ICIWRM – 2000, Proceedings of International Conference on Integrated Water Resources Management for Sustainable Development, 19 – 21 December, 2000, New Delhi, India

Some hydrological characteristics of the Australian arid zone

IAN CORDERY and JAMES FRASER
School of Civil and Environmental Engineering, The University of New South Wales, Sydney 2052, Australia.

Abstract
Analysis of Data collected over a 30 year period from a 400 km^2 arid zone research station in Australia show that the rainfall in this arid zone tends to be spatially uniform. Very few convective storms occur. The prevailing storm types reported for most other arid zones are typically of a convective nature. Correlations between rainfall at stations up to 25 km appart are much higher than any others reported for arid zones. Transmission losses were also investigated and it was shown that they were closely related to the volume of void spaces in the stream alluvium. This suggests that to arid zone transmission losses data on the alluvium characteristics of the stream beds will need to be obtained.

INTRODUCTION

Transport routes in and across the arid zone of Australia are becoming more important as mining and tourism increases. Surface transport is increasing, in parts of the arid zone, at a much greater rate than for the country in general. As a result roads and railways are being upgraded, and in some areas, newly developed, to meet the expectations of users for rapid, uninhibited movement. A major cost for surface transport infrastructure is the crossing of waterways. In humid regions waterway crossings are encountered every 300-700 m, but in the arid zone they occur less frequently and the waterways are usually smaller. However the wash-away of a small diameter culvert, or a pond of water over a road or right-of-way can stop surface transport just as effectively as the collapse of a bridge over a large river.

The increased demands for reliable transport routes has led to demands for improved hydrological design of waterway crossings. One of the major difficulties for designers is the small amount of hydrological monitoring that has been undertaken in the vast Australian arid zone. This was increasing in the 1970s but by the mid 1980s it began to decline as public interest decreased. Monitoring in the arid zone is generally more expensive than in the humid zone because arid zone sites are almost always remote from the home base of installation and maintenance teams. Low levels of monitoring and lack of interest in analysis of the data has meant that little real hydrological information is available about the Australian arid zone. Hydrological characteristics of the Australian arid zone are not mentioned in any text-books. The only discussion of arid zone hydrology to be found in text-books is based on experience from the south-west of the United States with passing reference to experiences in the Middle East. There is a great need for the small amount of data that has been collected in Australia to be analysed and the hydrological characteristics of the Australian arid zone to be widely publicised.

Some of the data collected at the University of New South Wales Arid Zone Research Station at Fowlers Gap, 100 km north of Broken Hill, has been analysed recently and the findings are reported here. These findings have to do with the temporal and spatial characteristics of precipitation in this part of the arid zone and with the transmission losses that occur from arid zone streams.

DATA AVAILABILITY

Streamflow and rainfall data has been collected over an area of 400 km^2 at Fowlers Gap in western NSW (Figure 1) for various periods between 1967 and 1999. The region is flat and featureless over its eastern half with slopes typically less than 0.5%. The western half includes extensions of the Barrier Range, an eroded series of folds which, in the study area provide elevation differences of up to 150 m and surface slopes of 5-10%. The only near-continuous record data from 1967 to 1999 is of daily rainfall observations at the meteorological station. Two streamflow recorders operated by the NSW Dept. of Land and Water Conservation have almost continuous water level records from 1972 to the present. A number of recording raingauges and small-plot runoff recorders together with water level recorders on 4 reservoirs fed by basins of between 4 and 20 km^2 were operated continuously from 1976 until 1988. Eighteen monthly read storage raingauges were installed in or after 1981 and continue to operate.

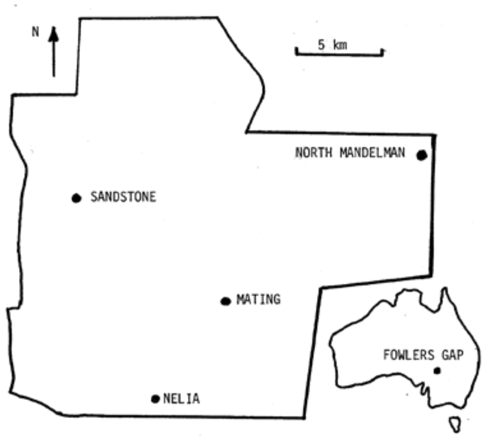

Figure 1. Fowlers Gap Research Station, showing location of recording raingauges.

CHARACTERISTICS OF ARID ZONE RAINFALL

Most text-book pronouncements indicate that the bulk of arid zone rainfall results from convective storms. Studies of arid zone rainfall from Arizona, (Osborne et al, 1979), Tanzania (Sharon 1974) Namibia (Sharon 1981), Jordan (Sharon 1979) and Saudi Arabia (Wheater et al, 1991) showed that spatial non-uniformity of the rainfall was large and suggested this was because the dominant storm mechanism in these regions was convection. Slatyer and Mabbutt (1964) were probably the first to suggest that Australian arid zone rainfall was different from the rainfall of most other arid zones in that it was not usually produced by convection. However they did not have data to demonstrate the spatial uniformity of rainfall that actually reached the land surface. More recently Cordery et al (1983) showed that over a period of 7 years in which surface runoff occurred on about 50 occasions, there were very few occasions when runoff was not observed at all 15 monitoring stations in the 400 km^2 Fowlers Gap arid zone region. This led to the conclusion that although convective storms do occur in the region they occur infrequently and usually produce very little rainfall.

Since the report of Cordery et al further monitoring has occurred and the spatial distribution of rainfall in this arid zone has been analysed at annual, monthly and event time scales and the results of this analysis will now be reported.

Spatial Uniformity of Annual Rainfall

In the 400 km^2 research station at Fowlers Gap there were 18 monthly read rain gauges, approximately uniformly distributed over the area. 15 years of annual data (1982-1996) were available for these 18 stations. Mean annual rainfall during this time over the 18 stations varied from 180 to 240 mm. To examine the spatial uniformity of the rainfall simple linear regressions were determined between the annual rainfalls for all locations (153 variable pairs). The lowest correlation coefficient was observed between the stations at the northern and southern extremities of the Barrier Range area of relief, with r = 0.76. Between most of the stations (126 or 82% of the pairings) the correlation coefficients were greater than 0.90, even for stations 25 km apart. From these results it can be seen that the long term rainfall is almost uniform over the 400 km^2 area, but that it is similarly uniform from year to year. As would be expected the stations for which the correlation coefficients are lowest are those located in the hilly region.

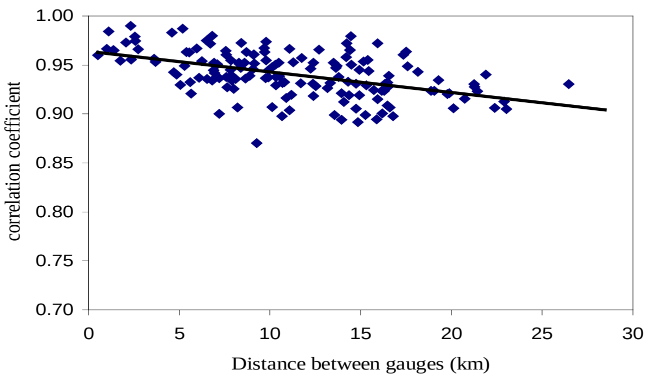

Figure 2. Correlations between monthly rainfalls for all possible combinations of the 18 gauges.

Spatial Uniformity of Monthly Rainfall

As for annual rainfalls, simple linear correlation coefficients for monthly data were calculated for all combinations of pairs of rainfall stations. In this case the number of data pairs for each correlation was large (180 for 15 years data). The correlation coefficients were higher for monthly data than for annual data, as shown in Figure 2. Of the 153 regressions only 8 had correlation coefficients below 0.90 and the lowest was 0.87.

Spatial Uniformity of Storm Rainfall

Storm rainfalls were extracted from recording raingauge charts for 4 stations for all events which produced more than 5 mm of rainfall at one or more of the gauges during the years 1980 – 1986 inclusive. The gauges were named Sandstone 1, Nelia 1, Mating and North Mandelman and their locations are shown on Figure 1. Distances between these gauges are shown in Table 1. In the 7 years there were 83 events with more than 5 mm of rain at one of the gauges. In 3 of these events the recording equipment failed at one or more of the stations. Rainfall depths in events ranged up to 92 mm and storm durations ranged from 15 minutes up to 31 hours. 51% of the storms had durations of 6 hours or less, 8% had durations of one hour or less and only 18% had durations greater than 12 hours. The durations of the rainfall at all four stations were very similar. In more than 90% of events the actual duration at all four stations were within one hour of each other. In only 34 of the 77 events was the difference between the rainfall depths more than 50% of the highest observation. Only 10 of these events could be considered to be convective storms. The maximum rainfall depth in these convective events was 19 mm but at most stations in the majority of these storms the observed rainfall depth was less than 5 mm. Regressions between all the observations at the four stations produced the correlation coefficients shown in Table 1. These correlation coefficients are very high, compared to the values for daily data given by Osborne et al (1979) and Sharon (1979). For southwest USA Osborne found that over a distance of 10 km correlation coefficient values were typically in the range 0.2 to 0.4. Sharon (1974) found similar low values for Tanzania and for summer thunderstorms in Ohio. The values for Fowlers Gap in arid western NSW are similar to values reported by Sharon (1979) for humid temperate regions and for the Jordan Valley.

Table 1. Correlations between storm rainfalls at Fowlers Gap 1980-1986.

Stations	Distance between stations (km)	Correlation coefficient	Number of events in correlation
Nelia 1 and Sandstone 1	13.5	0.79	81
Nelia 1 and North Mandelman	18	0.74	80
Nelia 1 and Mating	6.5	0.72	81
Sandstone 1 and North Mandelman	20	0.84	82
Sandstone 1 and Mating	14.5	0.85	76
North Mandelman and Mating	11.5	0.82	83

TRANSMISSION LOSSES

It has continually been observed that transmission losses are very large in arid zone streams. Typically it has been shown that within an arid region, runoff depths decrease dramatically as basin size increases (Cordery et al 1983), partly due to the small spatial size of convective storms and partly due to transmission losses. However efforts to model or predict these losses have generally been unsuccessful. It appears that local geomorphology and soil characteristics are totally dominant in determining the magnitude of the losses. Attempts to relate transmission losses to easily observed basin characteristics such as stream length or basin size have proved fruitless.

Description of Study

In an attempt to understand the nature of transmission losses better Telvari (1995) and Telvari et al (1998) reported a study in which the characteristics of the alluvial deposits in the valleys of a small basin were examined. The study was undertaken in the 4 km^2 Nelia Dam basin at Fowlers Gap. The major field activity of the study was to cut trenches across the valley bottoms at 65 locations within the basin. At each cross-section the physical characteristics were carefully examined.

The 65 cross sections were located at approximately equal intervals of between 100 and 200 m along all the channels in the 4 km^2 basin. Each cross-section was carefully mapped to delineate the surface and the boundary between alluvium and underlying local strata. The bulk density, particle density and hence the porosity of all alluvial materials was determined. The underlying stratum comprised clay-loams and weathered Devonian and Pre-Cambrian rocks.

Channel transmission losses were determined by observing overland flow volumes at three locations on the basin surface and the volume of flow into a storage reservoir at the outlet of the basin. Data for 51 runoff events in the period 1976-1988 were examined. Effectively the data examined were for all runoff events for which data were complete in the 13 year period of record.

Transmission Losses and Local Alluvium

Telvari et al (1998) reported that transmission loss appeared to vary erratically from event to event. However careful examination of the data showed that in all events the first 7000 m^3 of overland runoff was absorbed into the stream beds. Of any further overland flow during a runoff event, approximately two thirds reached the basin outlet and one third became transmission loss.

It was shown that the volume of void space in the alluvium up to a level of low flow, just above the stream bed, was very close to the 7000 m^3 that was lost in each runoff event. Hence it was concluded that the threshold transmission loss was determined by the void space in the bed alluvium up to the level of initiation of flow in the stream channels. The one third of subsequent overland flow runoff that became transmission loss was related to the volume of voids in the alluvium above the stream bed and to the rate of flow of water from the alluvium into the underlying strata. The total volume of void spaces in the alluvium of the streams was 23,000 m^3, or almost 6 mm of surface runoff, and it was postulated that when this space was filled the rate of transmission loss would decrease. Six of the observed runoff events had overland flow volumes greater than 23,000 m^3 but the data were insufficient to support this postulate.

Estimation of Transmission Losses

The work reported above suggests that it will only be possible to predict transmission losses in arid zone streams when it is possible to estimate the characteristics of the stream bed alluvium. At present the only techniques available involve time consuming field observations. It may be possible that in future aerially mounted radar or other electromagnetic sensing may be able to determine volumes of alluvium, but field work may still be needed to determine porosity and hence the volume of voids.

CONCLUSION

It has been shown here that Australian arid zone rainfall is different from the rainfall of other arid zones for which data have been analysed. Few storms with significant amounts of rain are produced by convective cells in the Australian arid zone. As a result Australian arid zone rainfall is spatially relatively uniform.

Modelling of arid zone stream transmission losses is unlikely to be successful until techniques become available for estimation of the characteristics of stream valley alluvium. It was shown here that stream transmission losses were closely related to the characteristics of the alluvium surrounding the stream bed. At present estimation of alluvium characteristics is so labour intensive that it does not offer a practical solution for estimation of transmission losses.

References

Cordery, I., Pilgrim, D.H. and Doran, D.G. (1983) Some hydrological characteristics of arid western New South Wales. Hydrol. & Water Res. Symp., Inst. Engrs. Aust., Nat. Conf. Publ. 83/13:287-297.

Osborne, H.B., Renard, K.G. and Simanton, J.R. (1979) Dense networks to measure convective rainfalls in southwest United States. Water Resources Res., 15:1701-1711.

Sharon, D. (1974) The spatial pattern of convective rainfall in Sukumaland, Tanzania – a statistical analysis. Arch. Met. Geoph. Biokl. Ser. 13, 22:201-218.

Sharon, D. (1979) Correlation analysis of the Jordan Valley rainfall field. Mon. Wea. Rev., 107:1042-1047.

Sharon, D. (1981) The distribution in space of local rainfall in the Namib desert. J. Climate, 1:169-76.

Slatyer, R.O. and Mabbutt, J.A. (1964) Hydrology of arid and semi arid regions. In Chow, V.T. (ed), Handbook of Applied Hydrology, 24-9, McGraw-Hill, New York.

Telvari, A. (1995) Rainfall runoff modelling in an arid zone small catchment. PhD Thesis, The University of New South Wales, Australia.

Telvari, A., Cordery, I. and Pilgrim, D.H. (1998) Relations between transmission losses and bed alluvium in an Australian arid zone stream. In: Wheater, H.S. and Kirby, C. (eds), Hydrology in a Changing Environment, British Hydrological Society, Vol. 2, 361-366.

Wheater, H.S., Butler, A.P., Stewart, E.J. and Hamilton, G.S. (1991) A multivariate spatial-temporal model of rainfall in Southwest Saudi Arabia. J. Hydrology, 125:175-199.