Flow Estimation for Flood Management
Understanding the Uncertainty.

Christopher Wright
Engineering Hydrologist - Bureau of Meteorology
25 College Road,
Kent Town SA 5071
AUSTRALIA
E-mail: c.wright@bom.gov.au

Dr David Kemp
Senior Stormwater Engineer
Dept for Transport Energy and Infrastructure
PO Box 1, Walkerville SA 5081
AUSTRALIA
E-mail: david.kemp@saugov.sa.gov.au

Abstract

Australian Rainfall and Runoff provides the standard for flood prediction and the engineering design of structures and channels that carry stormwater. However in the minds of our planners and managers there is a perception that hydrology is a precise science, compared with structural engineering, which can provide design solutions within a few percent accuracy, based on known material properties. By contrast, in hydrology and stormwater design, the common requirement to estimate the 100-Year ARI flood seldom takes account of the uncertainty in estimation. Often such estimates are required with little or no data on which to rely, and even where there is some data and history, the error bounds in estimating the flood are very wide. The paper explores uncertainty in flood estimation in South Australia, with examples showing the causes of uncertainty and the implications on cost of infrastructure and flood damage. A strong case is made for strengthening and expanding the hydrographic network for collecting and archiving flood data as a means of reducing uncertainty, as well as reviewing any management strategy with regards to sensitivity to the uncertainty.

BACKGROUND

Australian Rainfall and Runoff [Pilgrim, 1987] provides the standard for flood prediction and the engineering design of structures and channels that carry stormwater. However in the minds of our planners and managers there may be a perception that hydrology is a precise science, comparable with structural engineering, (which can provide design solutions based on known material properties.)

By contrast, in hydrology and stormwater design, the common requirement to estimate the 100-Year ARI flood seldom takes account of the uncertainty in estimation. Often such estimates are required with little or no data on which to rely, and even where there is some data and history, the error bounds in estimating a flood can be very wide.

A common task for engineers is to estimate the peak flow rate at a location on a river, and to provide this information in terms of risk. Typically, what is required is the 100-Year Average Recurrence Interval (ARI) peak flow rate. In its simplest form this is what an observer, standing on the bank of the river would see, over a long period of time. The 100-Year flood would occur or be exceeded about 10 times in a 1,000year period. In some situations, typically parts of Europe and in China, there may actually be 1,000 years of more of record. For these it is possible to estimate the 100-Year peak flow with some confidence. Furthermore, it will also be possible to detect changes in flow regime of the river, leading to greater or smaller flows, and to attribute these to long-term variability or perhaps to Global Climate Change.

WHY UNCERTAINTY EXISTS

However in Australia, flow records are not available for extended periods of that scale. There were no written records prior to European settlement, and flow measurement since then has been limited generally to the larger rivers and catchments. Hydrologists are faced with the task of estimating a vital piece of information without the ability to give a precise answer. This problem is well researched and understood, at least by hydrologists, and many studies have been undertaken to try to overcome this deficiency.

If the record of flow at a gauging station is short it is common to give the estimated flow rates for different recurrence intervals, together with Confidence Limits. So the best estimate is given, and at the same time the possible inaccuracy is indicated. However in the experience of the authors, this uncertainty is not universally understood.

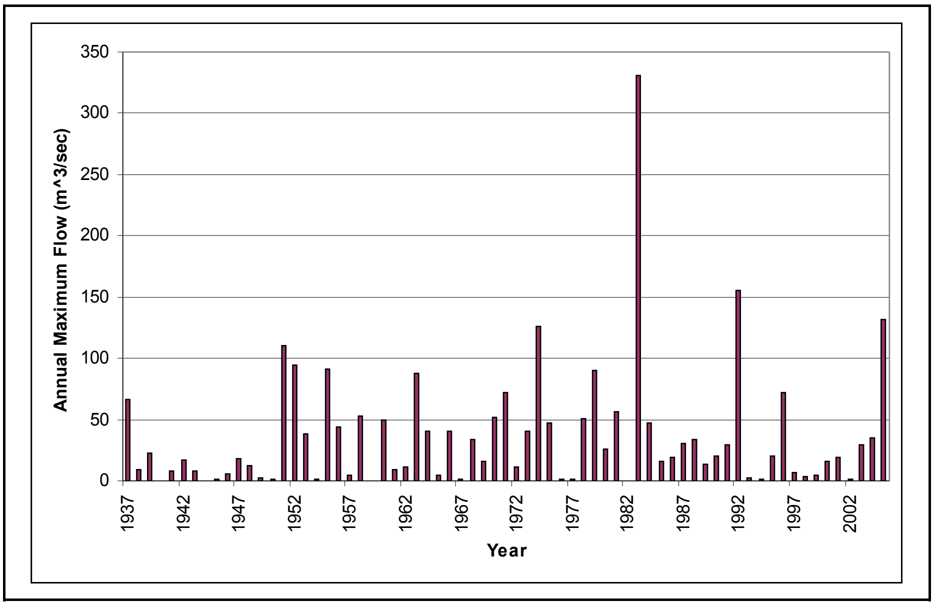

Figure 1: Annual Maximum Flows on the North Para River at Yaldara

Figure 1 illustrates the problem. This is 70-year long record of peak flows at the Yaldara gauging station on the North Para River in South Australia. This record is typical of Australian rivers, showing a great deal of variability, and periods when there appear to be a series of wetter or drier years, and some big floods which may or may not coincide with wet periods. If the period of record available is much shorter than the 70 years in Figure 1, then any judgement on the variability, or risk of floods, will be restricted by the window for which records are available.

To illustrate the effect of the window of record the annual maximum flows for two longer term (>60 years) stations in South Australia were fitted with a flood frequency distribution, firstly with the whole record, and then using shorter sub-sets of the data.

Table 1: Predicted flows using a sub-set of the whole data - Onkaparinga River at Houlgraves

ARI (years)	Full Record (m3/sec)	First 20 years (m3/sec)	Second 20 years (m3/sec)	Third 20 years (m3/sec)
2	102	112	123	84
20	338	304	418	444
50	428	349	567	662
100	493	374	696	860

Table 2. Predicted flows using a sub-set of whole data - North Para River at Yaldara

ARI (years)	Full Record (m3/sec)	First 20 years (m3/sec)	Second 20 years (m3/sec)	Third 20 years (m3/sec)
2	20	14	26	29
20	139	161	120	219
50	229	310	164	379
100	324	498	201	562

Table 1 and Table 2 show the results. There are very wide differences in predicted flows, and not only for the low probability floods. The predicted floods using a smaller window often vary by a factor of two.

In the world of Engineering and project development, decisions must be made on the water resources and stormwater infrastructure, eg. Bridges, dams, concrete channels, levee banks. The hydrologist is required to estimate the water flow or maximum flood capacity required. Other branches of engineering, (eg. structures, steel and concrete design,) are able to provide confident estimates of risk and safety against failure with a high degree of accuracy.

In terms of peak flow estimates, for flood maxima, how accurately can the risk be defined? By analogy, if a bridge is designed to span a river, the structural design of the bridge can be defined with +/- 3%, but how accurately can the span of the bridge be defined to provide adequate capacity for the "100 year ARI flood"? What are the consequences if the 100 year ARI flow rate is not accurately known? Do decision-makers, financial controllers and senior managers realise the potential risk of inaccurate estimates, due to inadequate hydrological record?

IMPLICATIONS OF USING A HYDROLOGICAL RECORD THAT IS TOO SHORT:

Example 1: New Housing Design in the floodplain of Keswick Creek

In 1984 flood mapping was undertaken for the Brownhill and Keswick Creek floodplains. This mapping identified the 100-year floodplain and the corresponding water levels. The consultants report acknowledged the inadequacy of hydrographic information, and the need to use representative data from other catchments. West Torrens council introduced planning controls in flood-prone areas in accordance with the information shown on the flood maps, and required that new housing should have floor levels above the 100-year flood. However in the Cowandilla and North Plympton areas this was found to require some new properties to be constructed on embankments a metre or more above the natural surface level, and above adjacent housing. Flood mapping was done again, in the year 2000, with better hydrology information, and the reassessed flood levels are much lower. Therefore part of the infrastructure cost of the new housing was unnecessary, and the cost to council of defending the height requirements wasted. It is beyond doubt that this problem was due to inadequate information. Furthermore the cost of obtaining that information was small in comparison with the infrastructure and administration costs.

Example 2: Flood Estimation for the Numbered Creeks

A lesson has been learnt from the hydrology of the Numbered Creeks in the Foothills of Mt Lofty Ranges. Flood studies were done in the 1980s to determine the 100-year flood. They were carried out in accordance with good professional standards of the time, but there were no flow gauging stations in the creeks at that time, and there were no pluviometers in the catchments. Much of the infrastructure within Burnside, Campbelltown and Norwood Payneham St Peters Councils has been designed on the basis of these hydrology studies.

Recently a major flood study, using records from gauging stations that were established since the 1980s, has determined new figures for the 100-year flood. In most cases the new figures are 50% or less than the earlier estimates. In one case the figure is 30% greater. The new figures were determined in the light of currently available historic record. The earlier estimates were made without the benefit of good data, and therefore had to make allowance for uncertainty. It is also likely that estimates from the early 1980s were biased by the occurrence of an extreme flow event at that time (March 1983). Without long-term records, it was not possible to place this flood in context, and it was estimated to be the 100-Year event.

If the new figures had been available for design of infrastructure within the council areas, significant economies in the cost of construction could have been possible. It is suggested that these savings were potentially very large when compared with the cost of establishing and maintaining the gauging network.

Example 3: Providing Water for the Mining Town of Leigh Creek

In 1982 the Leigh Creek mine was programmed for a major expansion with a population growth forecast to reach 3,000. Major studies were carried out to determine the source of water and cost of treatment, sufficient to support this population. Sources of water included the Aroona Dam, local saline bore-water, extension of an existing supply from Sliding Rock, a new pipeline from the Great Artesian Basin, and even filling coal trucks on their way back from Pt Augusta with water from the water supply pipeline(River Murray water). There was virtually no data on river flows entering Aroona Dam, and long-term rainfall data records were sparse. Major decisions on investment in the water supply had to be made, and resulted in the development of the Windy and Emu Creek borefields, including an extensive network of pumps, tanks, pipelines and controls. A reverse osmosis plant was constructed to purify the saline water. The extensive borefield development was necessary to guarantee the water supply, because there was insufficient information on the supply of surface water from Aroona Dam to determine the frequency and duration of drought periods, nor to quantify the inflows.

It is understood that 25 years later the water supply to the mine has been provided from Aroona Dam alone for the entire period, with one exception. It is not known how much investment could have been saved by the availability of good rainfall and river flow records, however it is suggested that the cost of setting up and running of gauging stations to record the data would have been small in comparison.

BENEFITS AND EFFECTS OF LENGTH OF HYDROGRAPHIC RECORD

In the following section, a case study is developed to illustrate the degree of uncertainty in practical terms, and the improved accuracy that is achieved by having longer records available.

Table 3. Confidence Limits for the Houlgraves Gauging Station

Years of record	5% Confidence Limit	95% Confidence Limit	Q100 (m3/sec)	% Difference		Range / Best Estimate
10	184	1,324	493	63%	169%	2.31
20	245	991	493	50%	101%	1.51
50	317	767	493	36%	56%	0.91
66	336	724	493	32%	47%	0.79
100	361	674	493	27%	37%	0.64
150	382	636	493	23%	29%	0.52

Table 3 provides the details of a flood frequency analysis for Houlgraves Weir on the Onkaparinga River. This gauging station measures inflow to the Mount Bold reservoir, and by including correlated data has 66 years of record, and the Q100 is known with reasonable confidence. The method in ARR for determining the 5% and 95% Confidence limits has been applied and the table shows the effect if, instead, the length of record is 10, 20, 50, 100 or 150 years. If only 10 years of record is available – with an estimated Q100 of 493 m3/s, the real Q100 could be as low as 184 m3/s or as high as 1,324 m3/s. By extending the period of record at the gauging station to 50 years, the range reduces to 317 and 767 for the respective limits. Figure 2 illustrates this.

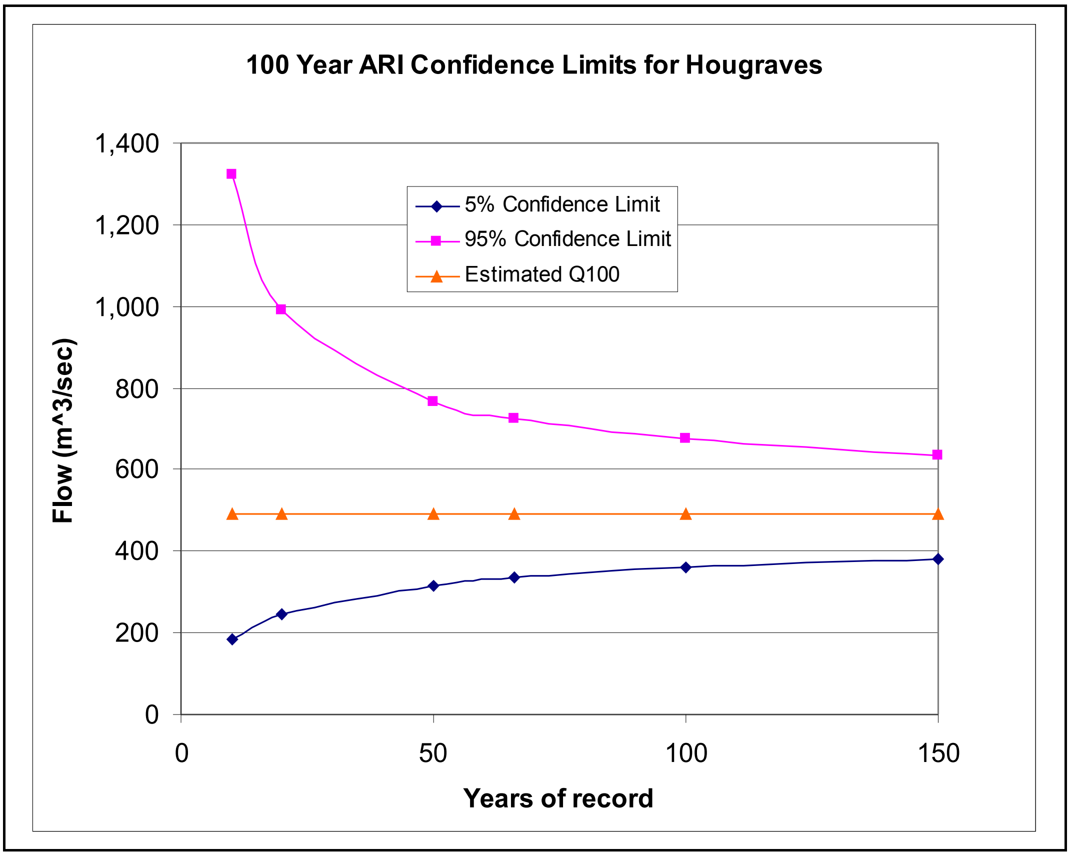

Figure 2 Effect of the Years of Record on Confidence Limits

An example from South Australia is provided in table 3, and shows the benefits of extending the record in the improved ability to estimate the Q100

Table 4. Confidence Limits for the Houlgraves Gauging Station

River	Gauging station	Length of record (Years)	Estimated Q100 m3/s	Lower Limit ,5% (Years of Record)				Upper Limit ,95% (Years of Record)			
				10	20	50	100	10	20	50	100
Brownhill Ck.	Scotch College	10	21.7	8.5	11.2	14.3	16.1	55.4	42.1	33.0	29.2

What are the implications of the uncertainty in the estimation of Q100, when the period of record is short?

- The risk of under-design or over-design of the structure is high. Can the decision-makers cope with 50% to 100% uncertainty in flood estimates?
- The risk of failure in estimating such things as water supply volumes and catchment yield is uncertain. The Kyle Dam in Zimbabwe was financed and constructed on the basis of short hydrographic record. After construction, it took more than 15 years before the dam filled to capacity;
- Arguably the construction and operation of the Reverse Osmosis plant at Leigh Creek may not have been necessary;
- The capacities of the stormwater structures, bridges and culverts on the main channels of 1st

to 5th Creeks may be significantly undersized or oversized.

REDUCING THE UNCERTAINTY

It follows from the information presented in this paper that hydrological estimates are commonly approximate, not precise. This is not due to any deficiencies in scientific or professional al analysis, but because they are based on inadequate data. While concrete and steel designers can test their designs in the laboratory, hydrologists have to wait until the next flood. (Once a flood event has occurred, the evidence of its progress degrades and is lost)

Obtain a reliable set of information on the major parameters (usually rainfall and streamflow.)
Clearly the best way of improving the understanding of flood flow behaviour is to measure rainfall and streamflow – preceding, during and after a flood event. This requires setting up and maintaining a network of gauging stations in the catchment or river basin of interest, designed to operate in the long term. The logner the period of record, the better the confidence in the flow estimate.

Use adjacent similar catchments to improve confidence. In some cases it may be feasible to determine hydrological similarity between adjacent catchments, and this may permit an alternative means of flow estimation.

Improve the quality of the records – low flow, high flow, yield. Uncertainties in flow estimation can be due to poor quality data, problems with water level measurement, equipment malfunction or incorrect cease-to-flow datum. By removal of sources of error, the quality of the data can be improved;

Improve the stage-discharge estimates. This paper does not include discussion on stage-discharge estimates. However the relationship between water level and rate of flow at a gauging station is seldom known with accuracy and this is particularly true for flood flows.; and

Take account of changes within the river catchment or basin, particularly urbanisation, but also changes from forestry to row-crops, and changes in cover that may occur during droughts. Construction of small agricultural dams will also affect flood frequency in the river or creek downstream.

CONCLUSION

The paper explores uncertainty in flood estimation in South Australia, with examples showing the causes of uncertainty and the implications on cost of infrastructure and flood damage. It has illustrated the uncertainty that is implicit in estimates of flood flow, and by implication, the uncertainty in drought and catchment yield estimation.

- This uncertainty is most effectively addressed by a long-term monitoring program, which records rainfall and streamflow over an extended period.
- Typically the benefit from increasing the period of measurement from 10 to 50 years will be a reduction in uncertainty of some 50%
- Estimates of rainfall, flood flow, catchment yield and drought based on short (10 to 20 years) of record cannot be made with confidence. Therefore the risk of failure of projects and developments based on inadequate data is high.
- At the present time, forecasting the changes to these basic parameters is central to a proper understanding of Climate Change.
- A strong case is made for strengthening and expanding the hydrographic network for collecting and archiving flood data as a means of reducing uncertainty, as well as reviewing any management strategy with regards to sensitivity to the uncertainty.

REFERENCES

Pilgrim, et al. (1987). Australian Rainfall and Runoff, A Guide to Flood Estimation. The Institution of Engineers Australia, 1987