DEVELOPMENT OF A DECISION-SUPPORT FRAMEWORK FOR PLACEMENT OF BMPs IN URBAN WATERSHEDS

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ABSTRACT

The U.S. Environmental Protection Agency (EPA) has initiated a research project to develop an evaluation framework for the optimal placement of best management practices (BMPs) options at strategic locations in mixed land use urban watersheds. The integrated watershed-based stormwater management decision-support framework (ISMDSF) is to be based on a geographical information system (GIS) watershed/BMP database, cost, and hydrologic, hydraulic, and water quality modeling to achieve desired water quality objectives. The initial phase of this research is expected to be completed in early 2005. While this work is ongoing and many tasks have yet to start, this paper presents the project background, rationale, approach, initial review findings of watershed and BMPs models, and the preliminary design recommendations of the framework.

KEYWORDS

Stormwater, best management practices, low impact development, GIS, flow and water quality modeling, cost, optimization.

INTRODUCTION

After passage of the Clean Water Act in 1972, water pollution control efforts have focused primarily on wastewater discharges from point sources consisting of municipal treatment plants, industrial plants, and combined sewer overflows (CSO). Far less emphasis has been placed on diffuse source pollution, i.e., pollution from contaminants picked up and carried into surface water by stormwater runoff. While the overall quality of the nation's waters has improved from point source control, a significant number of water bodies still suffer from poor water quality. In the 1998 Report to Congress (USEPA, 2000a), of the assessed stream miles (23% of the nation's 3.6 million miles of river and streams), about 40% are still impaired – that is, unsafe for fishing and swimming. Of the about 42%, or about 17.4 million acres of lakes, reservoirs, and ponds assessed, about 45% are impaired. The report identified agriculture as the leading source of the impairment, responsible for about 20% of the impaired river miles and about 33% of the impaired lake and reservoir acres.

Urban runoff/storm sewer discharges, on the other hand, are responsible for about 4.0% of impaired stream miles and about 13% of the impaired lake and reservoir acres. The top three pollutants/stressors for river and stream impairment are siltation, pathogens, and nutrients while that for lakes and reservoirs are nutrients, metals, and siltation. Urban areas are often proximal to highly valued recreational and environmentally significant waters such as Chesapeake Bay, Tampa Bay, and Lake Michigan. This indicates that while polluted runoff from agricultural sources may be an even more important source of pollution than urban runoff, urban runoff is still a critical source of solids and their associated toxic pollutants, particularly in the impairment of our lakes and reservoirs, the sources of most drinking water supplies, and critical estuarine and coastal waters. For example, it was found that the amount of lead contained in runoff from Washington, D.C. in 1988 (26,000 pounds) was nine times the total amount discharged from all of Virginia's factories in 1987 (2,900 pounds) (BNA Environmental Reporter, 1997). EPA reported that sediment loadings rates from construction sites are typically 10 to 20 times that of agricultural lands, with runoff rates as high as 100 times that of agricultural lands (USEPA, 2000b).

URBAN RUNOFF POLLUTION AND STORMWATER REGULATIONS

According to the U.S. Department of Agriculture, between 1945 and 1997, urban land area in the nation increased by almost 327 % from 15 million acres to about 64 million acres primarily developed from land that was previously forestland, pasture, and range (US Department of Agriculture, 2000). During the same time, paved road mileage has increased by about 280 % (USEPA, 2000c). As a result, urbanization, with its accompanying expansion of impervious surfaces, e.g., sidewalks, roofs, parking lots, and roads, has significantly increased the nation's total development land and paved surface area. This development reduces the amount of wetlands and other undeveloped land, and thus reduces the watershed's ability to mitigate floods, facilitate sediment replenishment, and improve water quality by removing excess nutrients and other chemical contaminants before runoff enters receiving waters. Urban development also causes changes in the hydrologic regime, which can result in more frequent bankful events, lower baseflows, and increased stream channel erosion (Roesner *et al*., 2001).

Urban runoff includes nutrients, solids, pathogens, metals, hydrocarbons, organics, salt, and trash. Water flowing over various surfaces, such as streets, parking lots, construction sites, industrial facilities, rooftops, and lawns carries these pollutants to receiving waters. Research conducted by the Center for Watershed Protection found that in general, when the percentage of impervious cover exceeds 25 to 30 percent of the watershed, streams tend to no longer support diverse fish and aquatic life and have poor water quality (Center for Watershed Protection, 1994).

Recognizing the significance of continuing adverse pollution effects of stormwater on the nation's waters from the municipal separate storm sewer systems (MS4s) and that associated with construction and industrial activities, the U.S. Environmental Protection Agency (USEPA) issued, under the National Pollutant Elimination System (NPDES) program, Phase I stormwater regulation in November 1990 to target large and medium-sized MS4s with a population of 100,000 or more and construction sites of 5 acres or larger. The Phase II Final Rule was published in the Federal Register in December 1999, and included the remaining small MS4s in urbanized areas and construction sites 1-5 acres. Phase I and Phase II stormwater regulations are designed to control stormwater runoff pollution generated from urban areas and highways in the same NPDES permit mold for controlling municipal and industrial wastewater point source discharges. From a legal standpoint, most urban runoff is discharged through conveyance systems such as MS4s that are point sources under the Clean Water Act.

BEST MANAGEMENT PRACTICES (BMPs)

While technology-based methods, e.g., upgrading of treatment plants, in-line and off-line storage facilities, and industrial pretreatment, can effectively achieve the NPDES municipal/industrial wastewater discharge permit conditions, control of storm-generated pollutants and flow can be relied on implementation of various structural and non-structural techniques known as best management practices (BMPs). Structural BMPs are designed to trap and detain runoff to settle or filter out the constituents before they enter receiving waters. Non-structural BMPs are designed to control pollutants at the source to prevent or reduce contamination of stormwater runoff. Preventing and controlling the sources of these types of pollution requires an aggressive public education program that aims to change people's behavior encouraging conformance with "good housekeeping practices." Examples of good housekeeping are proper handling and collection of motor oil, trash, hazardous wastes, lawn clippings, and pesticide and fertilizer application (USGAO, 2001). Non-structural BMPs also include local ordinances for control of pet waste, illicit connections, and illegal dumping; preventing and controlling erosion during construction, street sweeping, material storage and inventory practices and training; preventative maintenance of industrial and commercial sites; and spill prevention and response (UDFCD, 1999).

There are many types of structural BMPs available for stormwater runoff control and storage-treatment, and new treatment devices are frequently being introduced. Commonly available and typically used structural BMPs include: buffer strips, infiltration/ percolation systems, grass swales/ wetland channels, retention (wet) ponds, and wetland ponds. The removal mechanisms of particulate and soluble pollutants in the runoff by these structural BMPs can be grouped into the following nine fundamental unit processes: sedimentation, flotation, filtration, infiltration, adsorption, biological uptake, chemical treatment, degradation, and hydrodynamic separation (Huber *et al.*, 2003). Buffer strips and some infiltration systems use filtration and infiltration mechanisms to remove pollutants and are commonly used as control measures near the source. Riparian buffers function by intersecting the landscape immediately adjacent to streams. Vegetated swales/wetland channels are open channel systems that use grass to act as filtration media for intercepting suspended solids and other pollutants. Regional ponds and wetlands utilize a combination of physical, chemical, and biological processes to remove stormwater pollutants.

Low-Impact Development (LID)

In recent years, a BMP option called LID has rapidly been the target of growing interest and popularity as a means of intercepting pollutants and reducing flow rates during a storm event (Prince George's County, 1999). One of the primary goals of LID design is to reduce runoff volume by infiltrating rainfall water to the subsurface and groundwater, evaporating rainwater back to the atmosphere, and finding beneficial uses for the runoff rather than exporting it as a waste product through storm sewers. LID design can help replicate the pre-development hydrograph while reducing pollutants. LID stands apart from other approaches because of its emphasis on cost-effective, lot-level strategies that replicate pre-development hydrology and reduce the impacts of development. By addressing runoff close to the source, LID can enhance the local environment and protect public health while saving developers and local governments money. Instead of large investments in complex and costly engineering strategies for stormwater conveyance and management, LID strategies integrate green space, native landscaping, natural hydrologic functions, and various other techniques to generate less runoff from developed land. LID is different from the conventional engineering approach for stormwater management. While most engineering plans pipe water to low spots as quickly as possible, LID uses micro-scale techniques to manage precipitation-generated runoff as close to where it hits the ground as possible. This involves strategic placement of linked lot-level controls that are "customized" to reduce specific pollutant loads, flow rate, and volume.

LID uses a systems approach that relies on natural landscape functions. It includes integrating land and infrastructure management at the residential lot level. Common LID practices include: rain gardens and bioretention, rooftop gardens, sidewalk storage, vegetated swales, buffers and strips, tree preservation, roof leader disconnection, rain barrels and cisterns, porous pavement, soil amendments, and impervious surface reduction and disconnection. LID practices generally involve grading minimization, impervious area disconnections, increasing flow lengths, increasing time of concentration, and increasing opportunities to mimic pre-existing hydrology. The underlying philosophy of LID is the use of many small treatment areas and methods scattered throughout the watershed rather than regionalization of just a few larger treatment facilities (England, 2002). BMP placement strategies focus on trade-offs between the upstream BMP/LID options distributed throughout upstream drainage catchments with downstream more regionalized wet-retention basin/wetland systems. In the context of this paper, LID is considered a part of BMP.

THE USEPA PROJECT

The USEPA has initiated a research project to develop an evaluation framework for the optimal placement of BMPs options at strategic locations in mixed land use urban watersheds. The integrated watershed-based stormwater management decision-support framework (ISMDSF) is to be based on integrated geographical information system (GIS) watershed/BMP database, cost, and hydrologic, hydraulic, and water quality modeling to cost-effectively achieve desired water quality objectives. The initial phase of this project is expected to be completed in early 2005. While this work is ongoing and many tasks have yet to start, this paper will provide the project background, approach, initial findings, and preliminary conceptual framework design.

Rationale

A place-based analysis system is essential to support agencies as they move toward management evaluations and cost optimization. Potential end users of the ISMDSF will be local and county governmental planners, state and federal regulatory reviewers as well as concerned-citizen and stakeholder groups, all of whom will be involved in watershed and water quality/resource decision-making. The ISMDSF is not intended for engineers to use as a watershed drainage system design for flood and/or pollution control. It will, however, be useful for performing comprehensive evaluations of alternative options during the urban watershed WWF control plan formulation process. The project products can be used by state, inter-state, and local watershed management agencies in developing/reviewing their watershed stormwater management plans to achieve desired water quality objectives for receiving streams [i.e., total daily maximum load (TMDL)]. The modeling component in the ISMDSF will be based on sound urban hydrologic/hydraulic/water-quality routing principles that will include appropriate spatial and temporal scales. The modeling approaches will consider degrees of urbanization, nonstructural and structural BMPs, retrofitting existing, and design of new development. Only public domain computer codes will be used for both the ISMDSF and the models in simulating landside and receiving-water quality, flow routing, and WWF control practice performance.

Typically available modeling systems include watershed loading, receiving-water response, and partial representation of management practices. There is no comprehensive modeling system currently available for evaluating the location, type, and cost of wet-weather flow BMPs needed to meet water-quality goals. To meet the need for place-based evaluation techniques, this project aims for a process to systematically define needs, evaluate the currently available models and tools, design a comprehensive system, and build and test the system. At key milestones of the project, a technical work group, comprised of multiple EPA Office of Research and Development (ORD), Office of Water, and Regional representatives, will help evaluate and guide the progress of the system development.

Project Scope

It is envisioned that there are five design requirements for the ultimate development of ISMDSF. First, the system is designed for knowledgeable model users including those at local levels who are familiar with the technical aspects of watershed modeling. Second, it will include BMP selection and strategic placement to support decision-making. Third, the decision tool will be applicable to mixed land use urban watersheds. Fourth, it will include watershed and receiving-water hydrologic/hydraulic and water-quality modeling based on integrated data collection. Finally, it will have the capability to evaluate alternative solutions for achieving desired water-quality objectives based on cost-effectiveness (optimization).

The initial phase of this project will focus on overall framework design and watershed component development. The inclusion of optimization and receiving-water analysis modules will be the subject of future work.

Project Approach

The ISMDSF conceptual design will be derived from a systematic review and analysis process, followed by more detailed design and implementation, and finally testing of the system. The following five review and analysis steps will be followed in developing the conceptual design of the system: (1) evaluation of needs, (2) determination of technical requirements, (3) identification of modeling requirements, (4) review of available models/tools, and (5) preliminary design recommendations.

Evaluation of Needs

The first step in the review and analysis process is an evaluation of the specific needs of a system for optimal selection and placement of management practices in urban areas. The needs evaluation can be accomplished by addressing three questions whose criteria, if met, will provide the ability to meet the objective of the project: (1) What are the parameters for measuring the benefit or impact of management?; (2) What are the differences in performance associated with BMPs by types and by locations relative to the receiving water?; and (3) What are the costs of management alternatives? Added to the three questions below are specific considerations associated with each one:

1) *What are the parameters for measuring the benefit or impact of management?*
    i) Hydrology (volume, peak, frequency, duration)
    ii) Sediment (load, concentration)
    iii) Water Quality (for each pollutant), (load, acute concentration, chronic concentration)
    iv) Ecological (link to other habitat or biological indicators, e.g., temperature, habitat species/abundance/diversity, biological measures)
2) *What is the performance difference between management options/scenarios including one or more practices?*
    i) Individual performance for a range of structural and nonstructural practices, ability to evaluate impact based on multiple measures of benefit
    ii) Multiple practice performance evaluation including cumulative benefits
    iii) Location of individual or multiple practices relative to water body or receiving water
3) *What is the cost? What is the difference in cost vs. the measures of benefit or impact described in 1 and 2?*
    Individual practice costs including design, construction, and operation and maintenance (Heaney *et al*., 2002)

Technical Requirements

From the above three questions and associated consideration, a broad and ambitious set of technical needs for the project can be defined. For example, consideration of the full set of measures (i.e., hydrology, sediment, pollutants, and ecological impact) requires simulation of dynamic hydrology and time varying loads of sediment and pollutants, and potentially other ecological indicators such as temperature or relationships to biological indicators. Evaluating the implications of various configurations of management practices requires the ability to evaluate the performance of individual and multiple practices and sensitivity to location. For management analysis it will be necessary to simulate longer time periods over a sequence of storms. A sampling of the technical needs identified is show below:

- Ability to simulate hydrologic response (i.e., peak flow and volume)
- Ability to dynamically simulate pollutant concentrations and loads
- Ability to evaluate urban and mixed land uses, including pervious and impervious areas
- Consideration of short and long time periods (single and multiple event simulation)
- Consideration of a full range of management practices at a similar level of resolution
- Modeling of management practices on a time variable basis consistent with the need to evaluate hydrology and pollutant measures

- Ability to place management practices at any location within the watershed (i.e., at various distances from receiving waters and various stream orders)
- Ability to link watershed management to downstream measures of environmental condition (e.g., dissolved oxygen in a river, nutrient concentration in a lake)

These technical requirements will lead to a determination of specific modeling procedures or algorithms in the third step comprising the ISMDSF. For example, the need to simulate hydrologic response will require that the modeling procedures include the capability to simulate rainfall/runoff processes at sufficient detail/discretization for plotting hydrograph and pollutograph response curves.

Multiple-Scales

One dominant technical requirement of the system is the ability to place management practices at multiple scales. This is because placement of BMPs at different spatial levels, i.e., on-site, sub-regional, and regional (Figure 1), affects the overall cost effectiveness of the stormwater control system (Zhen, 2002; Zhen and Yu, 2002). In an urban setting, the on-site scale can be exemplified by building lots or neighborhoods with a drainage area in the range of 10-100 acres. Recently promoted LID technologies are normally applied on this scale. Retaining and treating the stormwater runoff at or near its source is the prime objective of the LID concept.

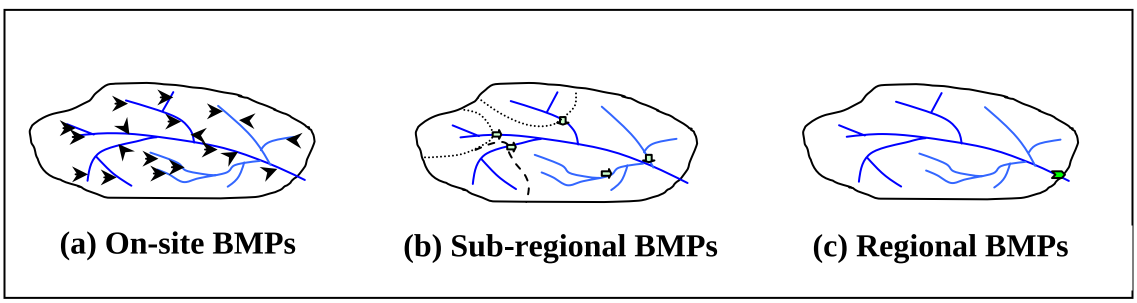

Figure 1 - Schematic diagrams showing BMP placement at various spatial levels: (a) On-site; (b) Sub-regional; and (c) Regional.

Other BMPs collect runoff at hydrologic junctions further downstream, at a level typically associated with the sub-regional scale. The sub-regional scale can be defined on a township level, with a drainage area of approximately 100-5,000 acres. At the regional scale the benefits of management are often measured by impacts to receiving streams, lakes, or other larger water bodies. The regional scale usually represents a watershed or sewershed on a county level with a drainage area greater than 5,000 acres.

To address the technical requirement for multiple-scale simulation, the modeling of the landscape, which provides the hydrologic and water quality time series data for simulation of BMPs, will need to have the capability to handle various spatial resolutions. Resolution of the analysis system will also need to vary depending on the density, type, and location of the BMPs evaluated. The model will need to provide an unbiased evaluation of the BMPs to provide input appropriate for optimization and comparative analysis of management plans.

Modeling Requirements

Based on a review of the technical requirements, modeling procedures or algorithms and system requirements can be identified. The required modeling procedures/capabilities are organized into four areas: 1) global system features, 2) watershed/landscape simulation, 3) management practice simulation, and 4) stream conveyance simulation. In evaluating modeling algorithms, practical constraints in simulation capabilities, options and flexibility in application are considered. Each area is described in more detail below:

Global System Configuration

The system must provide a framework for long-term simulation of landscapes, management practices, and hydrological systems. The overall system provides linkages between land characteristics, hydrologic responses, management practices, and stream networks. A generalized schematic of the relationships between the system components is shown in Figure 2. Several global requirements are placed on this system. For example, the system should be able to operate at a fixed or variable time step appropriate for the presentation of hydrographs and pollutographs, typically one hour or less and sometimes much less. The system may need to be configured to simulate small sub-watersheds or cells to a size on the order of 1 acre. To provide computational flexibility, the ability to define larger spatial units or a mixture of larger and smaller units should be considered.

The land units may be represented through lumped land use categories or distributed cells or grids representing a more refined variation of land areas. For cell-based systems, each cell has a definition of land use, soil or infiltration characteristics, slope, and other environmental features. For a lumped system, the watershed is represented by a small number of land units in which land use, soil, slope features and other environmental features are “lumped.” This formulation is not as spatially specific as cell-based models but is typically less data intensive and has faster computer runtime. ~~Use of small lumped watershed units can approach the complexity of a cell-based modeling system~~. Either approach could support the ISMDSF.

The system should also link to other external models, either watershed models for inputs of hydrology and pollutant time series, or receiving-water models for receiving-water assessment. For example, an evaluation of management scenarios to control nutrients in a watershed could be linked to a lake model to evaluate in-lake chlorophyll-a levels.

Watershed/Land Simulation

Consideration of watershed/land simulation includes algorithms to represent water, sediment, and pollutants generation and movement on the landscape. An initial assessment concludes that continuous simulation and smaller time steps are needed. The algorithms to represent these processes must also be of sufficient detail and discretization to evaluate changes in surface management and physical site characteristics that can be used for management. The needed algorithms to meet these objectives should include:

- Physical-based infiltration simulation (e.g., Green-Ampt)
- Overland flow routing/hydrograph generation
- Pollutant accumulation and washoff
- Sediment detachment and transport
- Land to land flow
- Groundwater interaction

Management Practice Simulation

The technical requirements also set out the need for unbiased simulation of BMPs. Typical practices use various combinations of storage, infiltration, filtration, biological processes, and hydrologic separation to provide control of stormwater runoff and associated pollutants. Table 1 provides a summary of key functional processes employed in commonly used management practices. Examination of this table supports selection of the various algorithms and simulation capabilities required for examination of BMPs. Review of this table leads to the recommendations for specific capabilities/requirements for BMP simulation such as:

- Process-based simulation of retention and detention types of management with at a minimum first-order decay and settling
- Time series simulation of management practices by routing runoff through management practices
- Simulation of land-based practices (e.g., surface cover management) through analysis of surface cover and soil properties
- Routing surface and sub-surface runoff/pollutants from one land unit to the next

Stream Routing and Conveyance Network Simulation

The stream routing and conveyance network component provides a linkage between sub-watershed/land units, management practices, and other direct discharges within an urban watershed. The stream conveyance module is used to route runoff, sediment, and pollutants through a stream network that commonly exist within an urban watershed. The rigor of simulation for the stream portion is related to the dominant processes present in urban streams. Key features include settling, resuspension, and decay (i.e., fecal coliforms), and changes in the stream channel (i.e., stream bank erosion or degradation). Hence, during conveyance in a stream, the module should consider settling, resuspension, and decay processes. Accounting for stream bank erosion should be considered as an option as well. Larger water bodies, including rivers, lakes, and tidal waters may require more detailed simulation of chemical and biological processes. These systems can best be simulated through external linkage to several comprehensive receiving water models such as EFDC (Hamrick, 1992) and WASP (Wool *et al.*, 2003).

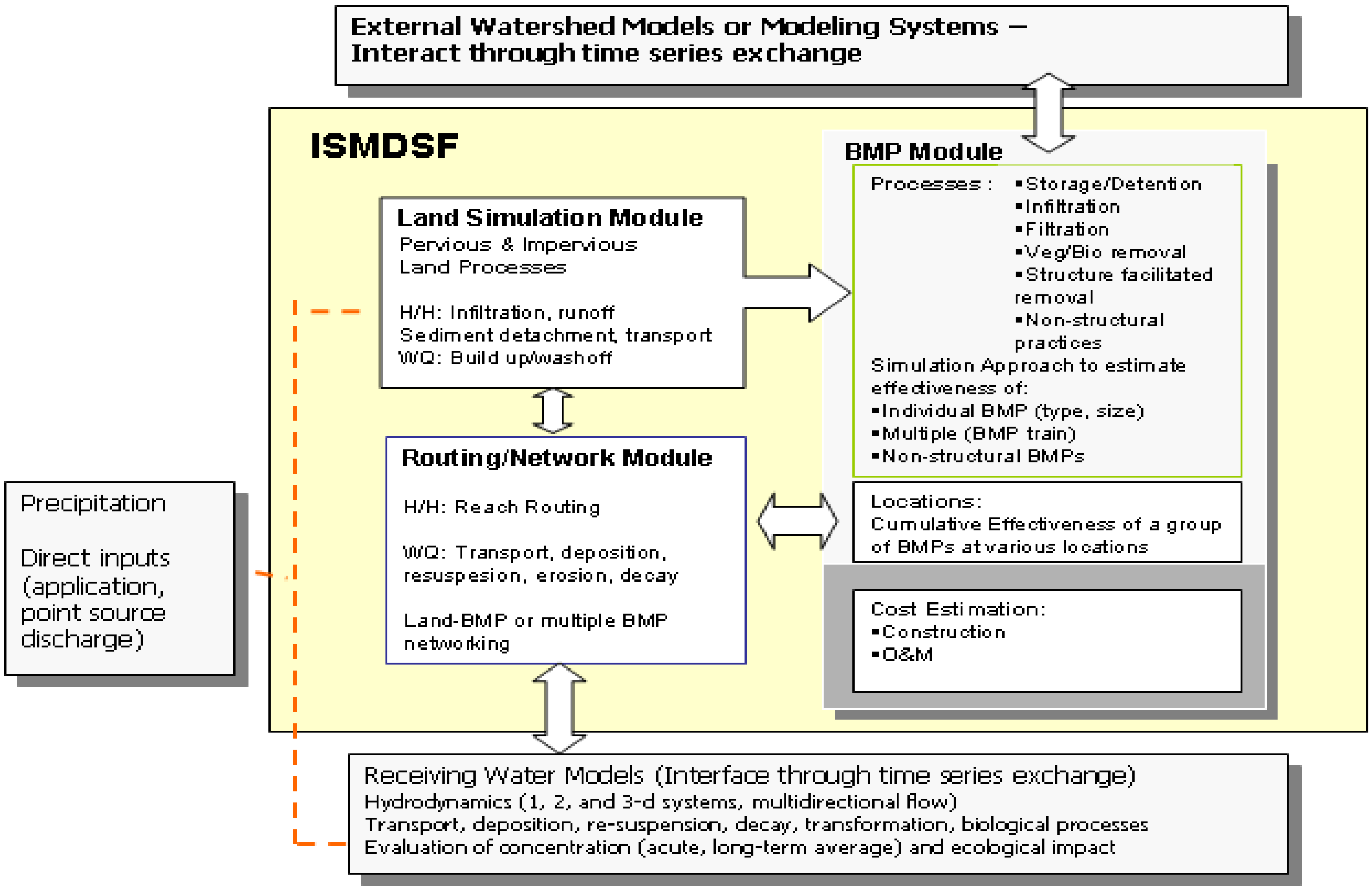

Figure 2 – Generalized Schematic of ISMDSF Components

Table 1 - Types of Structural BMPs and Major Processes

Structural BMP Types	Storage Detention	Infiltration	Filtration	Biological uptake and conversion	Structure facilitated hydrodynamic separation
Dry Extended Detention Pond	+	(o)	-	-	-
Wet Retention Pond	+	(o)	-	o	(o)
Shallow Marsh	+	(o)	-	+	(o)
Extended Detention Wetland	+	(o)	-	o	(o)
Submerged Gravel Wetland	+	(o)	+	+	-
Organic Filter	o	(+)	+	o	-
Sand Filter	o	(+)	+	o	-
Bioretention	o	(+)	+	+	-
Infiltration Trench	o	+	(o)	o	-
Porous Pavement	-	+	(o)	-	-
Dry Swale	o	(o)	-	-	-
Wet Swale	o	(o)	-	o	-
Buffer Strip	-	+	(o)	o	-
Baffle Box	+	-	-	-	+
Inlet Devices	-	-	+	(o)	(+)
Oil-Grit Separator	+	-	-	-	+

Note: ( ) optional; + major function; o secondary function; – insignificant function

Review of Available Models

A comprehensive review and evaluation of watershed and receiving-water models was previously prepared for the USEPA (Shoemaker *et al.*, 1997). For this project addressed in this paper, currently available models, particularly those in the public domain, are being further evaluated for their ability to meet the four areas of modeling algorithms/requirements identified. This current review effort is focused on identifying key models that addressed one or more of the specific algorithms or analysis methods required by the previously described technical evaluation criteria. The objective of the review is to identify candidate models or portions of models for integration or adaptation into the ISMDSF. Table 2 summarizes some of the watershed models evaluated so far and their capabilities across a range of modeling requirements. Table 3 summarizes BMP models, their key features, and simulation capabilities.

It can be concluded from a review of available models [e.g., SWMM (Huber and Dickinson, 1988; Huber, 2001), HSPF (Bicknell *et al.*, 1993), SLAMM (Pitt and Voorhees, 2000)] and available modeling systems [e.g., BASINS (USEPA, 2001), USEPA Region 4 Toolbox (USEPA Region 4, 2003)] that there is no single system or model with the flexibility and capability to incorporate all the required components of the ISMDSF at this time. However, many models can provide portions of the needed features and algorithms. For example, watershed models, e.g., SWMM, SLAMM, or

HSPF can provide time series hydrology and pollutant loading. Some models are inappropriate due to the use of large time steps (one day or greater) or insufficient rainfall-runoff processes. Stream conveyance routing can be provided by SWMM, HSPF, or specialized receiving-water models, e.g., EFDC (Hamrick, 1992).

For the process simulation of BMPs, the Prince George's County BMP module (Cheng *et al*., 2002), portions of the SWMM model, portions of the P8 model, and portions of other models are good candidates for incorporation into the ISMDSF. For BMPs, e.g., riparian buffers, special simulation is needed. Riparian buffers may be addressed using the procedures described in VFSMOD (Munoz-Carpena and Parsons, 2003) or from an adaptation of land-to-land transport routines used in SWMM or HSPF. One specialized need for BMP simulation is the ability to handle highly distributed management techniques, e.g., those employed in LID procedures. The Prince George's County BMP module (Cheng *et al*., 2002) was designed specifically to address LID simulation and networks with multiple management practices.

The models reviewed are based on a variety of software platforms. Some use the legacy code in FORTRAN [i.e., HSPF, SWMM4(Huber and Dickinson, 1988)]. Others were developed with code and graphical interfaces in C++ or Visual BASIC [i.e., LSPC (Tetra Tech and USEPA, 2002), SWMM5 (USEPA, 2002), WinHSPF (Aqua Terra Consultants, 2003)]. Often systems include links to a GIS using ESRI software ArcView, MapObjects, and more recently ArcGIS.

Considerations in selecting a modeling platform for integration of various components in the ISMDSF include functional capability within the framework, ability to link externally to existing watershed and receiving-water models, current trends in system development, and the ability to build on the existing framework while allowing for parallel development of supporting models. Since the development timeline of the ISMDSF is two years, consideration of the trends in software development is essential to the long-term adoption and use of the system. Most recently, ArcGIS and the ArcHydro data models provided a framework that is rapidly being adopted for watershed simulation. These emerging trends and the parallel development of other modeling systems, e.g., BASINS and USEPA Region 4 Toolbox are being considered in the recommended preliminary design of the ISMDSF.

Table 2 - Watershed Model Evaluation Summary

Criteria		SWMM	HSPF	LSPC	WAMview	WARMF	SLAMM	P8 UCM	ANSWERS	CASC2D	KINEROS	WEPP	DR3M-QUAL	SWAT	AnnAGNPS	AGNPS	GWLF
Land Uses	Urban	●	●	●	◖	●	●	●	--	--	--	--	●	○	--	--	●
	Rural	◖	●	●	●	●	-	-	●	●	●	●	-	●	●	●	●
	Point Sources	●	●	●	◖	●	●	●	-	-	-	-	●	●	●	●	◖
Time Scale	Continuous	●	●	●	●	●	-	●	●	●	-	●	●	●	●	-	●
	Single Event	●	●	●	●	●	●	●	●	●	●	●	-	-	-	●	-
	Time Step	V	V	Hour[1]	V	V	V	Hour	V	V	V	V	V	Day	Day	Event	Day
Hydrology	Runoff	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Baseflow	●	●	●	●	●	○	○	--	●	--	--	○	●	--	--	○
Pollutant Loading	Sediment	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Nutrients	●	●	●	●	●	●	●	●	-	-	-	●	●	●	●	●
	Others	●	●	●	●	●	●	●	-	-	-	-	-	●	●	-	-
Pollutant Routing	Transport	◖	●	●	◖[2]	●	◖	○	◖	●	●	◖	●	●	●	●	○
	Transformation	○	●	●	◖[2]	●	-	-	-	-	-	-	-	◖	-	-	-
Operation Unit		CM/Cell	CM	CM	CM/Cell	CM	CM	CM	Cell	Cell	Field	Field	CM	HRU	CM	Cell	Wsh
Public Domain		Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

References: LSPC (Tetra Tech, 2002), WAMview (SWET,2001), WARMF (Chen *et al*., 1999; Chen *et al*., 2001;Weintraub *et al*., 2001), P8 UCM (Walker, 1990), ANSWERS (Bouraoui *et al*., 1993), CASC2D (Ogden, 2001), KINEROS (USDA, 2003; Woolhiser *et al*., 1990), WEPP (Flanagan and Nearing, 1995), DR3M-QUAL (Alley *et al*., 1982; Alley *et al*., 1982), SWAT (Neitsch *et al*., 2001), AnnAGNPS (AnnAGNPS, 2000), AGNPS (Young *et al*., 1986; Needham and Young, 1993), GWLF (Haith *et al*., 1992)

● High ◖ Medium ○ Low - Not Incorporated

1 Ongoing work will covert to variable time-step
2 Ongoing work links WASP with the model.
V Variable simulation time-step
CM Catchment, i.e. subwatershed, sewershed, or watershed;
Cell Flow can be routed from cell to cell;
Field Similar to “cell”, but flow cannot be routed between “fields”
Wsh Single watershed
HRU Hydrologic Response Unit

Table 3 - Summary of BMP Models and Capabilities

Model	Types of BMP	Processes/ Mechanisms	Algorithms	Water Quality Constituents	Reference
PG BMP Module	• Detention Basin • Infiltration Practices (e.g. infiltration trench, dry well, porous pavement) • Vegetative Practices (e.g. wetland, swale, filter strip, bio-retention)	• Storage • Infiltration • Overflow/Outlet flow • Decay Process • Soil media pollutant removal	• Storage Routing • Holtan's equation • Weir/orifice flow • First-order decay	User defined pollutants	Prince George's County (2001)
P8 UCM	• Detention Basin • Infiltration Practices • Swale/Buffer Strip • Manhole/Splitter	• Storage • Infiltration • Overflow/Outlet flow • Settling/Decay	• Linear reservoir • Green-Ampt method • 2nd-order decay	Sediment User defined pollutants	Walker (1990)
VFSMOD	• Vegetative Filter Strip	• Infiltration • Overland flow routing • Sediment transport	• Green-Ampt's equation • Kinematic wave • University of Kentucky algorithm	Sediment	Munoz-Carpena and Parsons (2003)
MUSIC	• Detention Basin • Infiltration Practices (e.g. infiltration trench, dry well, porous pavement) • Vegetative Practices (e.g. wetland, swale, filter strip, bio-retention)	• Storage • Infiltration • Decay	• CSTR model • 1st order decay (k-C* model)	User defined pollutants	Wong (2001)
BMPAM	• Detention Basin • Infiltration Practices (e.g. infiltration trench, dry well, porous pavement) • Vegetative Practices (e.g. wetland, swale, filter strip, bio-retention)	• Evaporation • Evapotranspiration • Storage • Infiltration • Overflow/Outlet flow • Settling • Decay Process • Adsorption • Partitioning of metals between soils and water • Plant uptake of nutrients	• User specified infiltration rate • Infiltration regeneration ratio • First-order decay	BOD, TSS, TN, TP, Pesticides, other non-volatile organics Heavy Metals Non-reactive tracers	Xue (1996)

Preliminary Conceptual Design Recommendations

Figure 3 shows a simplified schematic of the system component relationship. Current plans include building a stand-alone BMP module for ISMDSF with the ability to link with various systems – thereby providing an essential missing piece in today's watershed modeling systems and the ability to support multiple development and simulation platforms. Essential to the functionality of the BMP module is the framework manager, which provides the linkages between external inputs/outputs, land simulation, BMP simulation, and the optimization engine. To address the need to evaluate distributed management techniques and multiple configurations of BMPs, the system design will include GIS-based visualization and network management.

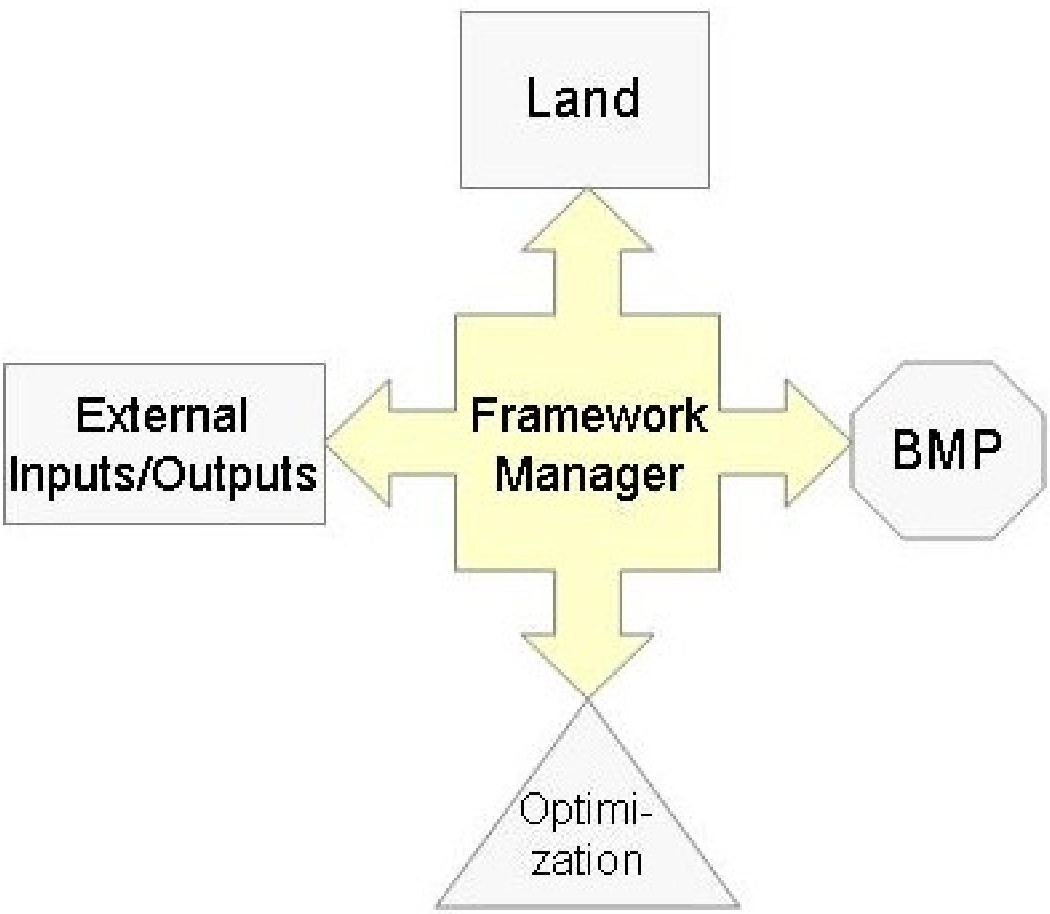

Figure 3 – Simplified Schematic of ISMDSF Components

The ISMDSF modeling system will need to provide linkages between watershed information, various computational modules, and a suite of management options. This modeling system will be applied iteratively to identify optimal solutions for the specified water quality goals. Figure 4 shows the recommended preliminary conceptual design of the modeling system. The conceptual design illustrates how the various components are organized for the development of optimal solutions. Beginning with a watershed area (represented by a map or GIS coverage), the

Framework Manager will translate spatial information into a relational database. This database defines the relationships between land area units, BMPs, and stream systems on a watershed basis. The Framework Manager will coordinate external inputs, call various modeling components (i.e., Land, BMP, Conduit, Reach), and provide output information to the post-processor. The Decision Matrix includes the types, configurations, locations, and costs of management solutions to consider. This information will be used by the Framework Manager to identify model simulations to be carried out. The Optimization Engine is used to select the preferred option based on cost and other defined decision criteria (i.e, hydrology, water quality criteria) contained in the Decision Matrix. Assuming an optimization goal is set based on meeting a target load, the location and type of management practices are varied over a range of alternative options and numerous iterations of the ISMDSF are performed. The Framework Manager and Decision Matrix are essential to providing a streamlined process for evaluation, comparison, and selection of optimal management approaches for meeting specified water quality goals.

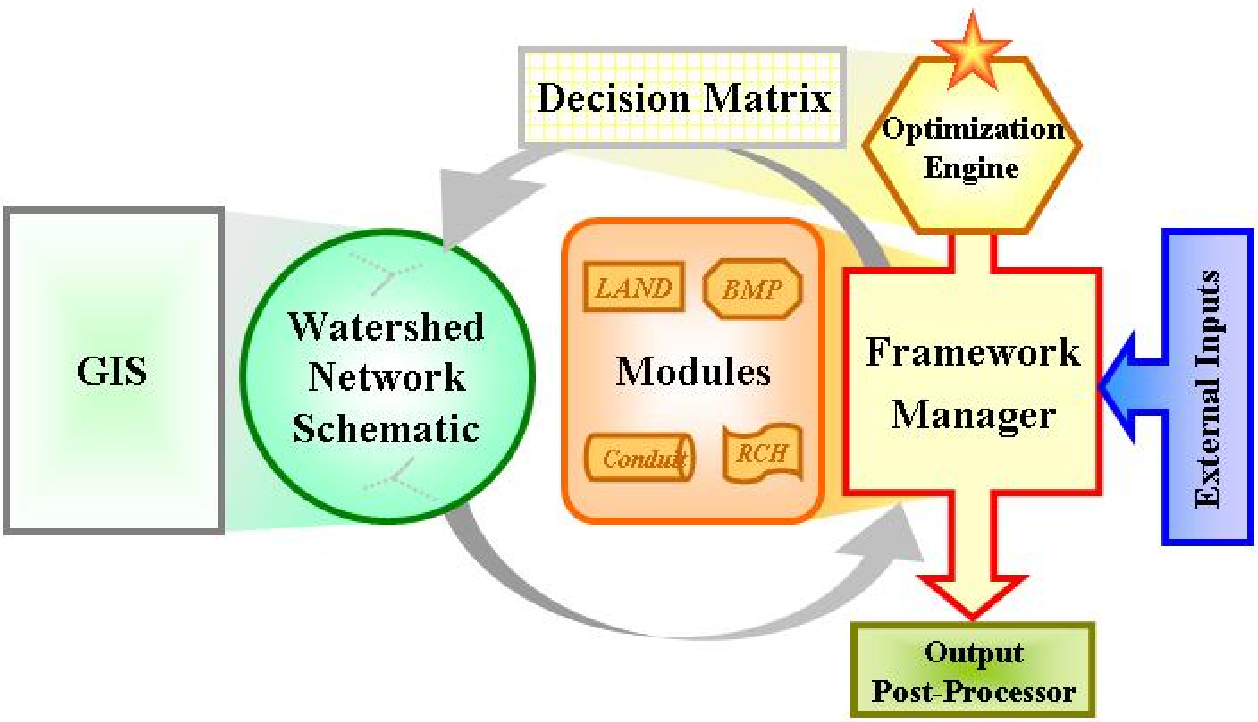

Figure 4. Conceptual diagram of the proposed ISMDSF modeling system

Additional needs were identified specific to how users will interact with the software system and what platform will be used for the framework development. Software selection also considers the ability to distribute the system to the public, and the trend in current system development. The preliminary recommendations include the use of currently evolving technology in ArcGIS/ArcHydro for the new system development. To build consistency, the initial recommendations are to provide an ARC/GIS framework and systems compatible with larger public-domain systems, e.g., BASINS and USEPA Region 4 Toolbox.

Benefits of these preliminary design recommendations include:

- Ability to link with commonly used watershed and receiving water models (i.e., SWWM, HSPF, LSPC, WASP)
- Ability to operate independently for specific small watershed applications and detailed BMP simulation
- Ability to incorporate simulation of new management practices as the technology evolves
- Consistency with current and future GIS technology
- Emphasis on development of the most needed analysis techniques
- Ability to update and maintain system cost effectively

Next Steps

The ISMDSF project will continue with development of a detailed design and prototype application. Testing will be performed on a case study watershed. Future development will identify additional modeling needs and evaluate the functionality of the place-based approach to watershed management modeling. Through a collaborative process with other federal agencies, modeling framework development will continue to provide linkages between various modeling systems and tools, e.g., BASINS and USEPA Region 4 Toolbox.

SUMMARY AND CONCLUSIONS

The USEPA has recently embarked on a research project to develop an integrated stormwater management decision-support framework for the optimal selection and placement of BMPs at strategic locations in mixed land use urban watersheds to achieve the desired watershed-based water-quality objectives. It is envisioned that there are five design requirements for the ultimate development of ISMDSF: (1) Models are intended for knowledgeable model users including those at local levels who are familiar with the technical aspects of watershed modeling; (2) BMP selection and strategic placement supports decision-making; (3) Models are applicable to mixed land use urban watersheds; (4) Watershed and receiving-water hydrologic/hydraulic and water quality modeling are based on integrated data collection; (5) Solution alternatives are based on cost-effectiveness (optimization) to achieve desired water quality objectives.

The initial task of the project included a definition of BMP options assessment criteria and technical requirements, particularly with respect to spatial scales of application watersheds, and watershed and BMP process modeling requirements. Currently available models, particularly those in the public domain, are being evaluated for their abilities to meet the identified modeling algorithms and requirements. It was concluded from the review that there is no single system or model with the flexibility and capability to incorporate all the required components of the ISMDSF at this time. However, many models can provide portions of the needed features and algorithms. For example, watershed models, e.g., SWMM, SLAMM, or HSPF can provide time-series hydrology and pollutant loading. Stream conveyance routing can be provided by SWMM and HSPF. For the process simulation of BMPs, the Prince George's County BMP module, portions of the SWMM model, portions of the P8 model (Walker, 1990) and portions of other models are good candidates for incorporation into the ISMDSF.

To integrate various components into the ISMDSF modeling platform, serious consideration is being given to the use of currently evolving technology in ArcGIS/ArcHydro and Visual Basic for system framework development. It is envisioned that the ISMDSF will build a stand-alone BMP module with the ability to link to the various systems, particularly with BASINS and the USEPA Region 4 Toolbox, which are under parallel development paths.

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