DESIGN STAGE MODELING REQUIREMENTS FOR REDUCING STORM WATER QUANTITY AND QUALITY RISKS OF URBAN DEVELOPMENT

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ABSTRACT

Recent prototype evaluations of alternative land development approaches indicate that storm water flow rates can be substantially reduced (as much as 50%), volumes reduced, peak flows delayed and water quality improved. This paper discusses the potential and challenges of implementing a design stage planning system to include storm water impacts as part of project review. Development and use of such a system in a watershed could result in saving lives and reducing property damage and economic dislocations associated with major floods.

INTRODUCTION

It is well known that Urban development reduces an area's natural capacitance that can moderate storm water flows. As a consequence, increased urbanization increases the frequency, severity, and impact of flooding in urban areas and in downstream locations (Newkirk, 1995, 1996). This can lead to emergency events that endanger large numbers of people and property. Significant and nonreversable changes in effective hydrology of areas may result from urban development. In addition, urban activity and land maintenance practices often substantially contaminate storm water quality. Bryan (1972) reports that urban storm water is, at times, as contaminated as the effluent discharged from primary sewage treatment facilities in terms of biological oxygen demand (BOD) and its chemical oxygen demand (COD) can be greater than raw sanitary sewage. Storm water transported contaminants, can compromise the quality of groundwater and supply of potable water for urban areas (Laurent *et al.*, 1995).

An individual urban development often experiences less effects from its storm water changes than the effects experienced by downstream areas. Historically, storm water has been handled as a waste product to be fast and efficiently moved off site (Imhof & Annable, 1993). It may be said that new urban developments export undesirable storm water effects to minimize costs of development. The impacts of upstream changes are cumulative within a watershed and can lead to very significant impacts on downstream safety. Yet storm water studies as part of the development design process are not used because of the time and cost; the time cost is perceived as an important limiting factor (Liong et al., 1991).

Two studies (Newkirk, 1996) with prototype evaluation systems show there is potential to realize significant reductions in storm water flow rates and volume, and improving storm water quality by altering subdivision design. However, this requires proposed development plans to have alternate development strategies evaluated for their storm water impacts as a regular part of the development design stage in the planning process. This would involve evaluating alternative location, density, nature of development, and vegetation planing and maintenance practices using of a suitable interactive geographical storm water simulation system. In many rapidly developing areas of the world, there is little direct control of development by governments. Even in jurisdictions where governments review and issue permits for development, it is normal that storm water assessment is usually completed only for larger scale projects, and it is applied in final project design to ensure that storm water management facilities will provide adequate service in the development itself. This is because detailed hydrology modeling requires the services of specialist engineering firms and is considered expensive by most developers and designers.

A "what if" assessment framework that would allow designers and planners to obtain a rough assessment of potential impacts of alternative conceptual development designs on storm water without requiring reference to external experts could provide a means of evolving more environmentally sensitive designs earlier in the planning process (Newkirk, 1995, 1996).

DESIGN STAGE PROTOTYPE

Two graduate students under direction of the author implemented prototype systems to study the potential impact of design changes on residential subdivision storm water outputs. A longer term objective was to establish a research agenda aimed at developing a design stage analysis capability that could be used by practicing planners (and other interested parties) when new urban development concepts are being proposed. The prototypes undertook to:

a) explore the potential scale of changes in storm water quantity and quality that might result from rather straight forward adjustments to development design. (One project examined storm water outputs related to relocating major sections of development within a development using standard subdivision design; the other project examined storm water quality aspects related to more individual site specific approaches using standard and more environmentally "friendly" alternative designs.)

b) assess the effectiveness and usefulness of well established computer application systems for design stage storm water purposes,

c) explore the potential to automate aspects of the model development process with the aim of making the overall assessment process more suitable for use by practicing planners,

d) determine a research and development agenda required to develop a system that could be used by professional planners who are not technical specialists.

METHOD

A general summary of the modeling process and general storm water results are reported in Newkirk (1996). Readers are directed to the theses (McKenzie, 1996, and Pascoe, 1996) for detailed discussion of the various steps and results of prototype activity. The prototypes were applied to constrained but real problems. Actual new development areas and normal development practices and densities were used. Constraints were necessary to facilitate prototype development within a reasonable time limit. Constraints applied to locating the test areas were:

- chosen to be similar in size but small. (Sizes were chosen to be about 100-150 acres to minimize modeling scale but still include a variety of site parameters.
- located far upstream to avoid having to model adjacent areas, and to avoid issues of overland flow from neighboring areas.
- selected in an area where there is a good supply of recent and detailed data
- located where site development would not require extensive of major surface engineering. This removed the necessity of altering the digital terrain model and associated drainage (i.e., catchment) area dimensions.
- Since the researchers are planners and not hydrologists or computing specialists, the prototype systems were based on "off the shelf' standard software application systems. The main systems used were: geographic information systems ARC/Info and PC-ARC/Info, and storm water modeling systems SWMM and SWMMDuet.

The design stage prototype analysis development is reviewed in Newkirk (1996) and is discussed in detail in McKenzie (1996) and Pascoe (1996). The general approach once a test site was selected was to first establish a base case. The steps involved were:

a) obtain or develop digital data information that describes the site characteristics and set up as a GIS application. This includes detailed mapping of soil type and drainage, vegetation, existing land use, and digital terrain elevation model (DEM).

b) complete a GIS analysis to determine a set of general drainage areas. This involved using GIS tools to analyze the DEM.

c) use GIS to combine the general drainage areas with soil information, vegetation, land use to subdivide drainage areas into a set of catchment areas of homogeneous characteristic.

d) develop a diagram (i.e., graph) that expresses the drainage linkages between the catchments.

e) develop a SWMM representation of the linkages and characteristics of the catchments. This involved GIS operations and analysis to calculate the parameters required for the SWMM model. In addition, this involved the specification of numerous SWMM parameters (Newkirk, 1995).

f) load appropriate meteorological observations into SWMM and run a simulation.

g) Compare SWMM output with field observations and finalize key model parameters.

Once the base case simulation system was developed, a process was initiated to assess how alternative site development would alter its performance. This required the analyst to:

a) develop and digitize site maps showing the several development proposals. These were added to the GIS system.

b) use the GIS to overlay the development proposals on the catchment mapping and calculate spatial values that allow the SWMM attributes in the base case to be recalculated to reflect the changes affected by the proposed developments.

c) develop and run a separate SWMM simulation model for each alternative development.

d) export the performance data from the base case and alternatives for analysis with external statistical and presentation systems.

Communication between the GIS and SWMM or SWMMDuet depends on numerous computer files each containing many variables. The analyst is required to invest substantial care and attention to this activity. It was possible to program some these processes as part of the prototype development; hence, some automation of technical development has been achieved. The interpretation of alternative designs and the assessment of how they alter the base case required substantial work by the analyst as well.

RESULTS

The results of both prototype studies as reported (McKenzie, 1996; Newkirk, 1996; Pascoe, 1996) show that substantial reductions in storm water effects of alternative development designs could be realized. For example, one simulation showed that a 50% reduction could be possible in storm water flow rates. Planners who have had an opportunity to view the prototype analysis results express strong interest in having such an analysis system available to be used in the design process as various design concepts are evolved and tested. On the other hand the high level of technical detail, system, and modeling knowledge required of the analyst makes use of this approach challenging for professional planners and site designers. In addition, it was found that it is not possible to simulate adequately flows of surface water from one catchment to another during rainfall events (without representing the flow as a single collection and single pour point connected by a pipe). Yet, it appears that the storm water modeling system is overly complex for a rough estimate design stage tool that can help guide design of alternative development concepts.

If one separates the technical aspects of prototype system development and modification from the fundamental application tasks that a user must complete to conduct a comparative analysis, one sees that even the data development and modeling is too time consuming to encourage use in practice. Table 1 adapted from Pascoe (1996) estimates the staff time, system resources used and staff skills required to complete an analysis of four scenarios on a small 100-150 acre site by a *trained* planning analyst. In considering these estimates, it should be understood that these are based on the constrained prototype studies. In particular, the studies did not involve any major reengineering of the sites. In many cases, urban development of an area may involve substantial engineering modifications that will alter the slope aspects and vegetation of extensive tracts of land. This would require specific modification to the original DEM and a recalculation of slope areas and catchments before alternative development or site designs could proceed. This estimate is not included in the table, but could easily add 10 to 20 hours to the estimates.

Table 1: Estimated Time for Alternative Development Proposals

Process Step	Time	System Resources	Staff Skills
Base map digitizing and input	8-10 hours	GIS	Basic GIS operations ability+
Soils map digitizing and input	3-5 hours	GIS	Basic GIS operations ability+
DEM slope area determination	1-2 hours	DEM for area. SWMMDuet	Familiarity with the basic GIS processes.#
Establish catchment areas by overlay	4-6 hours	GIS	Knowledge of GIS overlay techniques and editing.*
Estimation and input of catchment values	2 hours	SWMMDuet	Basic SWMMDuet knowledge#
Percent impervious calculation for catchments	1 hour	SWMMDuet	Basic SWMMDuet knowledge#
Field check stream flow data, soil parameters	10-20 hours	Data loggers, statistical summaries	Basic field hydrology and soil testing
Precipitation data input.	1-5 hours	SWMMDuet	Basic SWMMDuet knowledge+
Alternative development Scenario input			
Digitizing	1-2 hours	GIS	Knowledge of GIS overlay techniques and editing.*
Analysis	2-4 hours	GIS	
Changed data calculation	1-2 hours	SWMMDuet	
SWMM input files for alternatives	2-4 hours	WMMDuet	Basic SWMMDuet knowledge
SWMM simulation run and Output Analysis			
Sensitivity analysis	1 hour	PCSWMM	Statistical analysis
Graphing and interpretation	10-15 hours	Statistical package	
TOTAL	**47-70 hours**		

**Previous experience operating a GIS system*
#SWMMDuet provides on line required guidance
+could be accomplished with little GIS experience

After Pascoe (1996, p105)

With applications tasks requiring from 47 to 70 hours of dedicated trained staff time, such an analysis for a small (100 to 150 acre) site could require from 3 to 5 weeks elapsed time, and substantial staff costs. This is hardly fast enough to make such an analysis of much use in a project design process. SWMM

Modeling output remains tabular. It is up to the user to interpret the meaning of the hydrographs and to visualize this impacts on the site and downstream. No formal means are available to link the results from a design simulation study to other larger scale model systems that could estimate downstream effects. Furthermore, without some reduction of technical demands of the user, its use would normally be at arms length from the designer. These factors would discourage designers to use such a design assessment aid.

CONCLUSIONS

The prototype studies demonstrate that there is significant potential to reduce storm water effects of urban development if alternative development designs are considered. These designs can provide approximately the same number of development units and may not increase development costs. On the other hand, the technical complexity and time demands of current systems are such that they are not likely to be used for design stage analysis. The post hoc evaluation of the prototypes leads us to suggest that the following is required if a system is to be suitable for practical use:

- A simplified storm water modeling system that is aimed at providing only rough estimates suitable for use at the concept design stage is required. It would use a reduced set of variables and assumed values associated with urban development in a set of normal development contexts. More complex and detailed storm water modeling would be left for the one or two final proposals that result from the design process.

- A library of typical parameter and variable values that are keyed to common soil conditions, site development practices, structure types, etc. is required for system and user consultation.

- Overland flow calculations that could be modified by standard sets of vegetation and grading practices need to be processed by the simulation system and available for reference by users. This should include example graphics images that could help development designers select specific items to be applied to a concept development.

- Modeling interaction through an interactive graphics process is required to allow a designer to describe significant engineering changes that would alter the slope, and vegetation of the base case. This system should then automatically readjust the base case in preparation for simulation of several development scenarios. This will require some expert system operations in concert with the libraries of parameters and variables mentioned above and will likely involve requests for user input.

- An interactive graphics process is required to allow the user to (a) describe the layout of a proposed development, and (b) select from a library of site development structure types, site vegetation types, physical infrastructure types, etc. to develop an image of a development design concept. Various concepts developed by the user should be named and stored in the file system. The system, possibly involving some expert system processing, would use the layout and selected types to adjust the base model to develop and run storm water simulations.

•Analysis output should be presented by the system, named by the design alternative being evaluated, in statistical charts as well as tabular form and located as well at appropriate locations on the overall site map. Summary graphics and reports should be produced that display comparisons between the base case and the several alternative designs.

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