RAINSTORM CHARACTERISTICS IN OMAN AND AUSTRIA

Ghazi Al-Rawas[1], Caterina Valeo[2], Bernhard Kohl[3] and Robert Kirnbauer[4]

ABSTRACT

A prominent engineering problem is the estimation of design floods, necessary for river correction measures, torrent control, reservoirs, urban storm-sewer systems etc. If rainfall runoff models are used for one of these purposes a minimum requirement is to find adequate design precipitation values, temporal rainfall distributions and total rainfall of the design hyetograph. Hydrologists and meteorologists all over the world are confronted with this problem irrespective of different climate zones, special meteorological features and different rainfall characteristics and even – on a smaller scale – regional differences. In this paper some rainfall characteristics for extremely contrasting environments – Oman in the Middle East arid zone (mean annual precipitation 100 mm and less) and Austria in a humid Alpine climate (mean annual precipitation between 300 and 2500 mm) – are compared. Differences and similarities are discussed under the point of view of design precipitation.

Keywords: design precipitation, convective storm, hyetograph, Oman, Austria

INTRODUCTION

Estimation of design floods for river correction measures, torrent control, reservoirs, urban storm-sewer systems etc. is a prominent problem in hydrology. In general, flood formulae can no longer be considered as state of the art, and, thus, rainfall runoff modelling can be used as a relatively modern tool for estimation of design floods. The minimum requirement for the application of such models is a decision on the design precipitation, temporal rainfall distribution and total rainfall. This problem must be analysed carefully, considering regional and local peculiarities of the meteorological behaviour of the rainfall process, otherwise the GIG-principle („garbage in, garbage out“, Beven, 2001) comes into effect.

Consequently, since early times (e.g. Keifer & Chu, 1957) many studies on design precipitation were performed. Mainly, these design hyetographs were derived for designing urban storm-sewer systems. Considerations on design precipitation for urban or rural catchments are presented by many studies in the literature (e.g. Kirnbauer, 1977; Prodanovic & Simonovic, 2004; Kleidorfer, 2005; Al-Rawas & Valeo, 2009; Kohl, 2011) and others. The philosophy standing behind the assumption of such synthetic hyetographs is to maximise the load on the construction to be designed. However, the main disadvantage of this approach is the fact that the occurrence probability of any of these synthetic hyetographs is nearly zero and that the meteorological and climatic situation of the region where it is applied are not considered, except the hyetograph was developed for this specific region and the specific storm duration (see e.g. Kanton Aargau, 2009). Usually, the longer the duration of the design event which is chosen corresponding to the response time of the catchment, the greater are the difficulties with choosing the adequate time distribution of the design precipitation. In this case, an alternative to using design precipitation hyetographs, a stochastic precipitation model, could be considered. Such a model is presented by Viglione et al. (2011). The precipitation model is calibrated

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with local precipitation data of high time resolution and reproduces the extreme behaviour of rainfall quite well, as can be seen from a comparison with envelope curves. The model has proved of value for the simulation of design floods for torrents in Tyrol/Austria (Rogger et al., 2011).
In this paper we compare rainfall characteristics in two regions of the world, where climate and meteorological situations are extremely different, and we discuss the consequences for the simulation of design floods by rainfall-runoff models.

STUDY AREA OMAN

Oman is one of several countries located in an arid zone that is subject to flash flooding. Records show that major flash floods occurred in Oman in 1989, 1997, 2002, 2003, 2005, and 2007. Few flash flood studies in the literature have focused on the issue of flash flooding in an arid environment. Thus, this process affecting Wadis like in Oman, is poorly understood. Generally, mean annual precipitation is very low in Oman. In the coastal area of northern Oman it is 100 mm and less, and in the mountainous area it is around 350 mm. There are four principal mechanisms that cause rainfall in Oman: a) convective rain storms which can develop any time of the year but mostly during the summer months (May to October), b) cold frontal troughs, which are common during the winter and early spring (November to April), c) On-shore monsoon currents which frequently occur from June to September and bring a complex regional circulation that usually results in frequent drizzle along Dhofar, the southern part of Oman, near Yemen, and d) Tropical cyclones which move in from the Arabian Sea and occur on average about once in five years in Dhofar and once in ten years in Muscat (Al-Rawas & Valeo, 2009).
In the sequel, a more detailed study will concentrate on the area of the Rustaq watershed (Fig. 1).

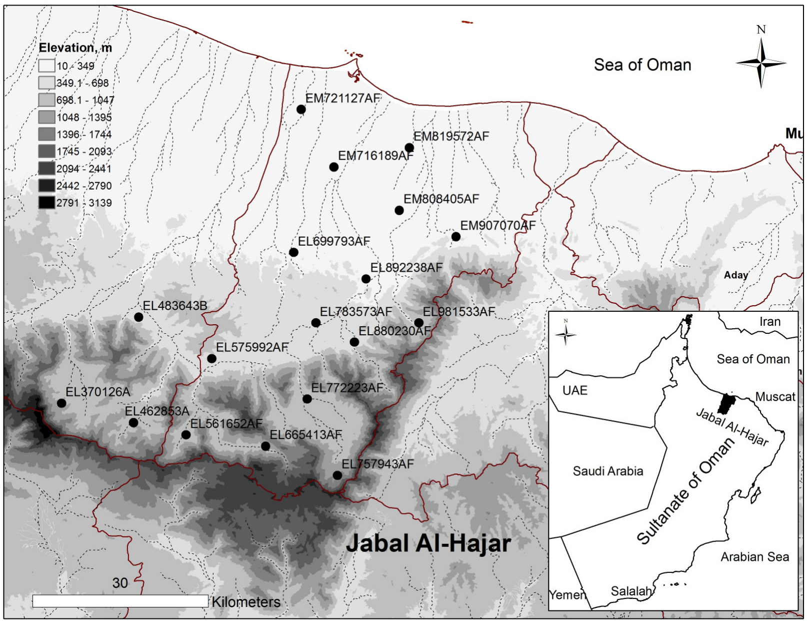

Fig. 1 Digital elevation map of Rustaq watershed with rain gauges.

The Rustaq watershed (2720 km²) is situated in northern Oman and it is characterised by two different types of landscape. The first is the coastal region, a rather smooth plane between the foot slope of the mountains and the Sea of Oman. The second, the Jabal Al-Hajar mountain range, reaches elevations from 350 m a.s.l. up to more than 3.000 m a.s.l., it generally consists of bare rock with just small areas of agricultural land in the Wadis and a few artificial terraces. In this part of the catchment precipitation reaches 350 mm per year (except in years when a Tropical cyclone hits the mountain range). Due to the greater and more frequent precipitation more rain gauges are situated in this region. Including the three stations in neighbouring catchments, data from eighteen rain gauges were used in this study.

In the coastal area the station density is not as high as in the mountainous area. Probably, when designing the observation network the smaller number of rainfall events was accounted for, because convective storms tend to be more frequent near the mountain side. During the observation period 1983-2003 411 storms in the coastal area and 1631 storms in the mountainous region were recorded at the rain gauges (Al-Rawas & Valeo, 2009). Average precipitation in the total Rustaq catchment is around 100 mm per year, with a clear seasonality and high correlation coefficient of R^2=0.83 between mean and maximum values (see Fig. 2).

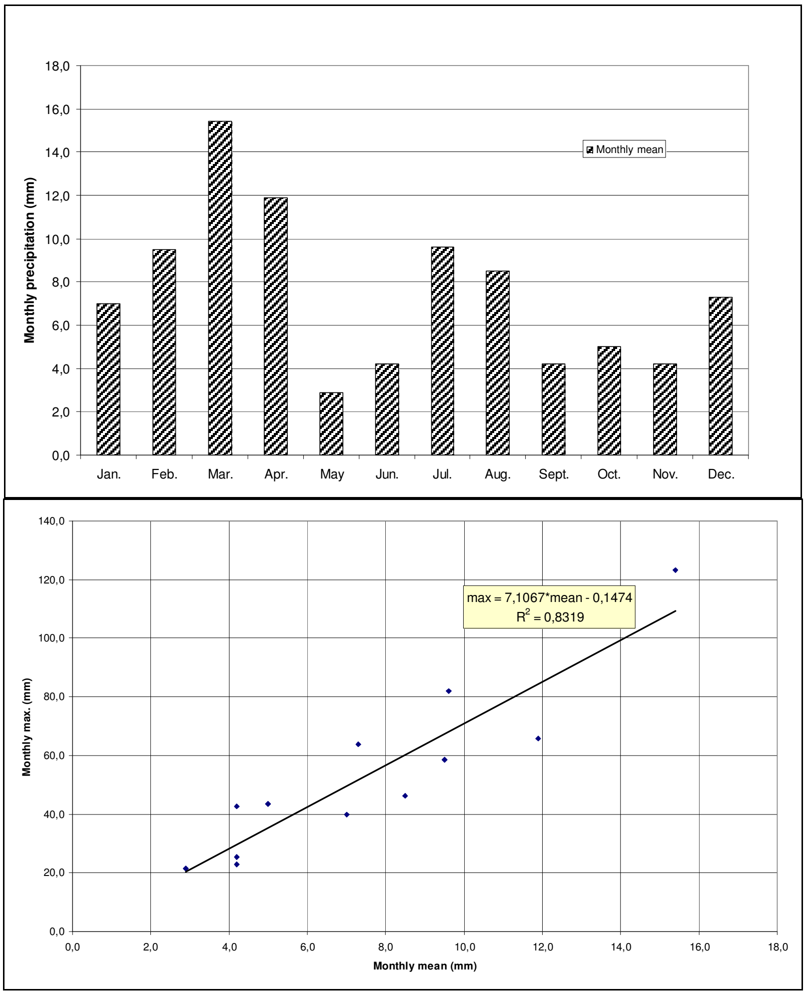

Fig. 2 Top: Mean monthly precipitation in the Rustaq catchment (1983-2003). Bottom: correlation between mean and maximum.

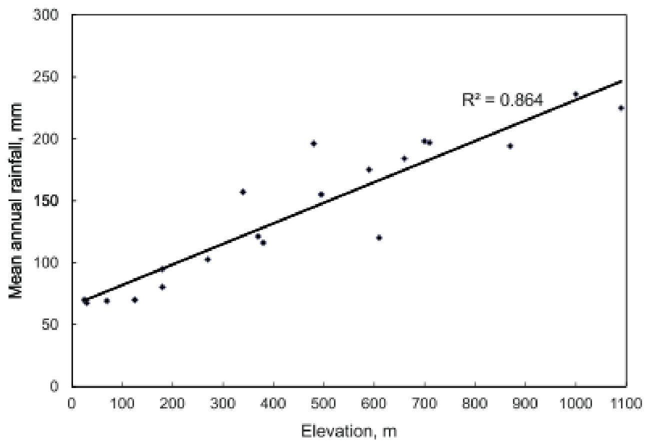

Fig. 3 Orographic effect on mean annual rainfall in Oman (from Al-Rawas & Valeo, 2009)

The high spatial and temporal variability of rainfall in Oman makes it difficult to analyse the influence of topography on precipitation on the basis of high resolution data over short observation periods. However, based on annual sums of precipitation, Fig. 3 shows a good correlation between mean annual rainfall and elevation (Al-Rawas & Valeo, 2009) as it is known from many regions of the world.

The mentioned data base 1983-2003 with 411 storms in the coastal and 1631 in the mountainous area was analysed with respect to the temporal distribution of precipitation during the storm. "The rainfall for each storm is expressed as a cumulative percentage of the total rainfall of the storm. The percentages are used to calculate separate temporal distributions for percentiles ranging from the 10th percentile to the 90th percentile in increments of 10 from the total number of storms for a specified duration. The different hyetographs permit the selection of a temporal distribution that is most appropriate for a particular application. In some cases the 50th percentile distribution will be the most useful and in other cases more extreme distributions may be desirable." (Al-Rawas & Valeo, 2009).

Some results of this procedure are presented in Fig. 4 for 6 hour storms in the coastal and mountainous regions of the Rustaq watershed in Oman respectively. In 50% of the storm events after 1.5 hours of rain, in the coastal region 80% of the total event precipitation has fallen, in the mountainous region 85%. This difference does not seem so big. However, for three hours rain duration and for the smaller events (90% percentile) the difference becomes greater (75% near the coast, 82% in the mountains). This result mirrors the great variability of the precipitation process in this arid region.

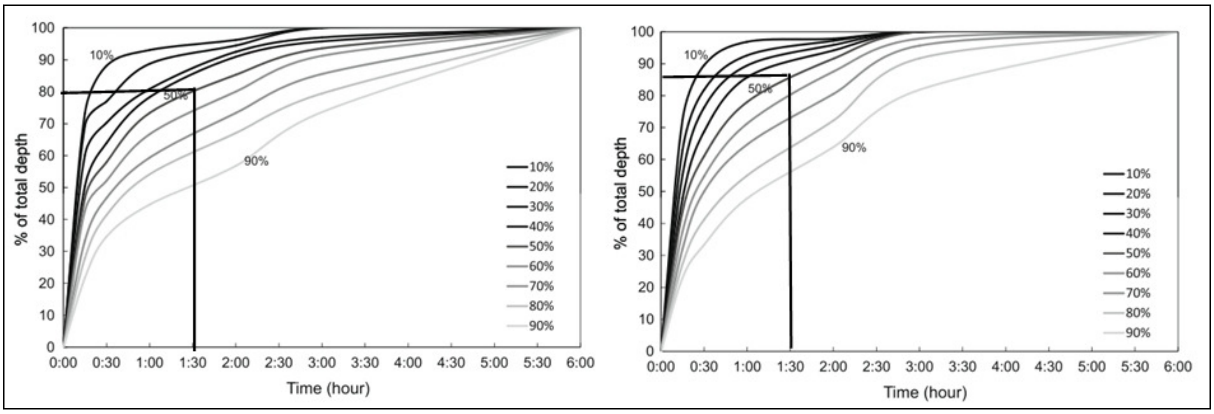

Fig. 4 Different long time behaviour coast region (left) and mountain region (right) for different probabilities (From Al-Rawas & Valeo, 2009, modified)

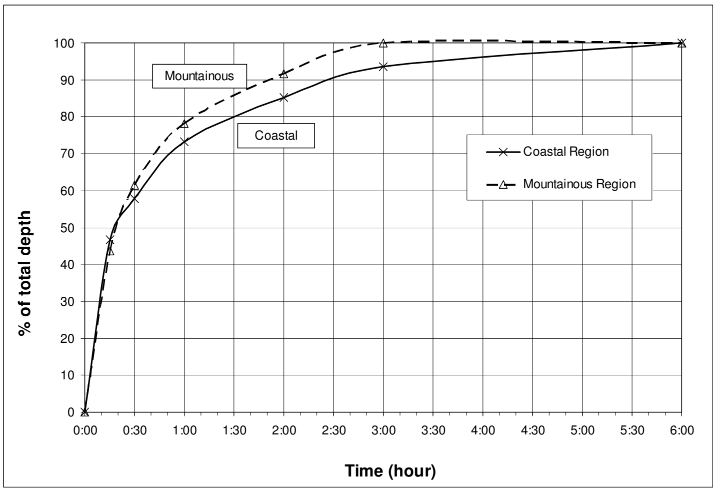

Fig. 5 Hyetographs of median (50%) events in mountainous and coastal region of Rustaq watershed

The 50% lines are jointly drawn in Fig. 5, and one can see that for this “median” event type during the first twenty minutes the precipitation intensity is virtually equal in both areas. The highest rain intensity occurs in the beginning of the event, irrespective of the region. This is typical of convective thunderstorms, mostly observed in this arid climate.

As can be seen from Fig. 6 (left) it is worthwhile to look at the short time behaviour of precipitation in the mountain area in more detail and to have a look at the amount of rain in this region.

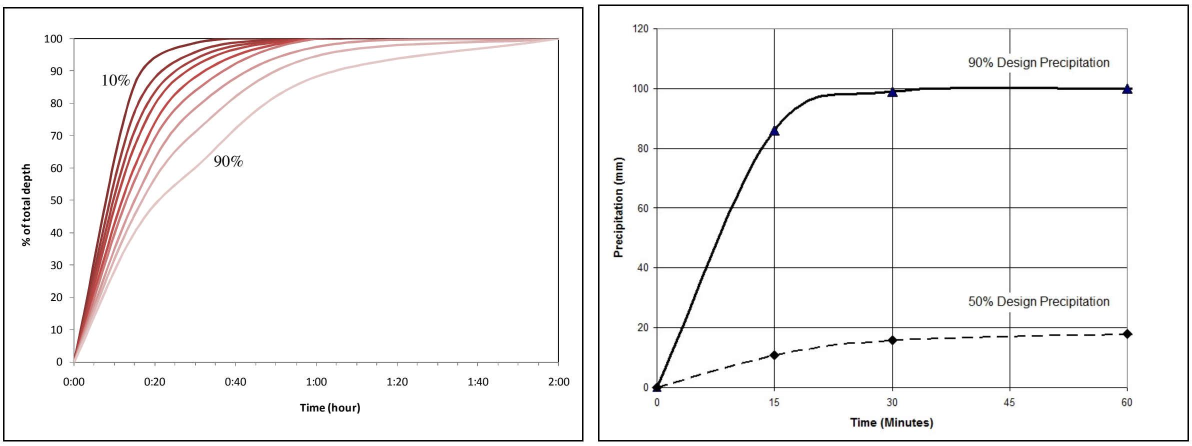

Fig. 6 Mountainous 2 hr probability curves of time distribution and total amount of rainfall

From 610 storms with less or equal duration of 2 hours in Rustaq catchment those with an exceedance probability of just 10% deliver 86% or more of the total rainfall within the first 15 minutes (Fig. 6 left), and Fig. 6 right shows that within these 15 minutes in 90 % of all cases precipitation reaches 86 mm. In 50 % it is less than 11 mm (Fig. 6 right; broken line). In general, these curves display a very high intensity at the beginning of the storms, which is known to be a characteristic of storms in arid regions (see Al-Rawas & Valeo, 2009).

STUDY AREA AUSTRIA

The long time behaviour of the precipitation regime in Austria is similar to that in Oman: On the basis of yearly sums of precipitation seasonal and orographic effects can be observed in Austria too. An outstanding feature of the hydrological situation in Austria is the great difference in precipitation between the western and the eastern part of the country. Monthly values of precipitation for the arbitrarily chosen year 2008 in these two regions of Austria are compared in Fig. 7. The long-time (1961-1990) average value in the wet region (Bregenzer Wald, Vorarlberg) is approximately 2020 mm/year, in the dry region (Weinviertel, Niederösterreich) 460 mm/year. Data bases for the wet and the dry region in this figure were the stations with the respective two greatest and two smallest long-time average values of precipitation: Fontanella and Ebnit for the wet and Retz and Mailberg for the dry region.

Generally the meteorological regime in Austria is not as stable in Oman. Due to varying directions of rain fronts, rain or snowfall can occur nearly any time of the year, and the types of precipitation events are variable: Mostly, rain or snowfall is brought by frontal currents, most of them originating over the Atlantic Ocean and approaching Austria from North-West or West. In fewer cases heavy precipitation is generated by low pressure systems in the Mediterranean Sea, near Geneva, which steer their fronts from South or South-East to the Alps. Especially during summer convective storms are incorporated in such frontal systems, but often convective storms develop spontaneously as a joint consequence of high temperatures, sunshine, wet air and saturated ground. How such convective storms are generated, especially over rugged terrain is not very well understood and the object of international research (see Quarterly Journal of the Royal Meteorological Society, 137, special issue on the Convective and Orographically-induced Precipitation Study (COPS)).

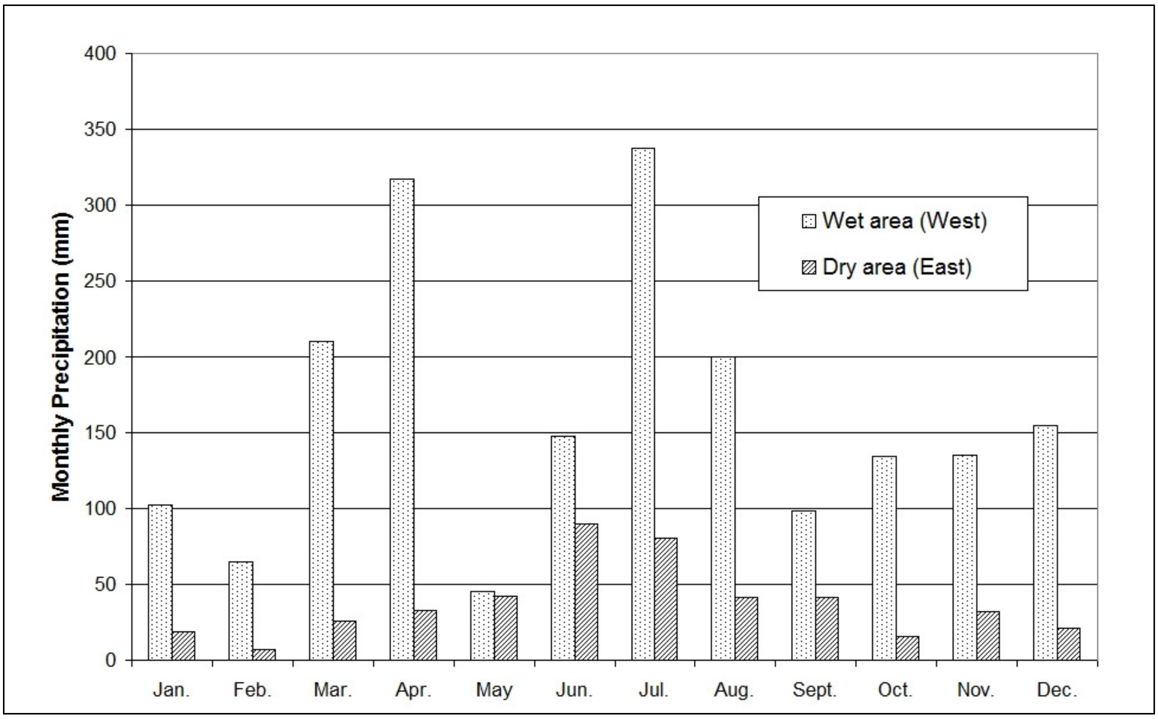

Fig. 7 Comparison of monthly precipitation sums for a wet and a dry region in Austria for 2008

On a smaller scale Pistotnik (2008, 2010) analysed convective storms for a region of around 1500 km² in Lower Austria, the so-called Bucklige Welt ("camel-backed world") where convective storms are very frequent and often cause great damage in torrent catchments. The data base for this research was provided by the results of the INCA-analyses (INCA = "Integrated Nowcasting through Comprehensive Analysis"): precipitation values on a 1x1 km grid with a temporal resolution of 15 minutes for the years 2003 to 2007. By a semi-automatic identification procedure 245 convection-days and a total number of almost 1.600 storms were identified and analysed. From these storms the characteristic parameters were derived, including the number of storms per day, their place and time of initiation, their motion, lifetime, maximum intensity and maximum "cell volume" (i.e. overall precipitation per time step). One result of this analysis is shown in Fig. 8, a statistic of the size of the cells.

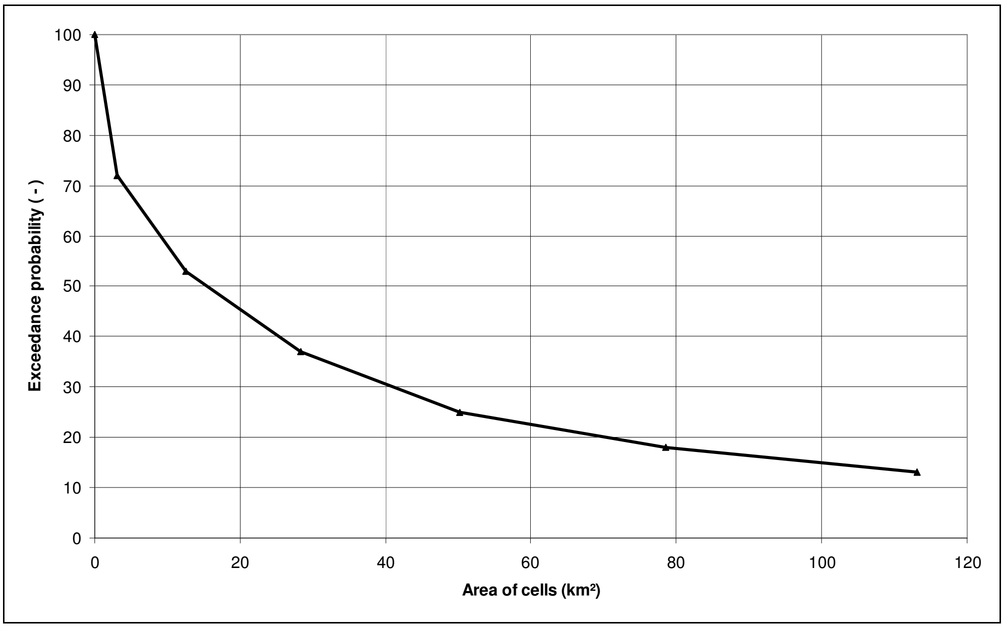

Fig. 8 Cell size of convective storms in Lower Austria (after Pistotnik, 2008)

As a consequence of the above mentioned variability of precipitation sources, frontal from NW or W, from S or SE, merged frontal and convective or mere convective, it is virtually impossible to declare a single precipitation event hyetograph as typical for Austria. For design purposes three different probability curves of total precipitation and for event durations from five minutes to six days and return periods from two to one hundred years were derived, based on three different data bases. These design values are announced via Internet by the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW). The data bases for these three design precipitation probabilities are MaxMod, which is based on a simulation model calibrated with measured data and accounting for the topography. MaxMod gives precipitation values that are usually higher than those observed. The second data base is ÖKOSTRA, which is based on measured data alone. DesignPrecip is a combination of the before-mentioned approaches. MaxMod, ÖKOSTRA and DesignPrecip results are interpolated on a 6x6 km grid. Fig. 9 gives an example of the DesignPrecip data for 15 minutes and one hour respectively for the total area of Austria (from Blöschl, 2010).

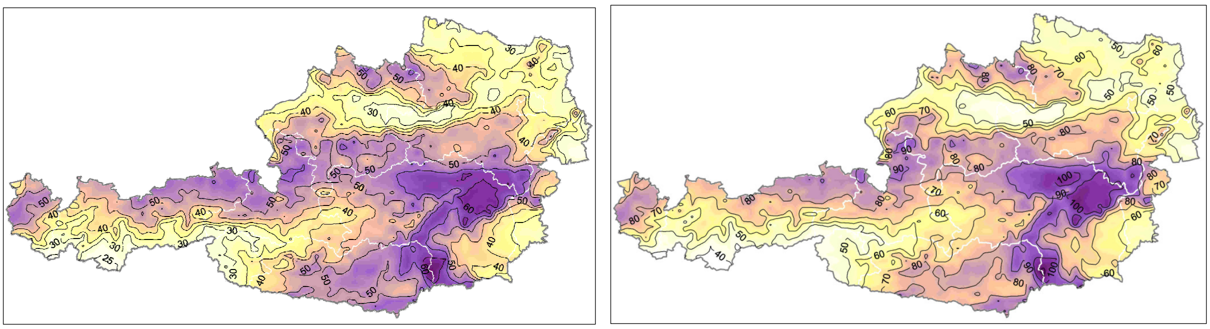

Fig. 9 Design precipitation for Austrian catchments following the assumptions DesignPrecip for 15 minutes (left) and 1 hour duration (right); Iso-lines are in mm. (from Blöschl, 2010)

These design precipitation data for different durations and return periods do not contain information on the design hyetographs (which is important for durations greater than 20 to 30 minutes) nor do they contain information on the areal distribution of the design event (which is important for catchments greater than 15 to 25 km²). And, unfortunately, these problems are not finally solved. The adequate time distribution of the design event as well as its areal distribution depends on the catchment characteristics and on the algorithms how the rainfall runoff model tries to reproduce them. Generally, the smaller the catchment and the quicker its reaction to rainfall, the shorter the design precipitation must be chosen. If the catchment shows delayed reaction to precipitation due to seepage and storage in the soils, and the model is capable of reproducing this behaviour in a process oriented way, then the time distribution of the design hyetograph is important. For such a catchment and a hyetograph with a delayed maximum intensity is adequate in order to fill up the soil retention storage until the high intensity rain begins. In this case a set of simulation runs must be calculated in order to find the maximum flood. Three possible assumptions for such hyetographs are shown in Fig. 10. However, the return period of this maximum flood is not clearly defined irrespective of the return period of the design precipitation.

Another problem that is not finally solved is the areal reduction of the design precipitation over a greater catchment. This can be seen from the many assumptions following different authors jointly plotted in Fig. 11 (Kohl, 2011). Point values of the design precipitation must be multiplied with the areal reduction factor (ARF) in order to estimate a uniform precipitation over a catchment. Factors influencing this ARF are defined differently by different authors (see Kohl, 2011). A consensus opinion can be found by analysing all these publications: ARF depends on catchment size, total precipitation and duration of the event. The dependence on the return period of the design event is discussed controversially.

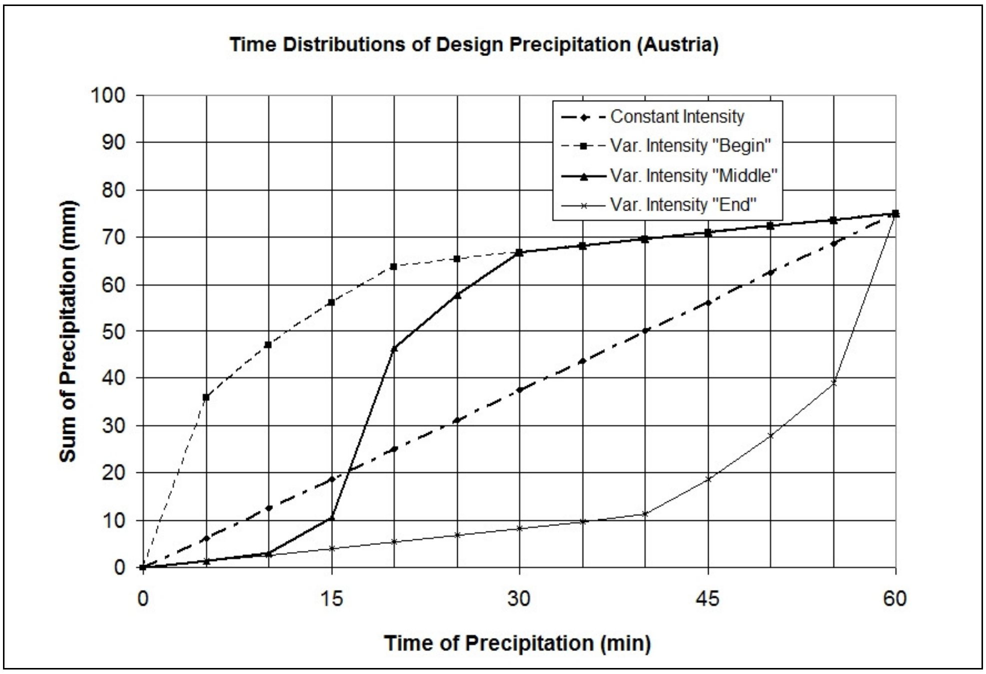

Fig. 10 Possible time distributions of synthetic hyetographs (from Kirnbauer, 2000, modified)

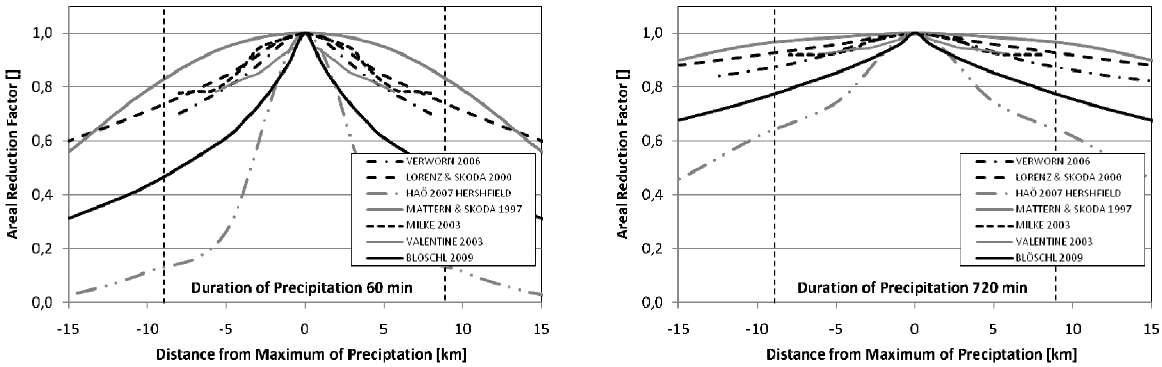

Fig. 11 Areal reduction of design storms following different authors (from Kohl, 2011, modified)

For Austria, Kohl (2011) compared the size of convective cells (according to Pistotnik, 2008) with that of Austrian torrents and found out that 50% of the convective cells are greater than 97% of the torrents. Thus, it seems reasonable to assume uniform precipitation over torrent catchments smaller than 20 km² (see Kohl, 2011; Fig. 8). Anyway, the strongest influencing factor on the result of the design flood estimation is the type of the design precipitation MaxMod, ÖKOSTRA or DesignPrecip. For greater catchments Kohl (2011) gives recommendations for the choice of design precipitation and areal reduction factor.

CONCLUSIONS

When comparing rainfall characteristics in Oman and Austria it becomes clear that the short time behaviour of precipitation in these countries with extremely contrasting climate is not very different for extreme events of duration up to approx. 20 minutes (but higher intensity earlier in the storm in the Oman curves than in the Austria) (see Fig. 12). This is due to the fact that short duration events in both countries are caused by convective storms of high intensity but rather small areal extent and short lifetime.

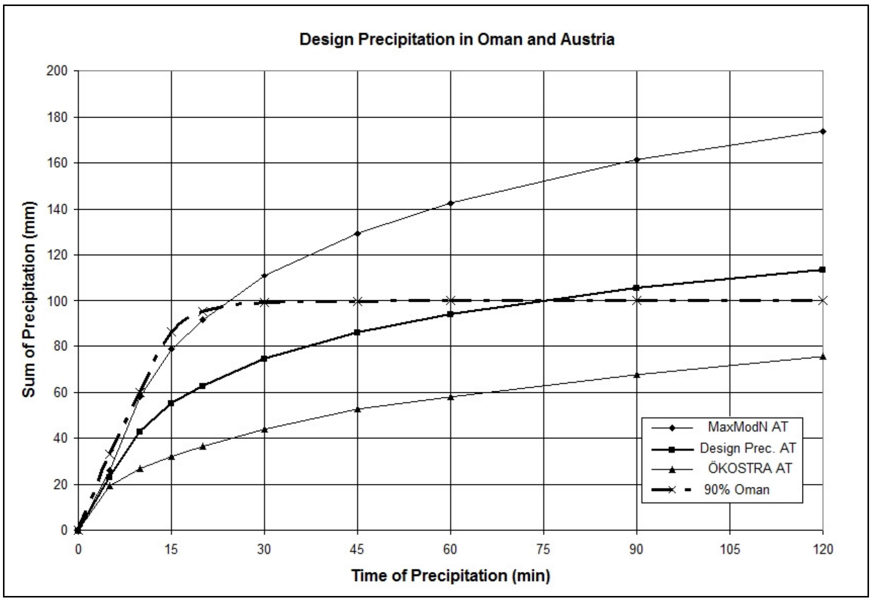

Fig. 12 Design storms in Oman and in Austria: Extreme events show high initial intensity in both countries.

Thus, for flood design purposes for quickly responding catchments, e.g. torrents or urban catchments, it seems reasonable to use design precipitation of constant rain intensity up to duration of about half an hour both in Oman and Austria. In any case, the longer the duration of the design event which is chosen corresponding to the response time of the catchment, the greater are the difficulties with choosing the adequate time distribution of the design precipitation. Climatic and meteorological differences are reflected in the precipitation regime. Rainfall runoff simulations with a great number of time distributions and areal reduction factors of the design precipitation will be necessary, and the resulting design floods have to be checked for plausibility against observed data. In this case, an alternative to using design precipitation hyetographs, necessarily derived for each region from real world data, a stochastic precipitation model could be considered. Such a model is presented by Viglione et al. (2011). The precipitation model is calibrated with local precipitation data of high time resolution and reproduces the extreme behaviour of rainfall quite well, as can be seen from a comparison with envelope curves. The model has proved of value for the simulation of design floods for torrents in Tyrol/Austria (Rogger et al., 2011).

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