Retarding Basins and Stormwater Management — A Critical Review

E.H. RIGBY
Director, Forbes, Rigby & Associates Pty. Ltd., Wollongong, N.S.W.

JMMARY A review is presented of literature on the design and performance of retarding asins, with particular reference to their use as an aid in stormwater management of an rea undergoing development. The review examines urbanisation and its effect on runoff, aich in turn leads to a discussion of stormwater management objectives. Various forms f retarding basin are discussed and their place as a tool in stormwater management ritically reviewed. Parameters relative to the design of a retarding basin in a ractical situation are discussed and recommendations made as to appropriate values or ethodology of choice. Trends in regulatory controls are examined and their effective-ess discussed. A short review of various computational aids is presented and in con-lusion comment is offered on the more critical or sensitive issues.

INTRODUCTION

ie use of retarding basins as an aid to cormwater management is not new. Such cructures have been used for many years ı Europe and the United States. Two in cance have been in use for over 250 years Voodward, 1920). Wide spread interest in ie application of retarding basins and in ieir operation would, however, appear to e much more recent with the majority of iterature on this subject having been ablished in the last two decades. Some arly Australian literature on this subject sstill quite relevant today (Gould,1967).

.nce the early sixties, a large body of aformation on the performance character-stics of retarding basins and their place ı the stormwater management field has een established. It is apparent from the ntent of literature spanning this period, iat there has been a shift in emphasis, in re recent years, from the purely techni-l aspects of flood routing towards water ality and other secondary considerations.

. reviewing the design and performance of tarding basins it is difficult to parate discussion on the design and rformance of retarding basins from the erall concept of stormwater management. ilst we have endeavoured to affect this paration for the purpose of this paper, ch separation is neither desirable nor gical.

. is clear that any future review of ainage problems will tend to involve nsideration of stormwater management jectives for the catchment as a whole. longer will we enjoy the simplicity of sign afforded by consideration of ainage problems in isolation, as has en largely the case in the past.

2 URBANISATION AND RUNOFF - THE PROBLEM

2.1 The Cause.

Much has been done to investigate the problem of urbanisation and its effect on runoff, in the last two decades. Whilst early investigators recognised the qualitative effect of urbanisation in increasing peak runoff, erosion and downstream siltation the more detailed quantitative aspects have only been evaluated in more recent years. In this respect the availability of comprehensive rainfall/runoff computer models has permitted analysis of the relative influence of each variable on the runoff process.

As an example of past land development practice, a typical subdivision of the early fifties would have involved removal of most vegetation from the land, filling and piping of any existing natural water courses, sealing streets and driveways and piping all water from paved surfaces and roofs to the main storm drain as directly as possible.

Such a process inevitably lead to,
(a) a marked reduction in interception and depression storage.
(b) a marked reduction in infiltration evaporation and transpiration.
(c) a significant increase in impervious cover (sealed areas and roofs).
(d) a considerable increase in the speed of removal of water from the site.

The nett effect of such change is to generally increase the volume of runoff from 1½ to 2 times that of runoff from the undeveloped catchment. As a result of both increased volume and shorter time to peak, runoff rate is doubly effected. Greater volume has now to runoff the catchment in shorter time, leading on average, to increases in the peak runoff rate from 1½ to 8 times that of the undeveloped catchment.

2.2 The Problem.

The most readily apparent result of these increases is likely to be,

(a) an increased flood stage at some point which had previously been flood prone and now finds itself flooded either more frequently or by a flood of higher stage and longer duration, or
(b) initiation of flooding of an area which was not normally subject to flooding.

The rate of erosion of banks and bed and deposition at some point further down stream is also likely to be increased, as is the presence of pollutants in the stream, particularly those related to oils, detergents and heavy metals. A less tangible, but perhaps longer term problem arises from the threat to the ecosystem associated with streams and creeks.

3 STORMWATER MANAGEMENT OBJECTIVES.

What then, are the objectives of stormwater management, as applied to an area undergoing urbanisation?

Insofar as an individual development is concerned, we would ideally seek to absorb, retain and/or treat, on site, runoff to the extent that after development, the quantity and quality of water leaving the developed site would neither create nor increase any of the problems previously discussed.

It should be noted that this does not necessarily mean that the resulting discharge must be less than the pre-existing discharge from the development. It is however likely that this will be the case in many situations. Since the problems previously discussed are generally the interactive result of input from the entire watershed (both upstream and downstream of the problem site), it is generally not possible to meet the stated objectives without considering the watershed as a whole.

In order to achieve these objectives it is obviously necessary to negate the harmful effects of development previously discussed. This would lead to,

(a) maximising interception and depression storage.
(b) maximising infiltration, evaporation and transpiration.
(c) minimising areas of impervious cover.
(d) maximising travel times in the major and minor systems.

These matters are covered in greater detail in the report by the A.S.C.E./U.L.I. joint committee on stormwater management (1975).

Many areas downstream of a given development unfortunately already suffer one or more of the problems described. In such cases, additional development may be possible without aggravating the problem, but it is wholly unlikely that a single development, however well planned, could solve entirely an existing problem. It is therefore necessary to add to the above, procedures for handling a problem which cannot be resolved by one of the above methods. Such measures are normally classified as structural or non-structur and involve,

(a) structural works such as levees and channel improvements, stabilisation banks, silt traps and treatment basi
(b) non-structural measures such as insu ance programmes and zoning controls.

4 THE RETARDING BASIN & STORMWATER MANAGEMENT

How then, does the retarding basin fit ir a stormwater management plan?

In order to answer this question, it is first necessary to understand the functic of a retarding basin. The retarding bas: may be pictured essentially as a hydrauli device for modifying the shape of runoff hydrographs. Since the retarding basin i by definition a device to retard the flow (but not retain), the volume of the outfl hydrograph will always equal the volume c the inflow hydrograph.

By judicious choice of geometry, we are generally able to effect a reduction in t peak flow rate by passing a flood hydrogr through a retarding basin. The flood hydrograph time base would generally lengthen in the process and the resulting outflow hydrograph is said to be lagged b the time difference between its centroid and that of the inflow hydrograph. In general, the longer the lag produced by a particular basin, the greater the reducti in peak flow rate.

A full analysis of this modification to t hydrograph involves what is termed a floo routing analysis. In essence the procedu involves the solution of the basic equati of continuity,

$$I\Delta T - O\Delta T = \Delta S \quad (1)$$

where,

I and O = rates of inflow and outflow
ΔS = storage volume increment
ΔT = time increment

Various simplified methods may however, b used to either initially size a larger ba or to effect final design of a retarding facility for a smaller, low risk applicat (e.g. parking areas and smaller urban catchments)(Hall & Hockin, 1980)(Poertner 1974)(Burton, 1980)(Thompson, 1975).

Without examining performance in detail a this stage, it is apparent that the retar ing basin is under certain conditions, capable of reducing peak flow rates, and may therefore meet part of our management objectives in terms of controlling downstream increases in flood stage. It is likely however, that the resulting increas in duration of high flow will lead to increased erosion, siltation and stream pollution, with a resultant threat to the stream associated ecosystem. Whilst the retarding basin is a useful tool in stormwater management it does have significant limitations which should be recognised.

Thoughtless development to which a retarding basin has been appended, does not constitute a generalised solution to storr water management problem. This matter is explored further by McCuen, (McCuen, 1979)

5 DESIGN CONSIDERATIONS

5.1 Upstream Considerations

Initial data required as input from the upstream area covers the parameters that determine the runoff from a given rainfall event, such as, contributary area, slope, cover, soil type etc., the duration of the design storm and its recurrence interval and details of the sediment and/or pollutant load carried into the basin.

Since it is the interaction of upstream considerations with basin and downstream controls which forms the primary constraint, discussion of upstream parameters will be presented concurrently with discussion on downstream considerations.

5.2 Basin Considerations

Existing topography and relationship to boundaries will play a large part in determining the volume and shape of any particular basin. As a result, the basin stage/storage curve is defined, within reasonable limits, at the outset.

The location and arrangement of the outlet structure will generally be determined by the designer on structural, hydraulic or economic grounds. The depth and width of overtopping of the weir is likely to be also controlled by topography and proximity to boundaries. Whilst the designer may initially assume a stage discharge relation -ship for the outlet, it is likely that downstream constraints will dominate in determining the ultimate stage discharge relationship for the basin.

It may be possible, in some cases, to configure the basin such that lag within the basin is appropriate to,
(a) the deposition of sediment carried into the basin or
(b) treatment of specific pollutants.
For basins of the size encountered in small developments however, it is unlikely that the lag time would be sufficient to deposit more than the coarse fraction of silts or sand.

Fundamental to the design process will be the choice of minimum recurrence interval for overtopping of the weir. Limitations on overflow depth, velocity and/or duration may also be constraints which we wish to impose.

5.3 Downstream considerations.

In order of decreasing importance, as currently viewed by society, these considerations would cover,
(a) flood stage, duration and frequency.
(b) bank and bed scour and/or deposition.
(c) sediment and/or pollutant load.

With respect to the determination of design storm duration and recurrence interval, we must first resolve,
(a) an acceptable recurrence interval for overtopping of the structure (local).
(b) an acceptable range of recurrence intervals for the assessment of flood stage and duration (downstream).

If we are to follow the previously stated management objectives, we will require for the downstream system, at least in flood prone or flood sensitive areas,
(a) no increase in flood stage,
(b) no increase in flood duration for floods of a given magnitude
(c) no increase in frequency of flooding.

Since we can reduce peak flow rate but not volume, we are in no position to solve all criteria simultaneously by use of a retarding basin. A reasonable compromise accepted in many circumstances would involve,
(a) local overtopping frequency, velocity and depth constraints, commensurate with safety, convenience and economy.
(b) a limitation on flood stage and frequency along downstream reaches to that which pre-existed.

From analysis of storms of different duration, for any given recurrence interval a storm duration will be found which produces maximum discharge from the basin at the basin outlet. This storm, the so called critical storm, is critical only for the particular recurrence interval chosen and point in the watershed at which the flows are being determined (viz. outlet). To determine peak flows at other points in the watershed will require consideration of a range of storm durations to determine the critical storm duration for each point.

If we are to generally, neither increase flood stage nor frequency at all points downstream of the basin, then we must do so for the full range of recurrence intervals and range of storm durations. Design for one frequency and/or storm duration, hoping the remainder will not lead to increased flood stage or frequency along the downstream reaches does not meet the stated management objectives.

If we accept, for example, that a given basin is to be designed for a 20 year recurrence interval over the critical storm duration range, for nil increase in discharge at specified points downstream, it is likely that for the 5 year and 100 year recurrence interval storms, that the runoff peaks would not be equal to or less than pre-existing peaks.

For the shorter recurrence interval (and lower discharge rate) runoff will pass largely unretarded through the basin with minimal storage. For the much greater recurrence interval (and increased discharge rate), runoff will surcharge the basin, passing over the weir with minimal retardation of the peak.

It is to be noted that, in reviewing a point downstream of the developing area, on a typically branched network, that the critical storm duration will in most cases be quite different to the critical storm duration for design of the basin locally. In most cases the critical storm duration for a downstream point would be expected to be longer than the duration of the critical storm for the basin outlet. As previously stated the general solution will necessarily involve analysis of the complete watershed above the area under review to determine if the combination of runoff events for the range of recurrence intervals and storm durations, does or does not meet the stated objectives.

It must be emphasised that there is no detail similarity between the choice of recurrence interval and design storm duration in the rational method design of a minor piped network and compliance with stormwater objectives in considering the recurrence intervals and storm durations applied to the design of retarding basins.

Whilst discussion to date has essentially dealt with a single retarding basin, in any partical application there may well be multiple basins involved. In this situation, where basins occur on a branched (typical) drainage network, one must deliberately consider the phase of discharge from the various basins as they meet at the chosen (problem) point downstream. It is quite possible that well intentioned construction of a retarding basin in one limb of a network, might well in fact increase discharge at some downstream flood prone point. (McCuen, 1979).

6 REGULATORY CONTROLS

It is likely that this area will lead to the greatest controversy both in the near future and for some considerable time yet to come. Most of Australia's populated areas suffer recurrent and at times severe flood damage. This does not take into account the much greater frequency of less obvious damage associated with increased erosion, siltation and pollution.

It is clearly mandatory therefore for local government to develop and maintain a well founded stormwater management policy, relevant to their particular area, if we are to improve on this problem in the future. Whilst the remainder of this section will discuss those controls relevant specifically to retarding basins, it must be understood that such isolation from the main body of a stormwater management policy is totally inappropriate.

In reviewing regulatory procedures determined by various authorities, both within Australia and overseas, it is immediately apparent that the various requirements are subject to considerable variation. Whilst the requirements of various authorities are seldom accompanied by an explanation of their intended objectives, it does appear that the primary cause of these variations is the result of an effort by authorities to reduce what is a most complex problem, to a procedure that may be followed with reasonable simplicity and applied as a matter of policy by that authority. This may in fact lead to local procedures that produce reasonable results in a given locality because of the special constraints of that locality. It creates a policy, however, in which the primary objectives are hidden and which may only with great care be extended to cover circumstances not originally envisaged.

Regulations fall essentially into three classes.
(1) Technical.
(2) Construction and Maintenance.
(3) Legal.

Technical regulations may be further divided into local and downstream controls. Local controls may include limits on the frequency and/or depth and/or velocity of overtopping of the weir, proximity of the free water surface at overtopping to boundaries, and constraints on the manner in which water is discharged from the piped system. At the watershed (downstream) level, controls might include limits on flood frequency, stage, velocity or duration at all or some specified points downstream.

Whilst one might seek to question the extreme variability in local controls imposed by the authorities, it is regulations associated with the downstream system that have the most far reaching consequences.

Of the various controls that do appear with some consistency in the requirements examined, the "nil" increase in discharge" clause appears most common. This particular clause, or clauses similar in intent are often associated with a nominated recurrence interval for a design storm.

In many cases the point at which the nil increase in discharge is to be determined is rather vague, but in most cases is accepted as the outlet of the catchment under development. Whilst some argument could perhaps be mounted for a 20 year recurrence interval design storm accepting increases in the discharge of a one in one hundred year storm, on the grounds of the rarity of the event, the question of where downstream discharge is not to be increasec is a much more specific and relevant issue.

Limiting the point at which discharge is computed to the outlet of the developing catchment, clearly overcomes the problem of watershed consideration by the designer and reduces the critical storm duration to one event for each recurrence interval. Whilst simplification wherever possible in a matter as complex as this is desirable, the above procedure leaves the original question of stormwater management of a downstream flood prone or flood sensitive area totally unresolved.

Since time and economic limitations generally prevent a full before and after analysis of flood stage, duration and frequency, for all points downstream of th development, it would seem that future regulatory controls will need to define areas which are either flood prone or floo sensitive, at which the authority wishes an upstream developer to maintain the status quo. This somewhat simplifies the problem but still leaves a major exercise for the designer if he seeks to responsibl consider his management objectives.

Regulations associated with construction and maintenance of retarding basins do not regularly appear as part of current regula tions. This is not to suggest that such matters are trivial. To the contrary, they are perhaps one of the most complex aspects of such regulations. The matter is further complicated when such work is undertaken on private land, where authority to enter and maintain may be in dispute.

Perhaps over-riding all technical aspects of regulation is the question of law. During recent years increasing attention has been directed to the problem of downstream owners, affected by upstream development, to the extent that a body of law is developing which will in the long run greatly influence the development of regulations. To date, the legal aspect of control of stormwater has passed from the common enemy rule, in which water was to be disposed of as rapidly as possible, to the civil law rule, in which one is constrained to not harm ones neighbour (downstream). In more recent years we have seen both in Australia and overseas the beginning of a middle ground "reasonable use" doctrine. It is most likely that a considerable growth will be seen in this area over the next decade.

As stated previously, it is of the utmost importance that we first determine our overall stormwater management objectives. With a clear understanding of these objectives there is some chance that we may then develop management objectives for the design and implementation of retarding basins and other elemental facilities which would find wide scale acceptance. The present highly localised and fragmented approach to the problem will only delay this consideration and is therefore to be discouraged. Presentation of a clear statement of objectives for stormwater management of a developing urban area and specific requirements for retarding basins in a national publication such as Australian Rainfall and Runoff would seem a highly desirable goal for the near future.

7 COMPUTATIONAL AIDS

As with the interaction between retarding basin design philosophy and stormwater management objectives, we are equally interlocked when it comes to the consideration of design aids for retarding basins and those for other aspects of hydrology and hydraulics. It is obviously necessary to calculate the inflow hydrograph from the rainfall runoff process before carrying out routing of the hydrograph through the basin. In turn, it may be necessary to route the outflow hydrograph through some substantial downstream reach to a point at which we wish to consider the resulting outflow hydrograph.

It is clear at the outset, that there is an order of magnitude difference in complexity between this process and that of the simple rational method design for a (minor) piped network. At the hand level, little has been done to simplify the task of computation associated with retarding basin design. This area seems most open to further investigation and development. The simplified methods presented in the references deserve further attention.(Hall & Hockin, 1980) (Poertner, 1974)(Thompson, 1975)(Burton, 1980). The ready availability today of programmable calculators, micro and mini computers and time sharing access to mainframe computers will most likely lead to the use of such aids in many cases.

For programmable calculators a good range of codes covering hydraulic, hydrologic and routing procedures has been compiled by Croley. (Croley, 1977)(Croley, 1980). A range of Basic programmes covering a similar field has been assembled by O'Loughlin & Sarian, (O'Loughlin & Sarian, 1979). In view of the proliferation of programmable calculators capable of handling quite sophisicated machine code programmes, and more recently Basic programmes, it is likely that many firms engaged in drainage work will have or will be considering the development of codes of their own.

At the micro and mini computer level there is presently a gap in readily available software, in this field. The capacity of such machines, with the ability to overlay sections of much larger programmes into their smaller memory, permits many existing programmes intended for much larger machines to be adapted. Be warned however, such conversion is not a rapid process. A dramatic growth in software available at this level may be anticipated over the next few years. Software in this catagory is described further in the references. (O'Loughlin & Sarian, 1979)(Microcomp,1980) Universal Software Applications, 1980) (C.E.P.A., 1980).

At the high end mini and mainframe level, most codes are lengthy and complex. Such codes are generally written by specialists in their field and made available at a price (sometimes nominal) to an intending user. In view of the number of available programmes at this level and their complexity, no attempt will be made to review them in this paper. A vast body of literature discussing the merits of each model may be found in the references. Our own current experiences with RORB (Laurenson & Mein, 1978) and PSRM (Aron, 1980), have provided valuable insight into problems associated with land development.

8 CONCLUSIONS

With respect to the design and implementation of a retarding basin in a drainage network, it appears that there has not yet been sufficient attention paid to the establishment of clear stormwater management objectives. Without a clear strategy it is impossible to place the retarding basin in perspective and determine relevant performance criteria for the basin. It is little surprise therefore, to discover such variability in design procedure for retarding basins when the various considerations behind the overall management strategy for stormwater are so widely dispersed in the literature and often specific to a given locality and law.

A clear statement from a body such as our national committee on hydrology, defining nationally accepted objectives for stormwater management of an area undergoing urbanisation, would do much to reduce the present fragmented approach. To be of maximum value such policy would need to cover the objectives of both watershed management and management at the elemental level (e.g. retarding basins). Inclusion in a future revision of Australian Rainfall and Runoff would do much to unify future approaches to this problem and lessen litigation.

Specific matters which would appear to warrant further attention include,

(a) development of more uniform requirements for the local constraints appropriate to the design and implementation of a retarding basin on a given site, recognising the independance of local criteria from those determined downstream of the basin.

(b) the need for a modification to the present trend in specification for retarding basins relative to nil increase in discharge (flow peak?) at the catchment outlet. This procedure does not offer any guarantee that pre existing conditions will be maintained at some downstream (flood prone) point. The delineation of flood prone and flood sensitive areas downstream of the basin appears a necessary prerequisite for determining the point at which comparative discharges will be assessed. If responsibility for regional management of stormwater is to be maintained the delineation of such areas should become the responsibility of local government and form part of information available to drainage engineers working in a given area.

(c) in undertaking the design of minor, low risk, retardation facilities, such as those associated with parking areas or small urban developments, simplified procedures are required if the profession at large is to readily accept and implement these measures. Simplified procedures based on the rational method appear a sensible first step. As with drainage in the past, the largest proportion of expenditure is associated with the simpler projects. Let us therefore begin, at least in these simpler low risk areas, with tools we readily understand, rather than await the outcome of the last decimal place.

9 REFERENCES

ARON G. (1980) PSRM Runoff Model User Manual. College of Engineering. The Pennsylvania State University. U.S.A.

A.S.C.E.(Amer.) (1975) Residential stormwater management. Joint publication of Urban Land Institute, American Society of Civil Engineers and the National Association of Home Builders, U.S.A.

BURTON K.R. (1980) Stormwater detention basin sizing. Journal of the Hydraulics Division of A.S.C.E. Vol. 106, No. HY3 March. pp 437-439.

C.E.P.A. (1980) Program library abstracts Society for Computer applications in Engineering Planning & Architecture Rocksville, Maryland. U.S.A.

CROLEY T.E. (1977) Hydrologic and Hydraulic computation on small programmable calculators. The Iowa Institute of Hydraulic Research, University of Iowa. U.S.A.

CROLEY T.E. (1980) Synthetic Hydrograph computations on small programmable calculators. The Iowa Institute of Hydraulic Research, University of Iowa. U.S.A.

GOULD B.W. (1967) Economical stormwater detention basin design. Australian Civil Engineering and Construction. March.

GOULD B.W. (1967) Stormwater detention basins. Australian Civil Engineering and Construction. April pp43.

HALL M.J. and HOCKIN D.L. (1980) Guide to the design of storage ponds for flood control in partly urbanised catchment areas (Draft). Construction Industry Research and Information Association, Technical Note 100. (Gt. Britain).

LAURENSON E.M. and MEIN R.G. (1978) RORB User Manual - General runoff routing computer program. Department of Civil Engineering, Monash University.

McCuen R.H. (1979) Downstream effects of stormwater management basins. Journal of the Hydraulics Division of A.C.E.A. Vol. 105, No. HY11. November. pp1343-1356.

MICROCOMP (1980) Civil engineering software systems - catalogue. Solana Beach, California. U.S.A.

O'LOUGHLIN C.F. and SARIAN D.Z. (1979) Minicomputer programs for hydrology. The N.S.W. Institute of Technology, Civil Engineering Monograph CE79/2. W.F.

O'LOUGHLIN C.G. and SARIAN D.Z. (1979). Minicomputer programs for hydrology. The N.S.W. Institute of Technology, Civil Engineering Monograph CE79/3. W.F.

POERTNER H.G. (1974) Practices in the detention of urban stormwater runoff. American Public Works Association, Special Report No.43.

THOMPSON D.G. (1975) Hydrologic design of retarding basins in small urban catchments. The Institution of Engineers Australia. Proc. Hydrology Symposium, Armidale. pp183-187.

UNIVERSAL SOFTWARE APPLICATIONS (1980) Civil Engineering Software Packages - catalogue. St. Louis, Missouri. U.S.A.

WOODWARD S.M. (1920) Hydraulics of the Miami Flood Control project. The Miami Conservancy District, Dayton, Ohio. U.S.A.