DETENTION POND SIZING
ISSUE PAPER

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EXECUTIVE SUMMARY

This Issue Paper discusses several interrelated topics affecting the sizing of stormwater detention ponds, namely: design techniques, performance standards, and factors of safety.

Three alternative and readily available design techniques are discussed in the Issue Paper: the Y&W Method, the SCS/SBUH Method, and HSPF. Because of deficiencies in design technique, detention ponds sized using either the Y&W Method or the SCS/SBUH Method are too small and cannot be expected to meet stated performance standards unless the design volumes are substantially increased through imposition of a correction factor or factor of safety. Ponds designed using the Y&W Method are grossly undersized and use of the Y&W Method should be discontinued as soon as practicable.

Experience throughout the Puget Sound lowlands is that the EPA's HSPF model is the most reliable tool currently available for sizing stormwater detention facilities for new developments. It is expected that ponds sized using HSPF will meet their design performance standards. HSPF is, however, a very difficult tool to use and its use is probably beyond the capabilities of many small development engineers. A simplified "Runoff Files" implementation of HSPF is discussed in the Issue Paper. Development, by the County, of a Runoff Files approach would provide a practical means by which developers could accurately size and design detention ponds while avoiding the technical and computational difficulties of using HSPF.

The Issue Paper discusses a number of alternative performance standards for the design of stormwater detention ponds. The standards discussed fall into one of two somewhat different categories; those that address control of flooding only, and those that address both control of flooding and protection of instream aquatic resources through control of increases in stream channel erosion. The current Department of Ecology Streambank Erosion Control standard (which requires 2/0.5*2, 10/10, 100/100 control[1]) falls into the latter category, i.e. control of both flooding and stream channel erosion. It is recommended that this standard be adopted by the County for consistency with both the Department of Ecology requirements and the County's own goals for protection of aquatic resources.

As an interim measure, it is recommended that the County adopt the SBUH 24-hour Method for detention pond design with a Department of Ecology 2/0.5*2, 10/10, 100/100 performance standard and with computed detention volumes increased by a factor of safety or correction factor varying from 2.5 for single family residential developments to 3.7 for commercial and industrial developments. Analyses performed for this Issue Paper and described in Section 6, show that ponds sized in this manner, with the stated correction factors, would have approximately the same storage volumes as ponds sized using HSPF.

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1 An x/y standard indicates control of the x-year post-development peak flow to the y-year pre-development peak flow. For example, a (2/0.5*2, 10/10) standard indicates control of the 2-year post-development peak flow to one-half of the 2-year pre-development peak flow, and control of the 10-year post-development peak flow to the 10-year pre-development rate. Other standards are similarly defined.

In the longer term, we recommend that the County develop a Runoff Files implementation of HSPF somewhat similar to the King County Runoff Time Series (KCRTS) package developed by King County but taking advantage of the more powerful personal computer technology now available. Pond volumes determined using a Runoff Files approach should be increased by a factor of safety of 10% to account for uncertainty in design.

1.0 ISSUE

Research and experience over the past several years have shown that detention pond sizing and the ability of detention ponds to meet stated performance standards is a function of a number of variables, including:

- the method of hydrologic analysis,
- the type of land use conversion in question, and,
- the detention pond performance standard.

As discussed in more detail below, there is very little quantitative data on the actual performance of stormwater detention ponds designed using different design tools and performance standards. Facility performance has historically been assessed in one of two ways: qualitatively, using field observations of flooding and erosion problems following development; and quantitatively using theoretical simulations of pond performance. Most of this work has concluded that the analytical tools and techniques commonly used to size detention ponds in western Washington, produce detention facilities that are too small and that fail to meet stated performance standards. To correct these deficiencies, several jurisdictions have adopted a "factor of safety" to be applied to the calculated detention pond volume.

Note that the term "factor of safety" has been used in two somewhat different ways by jurisdictions in the Puget Sound region:

- as a correction factor applied to computed pond volumes to account for known inadequacies in the design technique being used, and,
- as a true factor of safety where the analytical technique in use is believed to be sound and where greater assurance is needed that the stated performance standard will be met.

This issue paper considers detention pond design techniques, performance standards, and the need for imposing a factor of safety on calculated detention pond volumes. Selection of an appropriate value for the factor of safety is discussed and the approximate impact of design technique and performance standard on detention pond sizing is presented.

2.0 ALTERNATIVES

This issue paper addresses several interrelated items which cannot be treated separately: detention pond design technique, performance standard, and factor of safety. The paper therefore considers alternatives in each of these areas.

Alternative detention pond design techniques considered are:

- Y&W - the current method allowed for detention pond sizing for the majority of small developments in Snohomish County.

- SBUH 24-hour - a simple, widely used storm event method for estimating pre- and post-development runoff and sizing detention facilities.
- SBUH 7-day - an adaptation of the SBUH 24-hour method which uses a longer duration storm event for design and which is intended to circumvent some of the shortcomings of the SBUH 24-hour method.
- HSPF - a sophisticated continuous hydrologic simulation model which probably produces the most reliable and complete characterization of pre-and post-development hydrology of any technique available in western Washington.

Alternative detention pond performance standards considered are:

- 10/10[2] peak flow control
- 2/2, 10/10 peak flow control
- 2/2, 10/10, 100/100 peak flow control
- 2/0.5*2, 10/10, 100/100 peak flow control

Note that the above performance standards address control of peak flows. The second and third of the standards above are most appropriate for control of flooding. The (2/0.5*2, 10/10, 100/100) standard, which, with provision of an appropriate factor of safety, forms the basis for DOE's Streambank Erosion Control Standard, is, however, intended to control both the frequency and duration of erosive flows. This standard is appropriate for both control of flooding and protection of instream aquatic resources. Explicit flow duration control standards have been proposed and adopted in some jurisdictions in western Washington (notably by King County). Although these are discussed briefly in the following sections their use is not analyzed because of their complexity and budget limitations on preparation of this issue paper.

Several alternative approaches to adoption of a "factor of safety" are considered in this issue paper, as follows:

- no factor of safety applied to computed pond volumes,
- a factor of safety (more properly termed a "correction factor") applied to computed pond volumes to ensure that ponds designed using approximate analytical methods will, on average, meet stated performance standards, and,
- a factor of safety applied to computed pond volumes to provide a better than average assurance that ponds designed using advanced analytical methods will in fact meet stated performance standards.

Note that the term "factor of safety" is used throughout this issue paper even where the factor applied should more properly be termed a "correction factor".

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[2] An x/y standard indicates control of the x-year post-development peak flow to the y-year pre-development peak flow. For example, a 2/0.5*2 standard indicates control of the 2-year post-development peak flow to one-half of the 2-year pre-development peak flow.

3.0 COMPARISON OF ALTERNATIVE DESIGN TECHNIQUES

(Much of the material in this section is taken from an incomplete draft "Detention Issue Paper" prepared by King County Surface Water Management Division, dated April 1994. Permission to use this material is gratefully acknowledged.)

While there are a large number of hydrologic modeling tools available for evaluating the hydrologic impacts of development and designing appropriate mitigative measures, the choice of tools is in practice severely limited by the need for methods which:

- can produce reasonably reliable estimates of pre-development and post-development runoff without model calibration (i.e. without site specific hydrologic data);
- take account of the somewhat unusual meteorological and geologic conditions in the lowland Puget Sound area;
- can be used effectively and at reasonable cost both by engineers in the development community and by those responsible for review and regulation.

If the above criteria are applied, the choice of tools for detention design in western Washington is realistically limited to:

- the SCS Method (or one of its derivatives) for which model parameters (curve numbers) and rainfall distributions for western Washington have been published by the SCS;
- the HSPF model, for which generalized parameter estimates have been published by the U.S. Geological Survey.

However, a third method, the so-called "Y&W Method", has also seen wide use in western Washington. Its use is currently permitted in several local jurisdictions, including Snohomish County, and so has been included in the following discussions for completeness.

3.1 The Y&W Method

The "Y&W Method" for detention design was originally developed in Michigan and is described in detail in a paper by Yrjanainen and Warren[3]. The method assumes use of the Rational Method to estimate post-development peak flows and presents a set of very simple mathematical expressions to estimate directly the storage required to control post-development peak flows to pre-determined target releases. Estimates of storage requirements can be made on a hand calculator in a matter of minutes.

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[3] Yrjanainen, G. and A.W. Warren, A simple method for retention basin design, Water and Sewage Works, December 1973.

The method was adapted for use in King County (it first appears in the February 1977 "Requirements and Guidelines for Storm Drainage Control in King County") and was subsequently adopted by a number of other local jurisdictions for detention facility design, generally for sites smaller than about 200 acres. The reasons for adoption of the Y&W Method are not known but are presumably related to its ease of use. There is no information available on the level of scrutiny applied to the Y&W Method prior to its adoption.

In developing the Y&W Method, a large number of assumptions had to be made to simplify the mathematics sufficiently to produce an explicit solution for the detention storage required. Many of these assumptions are simply not credible. For example, one crucial assumption is that "storm water rises in the retention basin at a constant rate". A second inherent assumption is that rainfall can be characterized as a simple short duration event of constant intensity in which rainfall intensities are determined by fitting a mathematical expression to published rainfall intensity-duration-frequency curves.

Various reviews of the Y&W Method have shown that the method produces designs which, simply stated, cannot hope to meet required performance standards. One such review is included in Appendix AIII-1.2 of DOE's February 1992 "Stormwater Management Manual for the Puget Sound Basin." It is now generally accepted that ponds designed using the Y&W Method have little effect in controlling peak flows from developed properties. Two types of modifications to application of the Y&W Method have been made by various local jurisdictions in an apparent attempt to improve its performance. These are:

- use of multiple orifice outlets to control a range of flows
- imposition of apparently more stringent performance standards (e.g. control of post-development 100-year runoff to 2-year pre-development rates).

Paradoxically both modifications result in a deterioration of the method's performance.

In the first case, two or three orifices may be provided in the pond's outlet control structure with a small bottom orifice. The reduction in release through the bottom orifice is not offset by an adequate increase in pond volume, and so the pond frequently fills to discharge at relatively high rates through the larger upper orifices.

In the second case, the reduction in target release (usually through provision of a single small orifice outlet) is also not offset by an adequate increase in pond volume, and results in frequent uncontrolled pond overflows.

Although the Y&W Method is still widely used by local jurisdictions, its only advantage is extreme ease of use. Ponds designed by the Y&W Method are seriously undersized and have no benefit on either flood control or erosion control.

3.2 SCS Method

The SCS Method belongs to a class of what are known as "event" models in which a (usually hypothetical) design rainfall event of specified duration is transformed to a corresponding design flow hydrograph with the same return period through use of a transformation function known as a unit hydrograph. The SCS Method and its derivatives have a very limited physical basis and require that the user determine a priori the appropriate duration of the design rainfall event, and the soil moisture conditions antecedent to the design event. There are many different implementations of the SCS Method. Two alternative implementations discussed here are the SCS/SBUH 24-hour Method (the method currently required for the design of stormwater management facilities in King County and allowed in most other local jurisdictions) and Barker's adaptation of the SBUH Method for use with a 7-day design event.

3.2.1 SCS/SBUH 24-hour Event Method

The SCS Method (or one of its derivatives such as the Santa Barbara Urban Hydrograph or SBUH version of the SCS Method[4]) in conjunction with a simple level-pool reservoir routing model is superficially a very attractive tool for detention facility design. Design of a simple detention facility to control peak flows to pre-development rates is done in three basic steps:

- The SCS Method is used to determine peak pre-development flows that provide the control targets for storm events of selected frequency or return period.
- The SCS Method is used to generate post-development hydrographs for required design storms.
- The post-development hydrographs are routed through a simple reservoir whose size and outlet design are adjusted to control post-development peaks to target rates. (This typically involves a number of iterations to produce an "optimal" size for the facility).

The method as commonly applied assumes use of a hypothetical design storm event (as opposed to observed rainfall data) and rainfall distributions and model parameters specific to western Washington have been developed by the SCS.

The SBUH version of the SCS Method using a 24-hour design event was adopted for detention facility design by King County in the January 1990 "King County Surface Water Design Manual". Use of the SCS or SBUH Method in conjunction with a level-pool routing technique for sizing detention facilities offers some distinct advantages over the Y&W Method:

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[4] The terms SCS Method and SBUH Method are used interchangeably throughout the text.

- There is a clear separation between the estimation of design hydrographs and the sizing of detention facilities.

- The level-pool routing method is an accurate and reliable method for sizing detention facilities given an accurate inflow hydrograph and a realistic target release.

- The method uses storm rainfall distributions and model parameters developed specifically for western Washington.

- The method is widely known in the engineering community.

The SCS Method was originally developed for estimating flows from small ungaged catchments for use in the design of small agricultural drainage facilities and in its original development there appears to have been no thought or intent that the method would be used for the design of urban stormwater control facilities.

Work has been conducted, primarily at King County but also at the Washington State Department of Ecology, comparing flow rates and runoff volumes predicted by the U.S. EPA's HSPF model (currently believed to be the most reliable tool available for modeling stormwater runoff in the Puget Sound lowlands and described in detail in Section 3.3) and by the SCS 24-hour design storm method. Analyses have also been undertaken to determine the performance of detention facilities sized using the SCS Method when subject to flow rates predicted using HSPF. These analyses produced a number of interesting results, the principal findings being as follows:

- The SCS Method generally overestimates peak flows for undeveloped conditions. The degree of overestimation appears to increase as the return period of the event increases and varies with land use condition. Overestimation of peak flows appears to be especially severe for pasture cover; storm event peak flows for pasture cover may be overestimated by a factor of 2 or 3. Overestimation of pre-development peak flows by the SCS Method results in detention facility target releases being too high and, consequently, pond volumes too small.

- Use of the SCS hypothetical 24-hour design event appears to be inappropriate for detention pond design in the Pacific Northwest particularly where peak flows are restricted to the 2-year pre-development peaks flows or lower. Storm events in the fall and winter months in the Pacific Northwest are often long duration (three or four-day) events of relatively low intensity. The SCS Method's approach to design typically assumes a 24-hour design event with the detention pond empty at the start of that event. Continuous simulations with HSPF (using observed rainfall time series rather than hypothetical design events) however indicate that ponds will be part full as a result of antecedent rainfall before a major event occurs.

These findings strongly suggest that, as with the Y&W Method, ponds designed using the SCS 24-hour Method cannot meet stated performance standards.

The above findings are predicated to a large extent on the assumption that HSPF provides an accurate portrayal of pre- and post-development flow regimes. However, direct indications that the SCS Method overestimates peak flows for major events are also available from examination of rainfall and streamflow data collected on small catchments. There are also other less quantitative indications of overestimation of peak flows by the SCS Method. For example, the rate of failure of culverts and other conveyance facilities designed by the SCS Method is much lower than would be expected given that many designs are based on a 10 or 25-year design event, thus providing an indirect indication that estimates of peak flows are high. There are also frequent instances of the SCS method predicting significant discharges from sites with no evidence of channels or other drainage features capable of conveying such flows.

As with the Y&W Method, attempts have been made to improve the performance of detention ponds designed by the SCS 24-hour Method by a number of different techniques:

- imposition of a "factor of safety" applied to computed detention volumes.
- development of artificially restrictive performance standards.

"Factors of safety" for hydrologic design of detention ponds were first introduced into the 1990 King County Surface Water Design Manual as a way of accounting for uncertainties in design. Various interpretations or justifications for factors of safety have been put forward however the general result is some improvement in pond performance over what otherwise would have been achieved. As will be seen in Section 6, the 30% factor currently required in King County is too small to account for the intrinsic problems with the SCS 24-hour Method, and its inability to meet stated performance standards.

An alternative means of achieving desired standards of performance is to impose artificially restrictive design criteria which produce a design capable of meeting certain control targets. For example, one of King County's Stream Protection standards, the Critical Drainage Area standard, calls for design with the SCS 24-hour Method to a 2/0.5*2, 10/2, 100/10 standard with computed volumes increased by a 30% factor of safety. This standard was actually developed with the intent of controlling post-development durations of high flows to pre-development durations for a range of flows from 50% of the 2-year pre-development peak flow through the 50-year pre-development peak flow. (A somewhat similar standard has been adopted by DOE as its Streambank Erosion Control Standard.)

While this approach appears to produce the desired results for conversion of forest lands on till soils to residential or commercial use, it fails to do so for development on pasture or grass land. Furthermore, use of this approach has led to considerable confusion as to just what the intended control standard is, and it has also led to a proliferation of slightly different performance standards applicable in different parts of King County.

In a further attempt to improve the performance of designs, a number of modifications to the SCS/SBUH 24-hour Method have been investigated. These include:

- modification of the SCS Method to improve its ability to predict flow rates and
- a change in the basis for design from a 24-hour rainfall event to a 7-day rainfall event.

Both of these features were incorporated in a modified version of the method developed for King County by Barker and described in the following section.

3.2.2 SCS 7-Day Event Approach

Work on modifications to the SCS/SBUH 24-Hour Method to improve the performance of detention facilities is described in detail in a report by Barker[5]. Barker's approach to the problem was to assume that the HSPF model provides an accurate portrayal of actual flows and to modify the SCS method to produce flow rates and pond sizes equivalent to those produced if designs were done using HSPF. The principal changes to the SCS Method recommended by Barker were as follows:

- The duration of the design event should be increased from 24-hours to 7-days to account for the long durations of rainfall commonly encountered in the Pacific Northwest and the observation (both in practice and in HSPF simulations) that detention ponds are often part full at the start of major events.
- Use of the SCS Type 1A temporal distribution of rainfall should be dropped, and replaced by a distribution developed by the Dam Safety Section of the Washington State Department of Ecology (DOE). The SCS Type 1A distribution seems to produce unrealistically high rainfall intensities for western Washington and the DOE distribution, which is based on detailed analysis of rainfall data throughout the Puget Sound region, is believed to be more realistic.

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5 Barker, B., Modifications to the Santa Barbara Urban Hydrograph Method to Improve Detention Pond Performance. Report to King County Surface Water Management Division, April 1992.