the probability of a given flow being exceeded. The convention is to refer to the flow corresponding to an exceedance probability x as Q(x). The exceedence probability is usually expressed as the percentage of time that a flow is exceeded; hence Q95 is the flow exceeded 95% of the time. A FDC is usually constructed from a time series of rive flow data for a catchment that is thought to be representative of the underlying natural variability in river flows within that catchment(Smakhtin *et al*,1998). The reliability of the information extracted from a FDC is influenced by:

- The reliability of the hydrometry at the point of the measurement
- Sampling error. The error associated with the assumption that the sample of the river flow data used to construct the FDC is the representative of the underlying natural variability.

FDCs are widely used in hydrological practice. Vogel and Fennessey refer to several early studies related to the theory and application of FDC (Vogel *et al* ,1994):

Searcy was possibly the first to summarize a number of FDC applications including the analysis of catchment geology on low flow, hydropower and stream water quality studies (Searcy, 1959).

Warnick illustrated the application of FDCs to hydropower feasibility studies for run-of-river operations (Warnick, 1984)

Male and Ogawa advocated the use of FDCs in the evaluation of the trade-offs among various characteristics involved in determination of the capacity of waste-water treatment plants including flow, flow duration, water quality requirements and costs (Male and Ogawa,1984)

Alaouze developed the procedures based on FDC, for estimation of optimal release schedule from reservoirs, where each release has a unique reliability.

Pitman and Mallory and McKenzie illustrated the use of FDCs in design of flow
Diversions (Pitman,1993),(Mallory, McKenzie, 1993).

Estes and Osborn (1986) and Gordon *et al*., (1992) illustrated the use of FDC for the assessment of river habitats in estimation of in stream flow requirements

Hughes and Smakhtin (1996) suggested a nonlinear spatial interpolation approach (based on FDCs) for patching and extension of observed daily flow time series, which has latter been extended to generation of flow time series at the ungauged sites and to the restoration of natural stream flow sequences in regulated rivers .

Gustard and Wessel ink (1993), Lanen *et al*. (1997) and Smakhtin *et al*. (1998a) used a FDC as a tool for rainfall–runoff model calibration and/or for the comparison of flow-time series simulated for different scenarios of development .

Wilby *et al*., (1994) used FDC to assess the effects of different climate scenarios on stream flow with particular reference to low-flows .

Hughes *et al*., (1997) developed an operating rule model which is based on FDCs and is designed to convert the original tabulated values of estimated ecological instream flow requirements for each calendar month into a time series of daily reservoir releases. FDCs are used in abstraction licensing (Pirt and Simpson, 1983; Gustard *et al*., 1992; DWAF, 1995; Mhango and Joy, 1998), in water quality studies, e.g. to indicate the percentage of time that various levels of water pollution will occur after the introduction of a pollutant of a given volume and strength into a stream (so long as there exists an adequate correlation between the quality characteristics and discharge).

A recent review of numerous possible applications of FDCs in engineering practice, water resources management and water quality management is given by Vogel and Fennessey (1995).

Of most interest for low-flow studies is the ‘low flow section’ of a FDC, which may be arbitrarily determined as part of the curve with flows below MF (which corresponds to the discharge equaled or exceeded 50% of the time-Q50). This entire section of the curve may be interpreted as an index of groundwater (and/or subsurface flow) contribution to stream flow from subsurface catchment storage. If the slope of the low-flow part of the FDC is small, groundwater/subsurface flow contribution is normally significant and low-flows are sustainable. A steep curve indicates small and/or variable base flow contribution. In this sense, the shape of FDC is an indication of hydro-geological conditions in the catchment(Hughes *et al*,2003)

MATERIALS AND METHODS

As mentioned, FDC is one of the most informative methods of displaying the complete range of river discharges from low flows to flood events. It is a relationship between any given discharge value and the percentage of time that this discharge is equaled or exceeded, or in other words-the relationship between magnitude and frequency of stream flow discharges.

A FDC is constructed by reassembling the flow time series values in decreasing order of magnitude, assigning flow values to class intervals and counting the number of occurrences (time steps) within each class interval. Cumulated class frequencies are then calculated and expressed as a percentage of the total number of time steps in the record period. Finally, the lower limit of every discharge class interval is plotted against the percentage points. Alternatively, all ranked flows are plotted against their rank which is again expressed as a percentage of the total number of time steps in the record.

Of most interest for low-flow studies is the 'low flow section' of a FDC, which may be arbitrarily determined as part of the curve with flows below MF (which corresponds to the discharge equaled or exceeded 50% of the time-Q50). This entire section of the curve may be interpreted as an index of groundwater (and/or subsurface flow) contribution to stream flow from subsurface catchment storage. If the slope of the low-flow part of the FDC is small, groundwater flow contribution is normally significant and low-flows are sustainable. A steep curve indicates small and/or variable base flow contribution. In this sense, the shape of FDC is an indication of hydro-geological conditions in the catchment.

Various other low-flow indices may be estimated from this part of the FDC. The flows within the range of 70-99% time exceedence are usually most widely used as design low flows. Some common example indices are: one- or n-day discharges exceeded 75, 90, 95% of the time-e.g. Q75(7), Q75(10), Q90(1), Q95(1), Q95(10). Some less conventional indices include the percentage of time that 25% average flow is exceeded. Similarly to the ratio Q20/Q90 which may be interpreted as a measure of stream flow variability the ratio (Q50/Q90) may represent the variability of low-flow discharges. The reverse ratio (Q90/Q50) may be interpreted as an index representing the proportion of stream flow originating from groundwater stores, excluding the effects of catchment area(Arihood and Glatfelter, 1991)

In this paper, two approaches were applied to evaluate environmental flow, which are presented in the following subsections. Karoon river, in Ahwaz hydrometry station was used to application of following methods (Fig. 1).

Approach one:

In this method, daily discharge data collected from station of Ahwas to compute 1-day, 7-day mean and 30-day mean flow duration curves. Smakhtin (2001) indicated that the "design" low flow range of a flow duration curve is in the 70% to 99% range, or the value of probability of exceedance corresponding to the Q70 to Q99 range.

The Q95 and Q90 flows are most often used as low flow indices in the government literature and academic sources. The Q95 value corresponding to the probability of exceedance of 95% was found to be most suitable "environmental design flow" for Karoon River, and used for the duration curve drawn for daily, 7-day mean and 30-day mean values. The Q95 flow index has been used globally by researchers for different uses (Table 1).

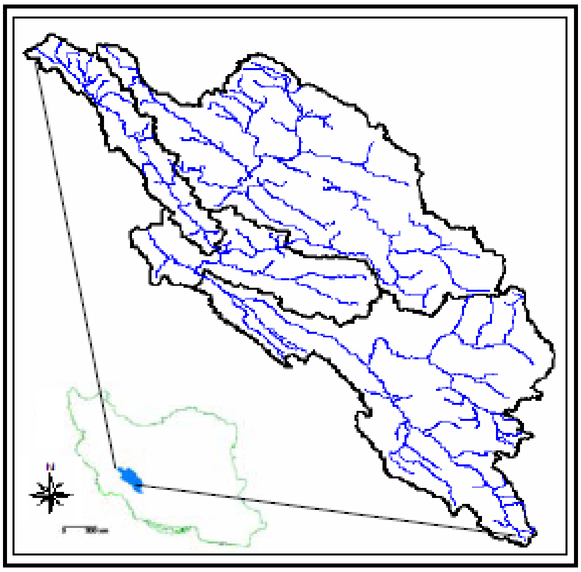

Fig. 1: Karoon River catchment.

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Table 1: Application of Q95 index for environmental flow assessment.

Index	Application	Researchers
Q95	commonly used low flow index or indicator of extreme low flow conditions	Riggs *et al.*(1980), Brilly *et al.* (1997), Smakhtin (2001), Wallace and Cox (2002), Tharme (2003)
	minimum flow to protect the river	Petts (1996)
	minimum monthly condition for point discharges	Michigan Department of Environmental Quality (2002)
	licensing of surface water extractions and effluent discharge limits assessment	Higgs and Petts (1988), Smakhtin and Toulouse (1998)
	biological index for mean monthly flow	Dakova *et al.* (2000)
	used to maintain the natural monthly seasonal variation used to optimize environmental flow rules	Stewardson and Gippel (2003)

Approach two:

In this approach, a flow duration curve of each water year was constructed by plotting and arranging the daily discharge values in descending order. The flow duration curve for various return periods were developed using the characteristics of distribution of probability plots of stream, calculated by the Weibull plotting formula, at suitable time intervals from 0 to 100 percent on the time axis. The developed flow duration curves (FDC) were used to evaluate the severity of high, ordinary, and low flow regimes of Karoon River system. The procedure followed to obtain the FDC of various return periods are as follows (Sugiyama *et al*., 2003):

1. After construction of an FDC for each year, read values of daily discharge at every 5% probability of exceedance.
2. Make separate Table for each year discharge versus probability of exceedance.
3. Rank discharge values in ascending order and read from each flow duration curve of a given N year term.
4. Calculate the plotting position with the following Weibull plotting formula, select the type probability paper to be used, and plot the data on the probability paper:

$$P=\frac{m}{N+1}\times 100$$

where P is the probability of all events less than or equal to a given discharge value, m is the rank of the event, and N is the number of events in the record.

5. Visually fit a straight line through the estimated values.
6. Using a straight line equation, get the discharge value down from the best fit line for the chosen probability value for various return periods (1 year, 2 year, 5 year, 10 year, 20 year, 50 year and 100 year).
7. Repeat steps 3 to 6 at suitable time intervals from 0 to 100 percent of the time axis (in the present case it is taken at every 5%).
8. Plot probability daily discharge values read at suitable intervals and draw a smooth FDC of return period of 1 year, 2 year, 5 year, 10 year, 20 year, and 50 year.

As discussed earlier, the value of probability of exceedance equal to 95% (Q95) was used as “environmental design flow” for Karoon River system to maintain its ecology.

RESULTS AND DISCUSSION

Table 2 shows statics of daily, 7-day mean and 30-day mean values for Karoon River, which is based on the first method. As it clear, not only there is no significant difference between average values, but also 7-daily mean and 30-daily mean have close values. This difference for the variation range of three flows type is insignificant. To select one flow regime, it is necessary to use another statistical indices (STDEV, Skewness, CV). 7-daily mean flow has the minimum value of standard deviation (STDEV) and skewness coefficient. Also, it has minimum coefficient of variation (CV) among the others. Therefore, considering all aspects, the 7-daily mean flow is found be suitable for the first method. According to calculation, the amount of environmental flow will be equaled to 244.36 $m^3.s^{-1}$.

Table 2: Statics of daily, 7-day mean and 30-day mean values of Q95.

Discharge	Average	Max	Min	Skewness	STDEV	CV
Daily	257.3	300	204	-0.1658	29.1	0.113
7-day mean	244.36	290	200	-0.0033	28.4	0.102
30-day mean	246.5	320	201	0.2641	32.9	0.133

Figures 2 to 4, which are based on the second method, show the FDC for daily, 7-daily mean, and 30-daily mean discharge, respectively. These figures are plotted for exceedance probability of 95%. Using straight line equations for each percentage exceedance, the discharge values for various return periods of 1 year, 2 year, 5 year, 10 year, 20 year, 50 year and 100 year were developed. The result of presented in table 3. Figures 5 to 7 show the graphical presentation of table 3. The amount of daily, 7-daily mean and 30-daily mean value of exceedance probability of 95%, using linear equations of Figs. 2 to 4, are equaled 211.75, 199.7 and 195.31 $m^3.s^{-1}$. As it clear, the amount of Q95 using the second approach are less than the first one. Table 4 shows frequency analysis of Karoon River. according to this table, amount of flow discharge in dry-period of return period 5 year is equaled to 242 $m^3.s^{-1}$. Therefore, it is reasonable to select the result of the first approach as environmental flow.

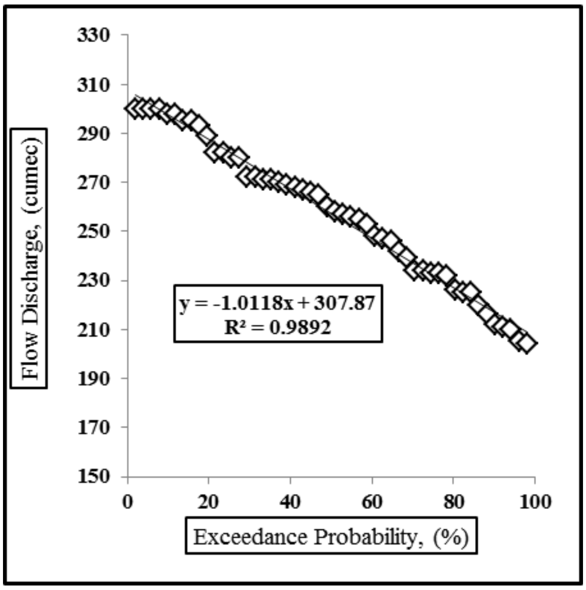

Fig. 2: Best fit line to obtain daily environmental flow for Q95 probability.

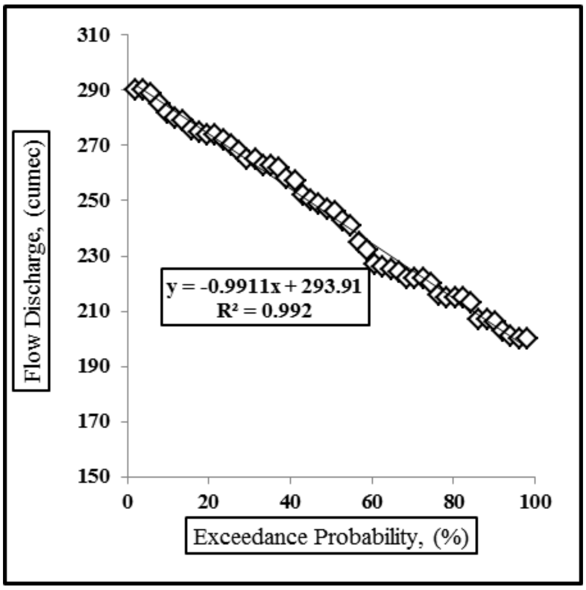

Fig. 3: Best fit line to obtain 7-daily mean environmental flow for Q95 probability.

Table 3: Flow Discharge for different return period for Q95.

Flow type	Return Period						
	1	2	5	10	25	50	100
Daily	306.81	307.42	307.71	307.76	30.82	307.85	307.86
7-daily mean	292.92	293.41	293.71	293.81	293.87	293.89	293.9
30-daily mean	302.28	302.85	303.19	303.3	303.37	303.39	303.4

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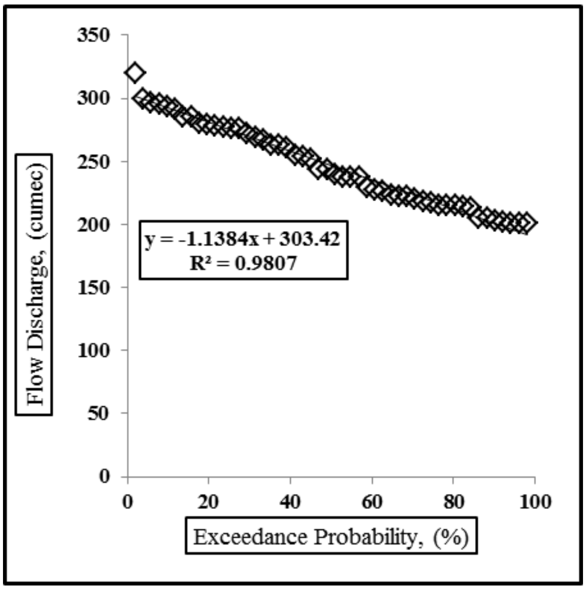

Fig. 4: Best fit line to obtain 30-daily mean environmental flow for Q95 probability.

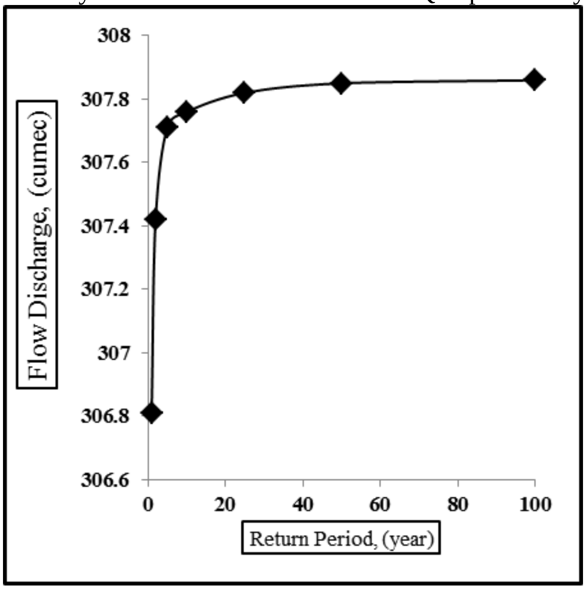

Fig. 5: Environmental flow daily discharge (Q95) vs. return period.

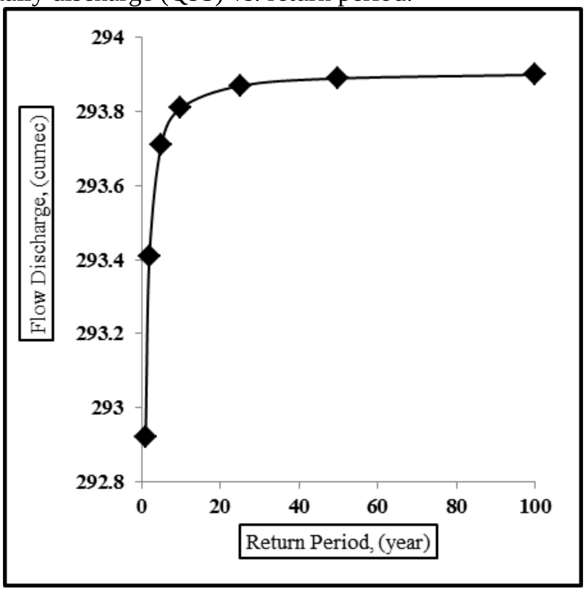

Fig. 6: Environmental flow 7-daily mean discharge (Q95) vs. return period.

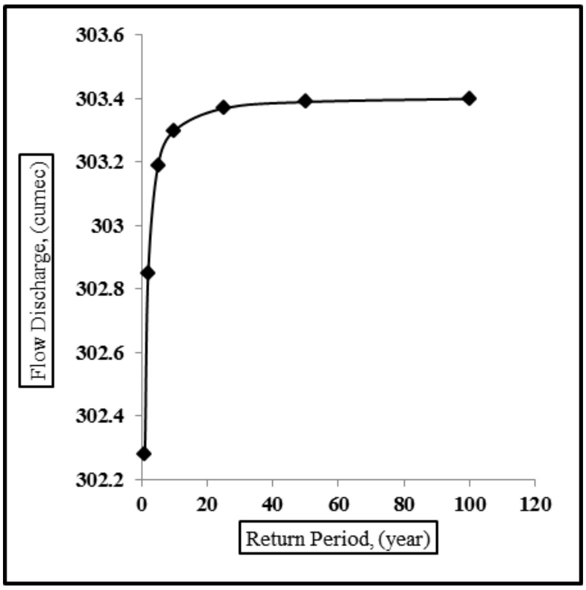

Fig. 7: Environmental flow 30-daily mean discharge (Q95) vs. return period.

Table 4: Frequency analysis of Karoon River discharge Flow parameters at Ahwaz station.

	Wet period					Mean	Dry period				
Return period	50	25	20	10	5	634.5	5	10	20	25	50
Discharge (m^3/s)	2240	2113	1958	1768	1464		242	198	168	160	125

Conclusion:

Because of important environmental aspects in rivers, several methods have been developed to assess environmental flow (EF). Hydrological methods are one the effective one which use the least available data for this purpose. In this paper, three types of flow classification in Karoon River, Ahwaz, Iran were applied to evaluate EF as following: daily, 7-daily mean and 30-daily mean. These three groups were studied in two methods. The first one was based on using index Q95, i.e. probability of exceedance corresponding to 95%. Based on calculations, 7-daily mean classification was suitable for EF in Karoon River. The amount of EF was equaled to 244.36 cms. The second method was based on flow duration curve(FDC) analysis. In this method, the exceedance of probability was calculated for different return periods of three flow types. Using Weibul plotting position formula, exceedance probability vs. flow discharge were plotted for each flow type. Then corresponding value of exeedance probability 95% was extracted from the curves. the closest result to the first method was obtained for daily FDC, i.e. 211.75 cms. But, based on dry-period analysis the result of the first method had good estimation for EF for Karoon River.

REFERENCES

Alaouze, C.M., 1989. Reservoir releases to uses with different reliability requirements. Water Resour. Bull. 25(6): 1163-1168.

Alaouze, C.M., 1991. Transferable water entitlements which satisfy heterogeneous risk preferences. Aus. J. Agric. Econ., 35(2): 197-208.

Arihood, L.D., D.R. Glatfelter, 1991. Method for estimating low flow characteristics of ungauged streams in Indiana. USGS Water Suppl. Pap. No. 2372, 22 pp.

Copestake, P. and A.R. Young, 2006. Hydropower and environmental regulation, a Scottish perspective, Ibis, 148: 169-179.

Estes, C., J.F. Osborn, 1986. Review and analysis of methods for quantifying instream flow requirements. Water Resour. Bull., 22(3): 389-398.

Gordon, N.D., T.A. McMahon, B.L. Finlayson, 1992. Stream Hydrology (An Introduction for Ecologists). Wiley, New York, 526 pp.

Gustard, A., A. Bullock, J.M. Dixon, 1992. Low flow estimation in the United Kingdom. Institute of Hydrology, Report No. 108, 88 pp.

Gustard, A., A. Wesselink, 1993. Impact of land use change on water resources: Balquidder catchments. J. Hydrol., 145: 389-401.

Journal of Applied Science and Agriculture, 8(7) December 2013, Pages: 1132-1139

Hughes, D.A., P. Hannart, 2003. A desktop model used to provide an initial estimate of the ecological in-stream flow requirements of rivers in South Africa. Journal of Hydrology, 270: 167-181.

Hughes, D.A., J.H. O'Keeffe, V.Y. Smakhtin, J. King, 1997. Development of an operating rule model to simulate time series of reservoir releases for instream flow requirements. Water SA, 23(1): 21-30.

Hughes, D.A., V.Y. Smakhtin, 1996. Daily flow time series patching or extension: a spatial interpolation approach based on flow duration curves. Hydrol. Sci. J., 41(6): 851-871.

King, J., C. Brown, H. Sabet, 2003. A scenario-based holistic approach to environmental flow assessments for rivers. River research and applications, 19: 619-639.

Lanen, H.A.J. van, L.M. Tallaksen, L. Kasparek, E.P. Querner, 1997. Hydrological drought analysis in Hupsel basin using different physically based models. In: FRIEND'97- Regional Hydrology: Concepts and Models for Sustainable Water Resource Management, IAHS Publication, 246: 189-196.

Male, J.W., H. Ogawa, 1984. Tradeoffs in water quality management. J. Water Resour. Plan. Manag., ASCE, 110(4): 434-444.

Mallory, S.J.L., R.S. McKenzie, 1993. Water resources modelling of flow diversions. Proceedings of the Sixth South African National Hydrology Symposium, Pietermarietzburg, South Africa, 1: 429-436.

Mazvimavi, D., E. Madamombe, H. Makurira, 2007. Assessment of environmental flow requirements for river basin planning in Zimbabwe. Physics and Chemistry of Earth, 32: 995-1006.

Pitman, W.V., 1993. Simulation of run-of-river schemes using monthly data. Proceedings of the Sixth South African Hydrology Symposium, Pietermarietzburg, South Africa, 1: 445-452.

Searcy, J.C., 1959. Flow duration curves. United States Geological Survey, Washington, DC, Water Supply Paper 1542A.

Smakhtin, V.Y., D.A. Watkins, D.A. Hughes, K. Sami, O.Y. Smakhtina, 1998. Methods of catchment-wide assessment of daily low-flow regimes in South Africa. Water SA, 24(3): 173-185.

Stikker, A., 1998. Water today and tomorrow. Prospects for overcoming scarcity. Futures, 30: 43-62.

Tallaksen, L.M., H.A.J. van Lanen, 2004. Introduction. Hydrological Drought-Processes and Estimation Methods for Stream flow and Groundwater. Developments in Water Science, 48. Amsterdam, Elsevier Science B.V.

Tharme, R.E., 2003. A global perspective on Environmental Flow Assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Application, 19: 397-441.

Vogel, R.M., N.M. Fennessey, 1994. Flow-Duration Curves. New Interpretation and Confidence Intervals. Journal of Water Resources Planning and Management, 120(4): 485-504.

Warnick, C.C., 1984. Hydropower Engineering. Prentice-Hall, Englewood-Cliffs, NJ (pp: 57-73).

Wilby, R., B. Greenfield, C. Glenny, 1994. A coupled synoptic-hydrological model for climate change impact assessment. J. Hydrol., 153: 265-290.