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GUEST EDITORIAL

FALLACIES IN FLOOD HYDROLOGIC DESIGN

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INTRODUCTION

Large amounts of time, money, technology and materials are often invested in the process of deciding the best ways to reduce the costs of flooding and other natural hazards. The results of the process, however, are not always satisfactory; flood damage costs sometimes have risen as a consequence of implementing such a decision. This implies that the decision-making process needs to be improved.

THE CONVENTIONAL DECISION-MAKING PROCESS

Let us suppose that a community sees the need to reduce the costs (monetary, psychological/emotional, social) caused by flooding. A decision is needed on the best strategies to employ (reduce river flow stages and hence overflows, reduce overflows from high stages, reduce community susceptibility to overflows); at what level, and for how long (design life). The river flow rates (and hence stages) under which these strategies will have to perform over the future design life can be estimated or extrapolated from statistics of past river flows. A variety of strategies, or combinations of strategies, is selected, and for each of these the consequence of a particular river flow rate is calculated in terms of the damage cost and number of deaths. The average annual cost of this scenario is then calculated by multiplying the cost of the event by its annual exceedence probability. This procedure is repeated for the full range of possible flows in the river. The net benefit (reduction in flood damage costs and/or number of deaths minus the cost of implementing the strategy) of each strategy over the design life of the scheme is assessed, and it then seems logical to adopt the strategy that yields the maximum net benefit. This decision is made in the light of qualitative assessments of social, cultural, political, ecological, landscape, recreational and amenity implications of the various scenarios.

IMPLICIT ASSUMPTIONS

The above process implies the following:

(i) That river flows have an identical statistical distribution to past flows during the design life of the project.

(ii) That the following costs can be estimated with sufficient accuracy that [(a) - (b)] - (c) is of useful precision (this is the net benefit of the strategy):

(a) Damage cost of particular flow rate with the existing flood protection measures.

(b) Damage cost of a particular flow rate with a particular flood protection strategy.

(c) Cost of implementing this particular strategy.

(iii) That (ii) can be done with useful precision throughout the design life of the scheme.

(iv) That the average annual damage for a particular flow rate is a useful indicator of the economic effect of the flow rate on the community.

(v) That the quantitative estimates of monetary cost, number of deaths, duration of disruption to transportation, etc., are adequately balanced with qualitative factors to give a 'best' decision.

ASSUMPTION (I) - RIVER FLOWS

Ignoring error of flow measurement altogether, and knowing flows that have occurred in the past, what flows will occur during the design life of the scheme?

To simplify the problem further, assume that we have 10,000 years of absolutely precise records of flows in our river, and that the design life is the next 100 years. We can thus accurately define the statistical parameters of the flows in the past. It might seem logical to assume that the series of flows over the next 100 years will have exactly these sample statistical parameters. Although this seems likely, it is in fact much more likely that something else - we do not know what - will occur. For example: if, in 10,000 years there have been 62 occasions on which 1,000 m^3/s has been exceeded, it does not follow that in the next 100 years the number of exceedences will be 0.62. Indeed, this number of exceedences cannot physically occur; it has a probability of occurrence of zero. In other words, the well-known statistics of a large sample don't apply to a very small sample of the same population. As another example, the mean of the numbers 1, 2,....100 is 50; if we select five of these numbers randomly, how likely is it that their mean will be 50? The flows of major significance in flood management are the big ones that can cause lots of damage, these occur rarely, only a very small number of times during a typical design life, and hence constitute a small sample for the purposes of statistics. We cannot know with confidence anything about the large events that will occur in the next 100 years, except that:

(a) They can occur at any time, and

(b) Their probability of occurrence in any give year is small, but finite.

If, as usual, we only have about 50 years of flow records instead of 10,000, it simply makes matters worse: the next 100 years' large flows are a small subsample of a very poorly defined data set, and doubts about the accuracy of flow measurement and frequency now become relatively insignificant.

ASSUMPTION (II) - COSTS AND BENEFITS

The damage caused by a particular flow depends on the level, duration, extent, velocity and silt content of flood waters. Of these, water level is probably the most important, in particular whether the flood level is below floor level, above floor level or above shelf level. The accuracy of flood damage calculations depends on the accuracy of hydraulic and financial calculations and estimates, but there must be an error of the order of 10%-20% involved. In calculating the reduction of damage costs due to a particular flood mitigation strategy, it is necessary to subtract two such figures to give a benefit or cost saving figure. The precision of the benefit figure must be much lower than that of the two damage cost figures, e.g.:

$10,000,000 ± 15% – $5,000,000 ± 15% = $5,000,000 ± 45%
(unmitigated cost) (mitigated cost) (benefit)

From this less precise figure must now be subtracted the cost of implementing the strategy, which is also liable to error; experience with major hydraulic structures indicates a minimum figure of ± 5% and a maximum of about + 50% to - 10%. Taking the minimum error might give us a net benefit of:

$5,000,000 ± 45% – $3,000,000 ± 5% = $2,000,000 ± 115%
(benefit) (cost) (net benefit)

so the best possible approximation for the net benefit is between $4,300,000 and - $300,000!

There is thus an inherent and significant degree of imprecision in calculating net benefit from predicted reduction in flood damage costs.

ASSUMPTION (III) - DISTANT FUTURE COSTS AND BENEFITS

Cost and benefit figures become even less precise when they are based on assumptions about the financial environment of the distant future. What will be interest rates and opportunity costs in the period 2050-2100? This is a crucial question if the true net benefit of the scheme over the next 100 years is to be known, which is necessary if a rational decision (as opposed to a leap of faith) is to be made about whether to adopt a particular strategy. One can, for comparison, make arbitrary economic assumptions and apply these equally to all strategies, but this does not help a 'go/no' decision, and might in any case affect some strategies more than others. It is clear that, beyond about 10 years in the future, one can have very little confidence in any prediction of financial and economic conditions. Hence any attempt to justify a decision on hazard management by cost vs benefit calculations has very serious inherent imprecisions and unknowns which call the whole process into question.

ASSUMPTION (IV) - USE OF AVERAGE ANNUAL DAMAGE

Even if assumption (i) were realistic, and it were possible to specify with confidence the a.e.p. of a given flow rate in the next 100 years, there are still fundamental problems with using the product of event cost and event probability as a measure of a flood's impact on the community. Consider the impact of a very rare event occurring during the 100 year design life - say an event with an a.e.p. of .0002, or a '5000 year return period', that, if it occurred, would cause damage of $\$10^9$. On the basis of assumption (iv) its significance is indicated by $\$10^9 \times .0002$, or, $200,000/year.

There are only two possibilities - either this event will occur during the design life, or it will not. If it does not, it will cost the community nothing, whereas assumption (iv) indicates its cost as 100 x $200,000 = $20,000,000 over the design life. If it does occur, it will cost the community $\$10^9$ - *and this cost will have to be met over a small number of years*, not over the next 5,000 years. The $\$10^9$ cost will certainly fall onto the community during the design life, and will probably be spread over a much smaller number of years, say ten, at $\$10^8$ per year. In neither case does the \$200,000/year give a useful indication of the economic impact of this event on the community. Assumption (iv) is really only valid for events with 'return periods' not much longer than the time over which the damage cost can be spread - say up to 5-20 years.

Even as an indicator of the relative significance of damages due to flows of different magnitudes, average annual damage is not particularly useful. To say that a flow with an a.e.p. in the range 0.05-0.005 is more damaging than those with a.e.p. <.005 again misses the point that, in a relatively short design life, the a.e.p. of an event is much less important than whether the event will happen or not - and this we cannot know.

Insurance against damage is one method which does allow damage costs to be spread over a large number of years. This is done by the insurance company spreading the risk spatially, even over a large number of risk-takers in other communities, and ultimately, by re-insuring, over a large proportion of the globe. Even in this case, though, it is clearly unreal to spread the cost of a 0.0002 a.e.p. event over 5,000 years. I do not know at what stage an insurance company ceases to be willing to insure against flood damage - but it has happened in Greymouth, following two floods of relatively unexceptional a.e.p., suggesting that the insurance industry is rather reluctant to carry flood risk to the extent of allowing major damage costs to be spread over long time periods.

DISCUSSION

From the above, it appears that:

(a) It is impossible to predict with useful confidence what high flow rates a flood damage mitigation strategy will be subject to during the product life.

(b) It is very difficult to predict with useful precision the net economic benefits that will result from the choice of a particular flood mitigation strategy, even if the high flows that will occur during the design life are assumed to be known.

(c) The difficulty in (b) becomes much greater for times in the unknown economic environment of the more distant future (≥10 years).

(d) Average annual damage is not a realistic economic criterion for comparing the effectiveness of strategies under less frequently occurring flows.

The conventional process of making flood management decisions is thus based on dubious assumptions, and this might be one reason why many such decisions have unsuccessful outcomes. It is interesting that (a), (b) and (d) above refer to 'high' flows, and in fact assumptions (i), (ii), and (iv) are applicable to flows that occur a reasonable number of times during the design life. Thus the conventional process is probably a realistic way of choosing strategies to cope with flows of

$$(TD)\ (a.e.p.) \geq 10$$

where TD is the design life of the scheme in years. In colloquial terms this means that we *can* sensibly decide how to cope with flows up to about a 10-year return period for a design life of 100 years.

Greater flows are more difficult because their impact depends so much on how many times, or whether, they occur. All that we know about these greater flows is that they will all occur one day, and that *any* of them *can* occur in *any* year. This suggests that we need a strategy that will cope with any possible flow, up to the maximum possible, because the maximum possible flow can occur within the design life.

It seems logical to suggest that perhaps these two sets of flows - frequent and infrequent - could be dealt with by two different but related strategies. For flows up to 10- or 20-year return period (for a 100-year scheme life), overflow prevention should be possible at reasonable cost, with reasonable reliability and with estimable economic result. A flood-prone property in the community might then be flooded a small number of times, if at all, during its maximum 50-year occupancy by one owner. When overflows do occur, flood damage and deaths could be reduced by establishing a flood readiness-warning-evacuation routine, based on rainfall and river flow monitoring. The obvious difficulty with this approach is the choice of the highest flow rate which containment measures are designed to cope with. This must be related to the flow rate at which the number of occurrences within the design life becomes sufficiently small to render assumptions (i), (ii) and (iv) questionable. I don't know how to do this analytically, but any flow with (TD) (a.e.p.)$\leq$10 is (a) large enough to cause significant damage, and (b) quite likely not to occur at all within TD, and it is here that I would become uncomfortable with the assumptions.

An important point to bear in mind here is that any decision involving infrequent flow events, no matter how 'good' or 'realistic' its basis, can have a poor outcome; conversely a decision based on ignorance and unjustified assumptions can have a good outcome. Even if engineer A spends 3 years deeply and seriously considering a decision, and his strategy is adopted, it is possible that due to an unfortunate sequence of high flows, flood damage costs following completion of the scheme increase dramatically. Hydrologist B, however, who makes her decision by spinning a coin, is lucky in that no overflows at all occur during the design life of her scheme, and a statue of her is therefore erected. The quality of such a decision cannot be judged on its outcome, but only on the quality of the decision-making process; however when many such decisions have poor outcomes, one is justified in scrutinising the decision-making process.

At this stage it is necessary to reiterate that decisions of floodplain management do not have only economic results; they also affect the lives of the inhabitants. Methods for formally including social, cultural and environmental effects in decision-making are still crude relative to the apparent sophistication attainable in cost-benefit methods; however much of this latter sophistication is questionable and might well be entirely spurious. There is thus a very strong case for giving the 'intangible' (i.e., non-dollar) impacts equal weighting with economic impacts, since both are, for less frequent events, essentially unquantifiable using conventional decision-making processes.