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A BASIN MANAGEMENT CUMULATIVE IMPACT MODEL

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ABSTRACT An aggregate systems model is used to examine synergistic links between land use planning, water quality, and watershed management policies. The systems-based runoff model is linked to an adaptation of Mackay and Paterson's ecosystem partitioning models to provide an estimate of the cumulative impact of changes in land use on downstream aquatic systems.

Advantages of the model are its comprehensive structure and ease of use, allowing rapid scenario testing with minimal input requirements. Another advantage is that the output supports analysis of comparative risk not only in terms of total load but also as a function of relative persistence and toxicity.

Other features include:

- Options assessing the cumulative effect of stormwater management techniques (including wetland buffer zones and permeable pavements);
- Highlight of results where concentrations exceed regulatory and risk-based thresholds; and
- Management simulation games for use as an interactive decision and conflict resolution tool.

KEY WORDS: Watershed management, basin planning, ecological engineering, environmental land development, stormwater management

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INTRODUCTION

In terms of policy and management there are few regulatory links between land use planning, water supply, and water quality. Public land acquisition, conservation easements, and wetland mitigation are significant actions in this direction. Integrated watershed or bioregional approaches to land planning, development, and permitting have also become widely accepted concepts that are used in a proactive manner at larger scales by state agencies in Florida. However, private and local incentives for regional planning and conservation or resource-based development designs are not well recognized. Implementation of these interdisciplinary concepts at local and regional levels may be furthered by dynamic models and decision tools demonstrating the effect of land use changes and the efficiency of stormwater management tools at varying scales. The use and application of these models may also provide insight into private and public incentives for environmental resource-based design, development, and basin management.

Policy implementation for regional planning is complex at best. The difficulties do not necessarily lie with a lack of knowledge or inadequate tools; they stem more from three sources:

- the dilemmas of attempting to quantify complex, dynamic systems;
- the uncertainty of evaluating long term resource and monetary flows; and
- The variations in perspectives between short and long term private and public interests.

There appears to be some consensus in the literature regarding what should be done – i.e., large scale regional planning based on efficient allocation and sustainable maintenance of finite resources -- supported by self-maintaining local institutions driven by local self-interest. However, this requires some consensus on a local vision and widespread understanding of the integral role of natural resources in maintaining a given standard of living.

Given the goal**:** **'**Regional planning supported by policies encouraging voluntary action to sustain local resources', What tools are available to mediate toward a common understanding and consensus movement toward this goal? Given diversity, complexity, and multiple competing objectives, how can policies be designed to allow adaptive response to dynamic, non-steady state conditions while still providing sufficient incentive for action? Examining various stakeholder perspectives and existing policies surrounding these concepts may give insight to mediation techniques, policy options, and incentives that stimulate the use of environmental land planning and development.

This study proposes the use of a systems based cumulative impact model to evaluate land use designs and watershed management techniques at varying scales. Perhaps not surprisingly, research and experience indicate that the cumulative loss of vegetated areas and natural buffers have a significant impact on water quantity and quality of receiving water bodies. However, there are a number of ways to plan for and mitigate this impact. The use of a model that allows rapid assessment of various combinations of mitigation efforts is useful in decision analysis and in developing creative solutions.

MODEL OVERVIEW The Cumulative Impact Model allows rapid estimation of the effect of land use changes on wetlands, receiving water bodies, and aquatic systems. It is an aggregate system dynamics model that is not spatially based but has the advantage of allowing rapid scenario testing with minimal input data. The model format and ease of use is designed to act as a 'link between science and policy' in terms of land planning and water quality management. Briefly, the model consists of two main components:

1. a runoff model that calculates a water balance and a contaminant mass balance for user-input land uses; and

2. a link to a fugacity-based ecosystem partitioning model (developed by Mackay and Paterson) that calculates the distribution and fate of constituents in a pre-defined or user-defined aquatic ecosystem.

The model allows rapid estimation of the effect of changes in land use in terms of runoff volumes, water balances, and contaminant distributions in receiving water bodies. The value with respect to the many other models available is its simplicity and minimum input variable requirements. The only required data are a land use map with estimates or percentages of land use category areas and annual rainfall (Figure 1). When complete, it will include pull-down menus with default profiles for various region-specific ecosystems; physico-chemical properties of common stormwater contaminants; and regulatory, bioassay, and other risk-based thresholds for contaminants in various media.

Additional features include options for assessing the cumulative effect of various stormwater management techniques. For example, the model currently estimates the retention of contaminants by wetlands on an areal basis. Options assessing the reduction capacity of stormwater ponds, vegetated zones, or of permeable pavements in user-defined areas can be added. Then the cumulative downstream effect on the receiving ecosystem of using various percentages of these remedial techniques can be estimated.

One of many advantages of the ecosystem partitioning models is that the output supports analysis of relative risk as due not only to the mass released but also as a of function of the transport, fate, relative persistence, toxicity, and bioavailability in the environment. This provides an interpretive dimension to watershed planning, extending an analysis beyond a single concentration or total load entering a water body to an assessment of the distribution and risk associated with that concentration distributed across various media and over given time frames.

Management and policy simulation games will be prepared as an interactive mediation tool for consensus building meetings and training in complex, dynamic decision-making. A central question is: Given diversity, complexity, and multiple competing objectives, how can policies be designed to allow adaptive response to non-steady state conditions while still providing sufficient incentive for action? Goals of the simulations will include: demonstration of adaptive management techniques; consideration of various stakeholder perspectives; and insight to new policy and design options. At private, public, local government, or state levels, proposed features and default parameters make the Basin Planning, Cumulative Impact Model useful for:

- assessing the aggregate effectiveness of various watershed management options (such as retention ponds, wetland buffer zones, vegetated corridors, and permeable pavements);
- cumulative assessment of impacts on receiving water bodies;
- and as an interactive tool for planners, developers, policy-makers, regulatory authorities, and consultants.

BASIN PLANNING CUMULATIVE IMPACT MODEL

Data needed: Land use areas for 3 major ecosystem types: uplands, wetlands, and aquatic (open water)
Optional -- land use area for subcategories of upland land uses (see below) and
Annual Rainfall

BASELINE ENTRY SCREEN
1. Enter the total area of wetland and aquatic land cover types (in square meters).
2. Enter the total area of uplands or the area of each land use category for the upland area.
3. Enter the total annual rainfall for the area in inches.

FUTURE LAND USE CHANGES
4. 'Page down' to go to the Future Land Use Changes screen to enter projected changes in land use a
5. View graphs comparing results from changes on separate sheet tabs at bottom of screen.

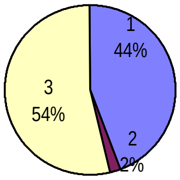
BASELINE ENTRY SCREEN

Enter current baseline land use areas.

	Inches	Meters
TOTAL ANNUAL RAINFALL	51.14	1.30

ECOSYSTEM — AREA

% of Total			Square Meters	ACRES	HECTARES
44%	WETLAND	LAND USE CATEGORY	213,502,126	52,735	21,350
2%	AQUATIC		9,419,211	2,327	942
54%	UPLAND				



% of Upland		Square Meters		ACRES	HECTARES
28%	Urban/High Int. Commercial	72,117,347		17,813	7,209
0%	*Urban with Stormwater Trtmt				
27%	Agriculture	70,764,845		17,479	7,074
14%	Rangeland/Disturbed/Unclass	37,097,202		9,163	3,708
6%	Silviculture	16,133,419		3,985	1,613
22%	Pine & Oak Uplands	56,756,787		14,019	5,673
3%	Sand Pine	7,148,940		1,766	715
		Total Upland Area	260,018,539	64,225	25,992
	TOTAL BASIN AREA		482,939,877	119,286	48,294

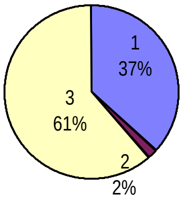
FUTURE LAND USE CHANGES

Enter projected changes in land use areas.

	Inches	Meters
TOTAL ANNUAL RAINFALL	51.14	1.30

ECOSYSTEM — AREA

% of Total			Square Meters	ACRES	HECTARES
37%	WETLAND	LAND USE CATEGORY	177,443,452	43,829	17,744
2%	AQUATIC		9,419,211	2,327	942
61%	UPLAND				



% of Upland		Square Meters		ACRES	HECTARES
37%	Urban/High Int. Commercial	108,176,021		26,719	10,813
0%	*Urban with Stormwater Trtmt				
24%	Agriculture	70,764,845		17,479	7,074
13%	Rangeland/Disturbed/Unclass	37,097,202		9,163	3,708
5%	Silviculture	16,133,419		3,985	1,613
19%	Pine & Oak Uplands	56,756,787		14,019	5,673
2%	Sand Pine	7,148,940		1,766	715
		Total Upland Area	296,077,213	73,131	29,596
	TOTAL BASIN AREA		482,939,877	119,286	48,294

STORMWATER MANAGEMENT In evaluating the efficiency of stormwater management techniques, it is helpful to review the regulatory criteria guiding the action and underlying the policies. The Federal Water Pollution Control Act, as amended 1977 and also known as the Clean Water Act, requires states to prepare and conduct programs reducing point source discharges and non-point source 'run-in' to navigable water bodies. In response, in 1990 the EPA published National Pollution Discharge Elimination System (N.P.D.E.S) stormwater regulations consisting of a two-part application and permit. Part 2 of the application includes modeling for pollutant loading across the contributing watershed.

State of Florida water policy Chapter 62-40Florida Administrative Code (FAC), section 420 'Surface Water Protection and Management' set the foundation for stormwater treatment design. In a summary of this policy, Herr (1995) quotes section 420 as:

> The primary goals of the state's stormwater management program are: to maintain, to the maximum extent practicable, during and after construction and development, the pre-development stormwater characteristics of a site; to reduce stream channel erosion, pollution, siltation, sedimentation and flooding; to reduce stormwater pollutant loadings discharged to waters to preserve or restore beneficial uses; to reduce the loss of freshwater resources by encouraging the reuse of stormwater; to enchance groundwater recharge by promoting infiltration of stormwater in areas with appropriate soils and geology; to maintain the appropriate salinity regimes in estuaries needed to support the natural flora and fauna; and to address stormwater management on a watershed basis, to provide cost-effective water quality and water quantity solutions to specific watershed problems.

And , from the same paragraph, minimum treatment volumes are set forth as:

> When a stormwater management system complies with rules establishing the design and performance criteria for stormwater management systems, there shall be a rebuttable presumption that such systems will comply with state water quality standards. The Department and The Districts, pursuant to Section 373.436, F.S., shall adopt rules that specify design and performance criteria for new stormwater management systems which:
>
> 1. Shall be designed to achieve at least 80% reduction of the average annual load of pollutants that would cause or contribute to violations of state water quality standards.
>
> 2. Shall be designed to achieve at least 95% reduction of the average annual load of pollutant that would cause or contribute to violations of state water quality standards in Outstanding Florida Waters.

The Water Management Districts in Florida are authorized to permit and regulate stormwater runoff treatment systems under Chapters 40D-4 and 40D-40 FAC, Rules for Management and Storage of Surface Water (MSSW). These rules require stormwater runoff from *new* developments that discharge into state water to meet Florida State Surface Water Quality Standards (FAC 62-302, 1992) in the receiving waters.

Stormwater regulations originally emphasized calculations for determining the size of the treatment facility necessary to attenuate peak discharge for the design storm event so that the rate of post-development discharge does not exceed pre-development rates. It was generally accepted that all types of management systems provided adequate pollutant removal. However, studies conducted since the late 1980's have shown that simple detention will not always provide 80 % or higher removals and that systems' designs, sizes, features, and detention/retention times provide a range of treatment efficiencies for various pollutants.

Wetland and Wet Detention Treatment Wetlands are the landscape's natural response to stormwater management. Among numerous other benefits, these ecosystems store fresh water; buffer peak storm discharges; prevent flooding; buffer droughts; stem soil and shoreline erosion; and filter silt, sediments, excess nutrients and contaminants. Using the natural attributes of existing systems in basin management is often more efficient than attempting to re-create or engineer substitutions (Odum, 1994). Weaving extensive vegetated areas and existing wetlands into a landscape design may be one of the most cost effective stormwater management solutions available.

A review of recent literature indicates that overall:

- wet detention, on-site retention, and wetland systems perform better for more parameters than dry detention and with sufficient residence time can achieve the state's recommended 80 to 95% removal goals (Carr and Rushton, 1995; Nepshinsky et al., 1995; Rushton et al., 1995; Rushton and Dye, 1993; Hares and Ward, 1999);

- wet retention and wetland systems have been shown to be substantially more cost effective than conventional technologies (Lipton et al., 1995; Sear et al.,1995);

- dry bottom ponds and curb cut swales may require significantly more land than wet systems per unit pound of TSS removal (Sear et al., 1995);

- contrary to common practice, the unit cost of TSS removal is less if treatments are applied in parallel rather than as a treatment train (a series mode provides successively less TSS to downstream treatments, resulting in increasing unit treatment costs (Sear et al., 1995));

- wet detention and wetland systems fulfill more, if not all, of the water regulation goals than other types of systems including:
  - maintenance of the pre-development stormwater characteristics of a site;
  - reduction of stream channel erosion, pollution, siltation, sedimentation and flooding;
  - reduction of stormwater pollutant loadings discharged to waters;
  - preservation and restoration of beneficial uses;
  - reduction of the loss of freshwater resources by encouraging the reuse of stormwater;
  - enhancement of groundwater recharge by promoting infiltration of stormwater;
  - maintenance of the appropriate salinity regimes in estuaries;
  - addressing stormwater management on a watershed basis; and
  - providing cost-effective water quality solutions to specific watershed problems.

Permeable Pavement Increased rates of land clearing, development, paving, and urbanization over the past several decades has altered natural drainage, storage, and dispersal patterns. This alteration is evident at several scales ranging from local erosion and higher peak stormwater flows to regional degradation of water resources in terms of quality and quantity. If these alterations are at least in part due to an increase in impermeable surface and a decrease in vegetated area, then a logical remedy may be the converse: to use permeable materials where possible and to incorporated existing vegetated and wetland areas as multiple function units in land planning and design.

In response to an international focus on pollution prevention and the control of non-point source discharges, interest in stormwater management and treatment has increased steadily over the past 10 years. As a part of this emphasis, the study and use of permeable pavement, porous asphalt, permeable concrete, and related infiltration and exfiltration systems has also consistently increased. These materials have been found to offer both safer and cleaner transportation surfaces.

The Netherlands, Belgium, France, Spain, Italy, Switzerland, the UK, and more recently the U.S., appear to be leaders in the research and use of permeable surfaces. Porous pavement has become the standard surface option for roads, airfields, and tunnels in much of Europe and Scandinavia. Initial research focused on the transportation safety benefits and noise reduction features of permeable surfaces and more recent studies focus on environmental aspects. Cost analysis of benefits from safety features alone appear to justify the additional construction and maintenance costs of permeable asphalt on highways and roads.

Independent research reported at an international conference of the Transportation Research Board (69th Annual Meeting, 1990) repeatedly demonstrated some of the safety and performance benefits of various porous pavement mixtures including:

- increased highway safety (Berengier et al.; van Heystraeten and Moraux; Isenring et al., in Transportation Research Record 1265, 1990) through
  - increased skid resistance (higher friction level between the tire and wet pavement),
  - reduced flooding and hydroplaning,
  - reduced water splashing or spray (mainly from large trucks in wet weather),
  - and decreased light reflection or glare;

- improved sound absorption, reducing traffic and vehicle noise by 3 to 4 dB(A) (Berringer et al.; Camomilla et al.; Nelson and Abbott; van Heystraeten and Moraux,; Isenring et al.; and Perez-Jimenez and Gordillo, in Transportation Research Record 1265, 1990);

- good durability with life spans reported greater than 9 years (Ruiz et al., 1990; Sansalone, 1999); and

- excellent resistance to permanent deformation (Huet et al.; Isenring et al.; and Perez-Jimenez and Gordillo in Transportation Research Record 1265, 1990).

Other international studies of environmental benefits demonstrate:

- mass removal rates of 80 to 98% of metals, organic contaminants, and suspended solids in runoff (Sansalone, 1999; Pratt et al, 1999; Berbee et al., 1999; Legret et al., 1999);
- reductions of COD and BOD of 83 and 88 %, respectively in runoff (Berbee et al., 1999);
- reduction of blown dispersal of metals by as much as 90% (Wyers et al., 1994 as cited in Berbee et al., 1999).
- increased groundwater recharge at rates and surface areas closer to natural drainage rates (Sansalone, 1999);
- reduction in total volume and in peak stormwater flows;
- long-term sorption and selective degradation of contaminants -- vertical migration of contaminants appears negligible and is restricted to the upper few centimeters of soil underlying the porous system (Legret and Colandini, 1999; Legret et al., 1999; Sansalone, 1999).

The primary disadvantages of permeable paving appear to include: slightly higher construction costs; maintenance in terms of periodic cleaning of low traffic areas; a tradeoff of safety benefits in freezing weather (for example, road salt is not as effective but the pavement itself is slower to freeze); and a learning curve to achieve proper design, mix, and construction techniques.

Other possible advantages of permeable paving includes:

- potential for reduced concentration and accumulation of contaminants in holding ponds –thereby also reducing the concentrations available for bioaccumulation;
- maintenance of more natural hydrologic drainage, recharge, and storage functions (in the absence of other large withdrawals) helping to maintain groundwater levels, baseflow to streams, and wetland hydroperiods – and perhaps in turn helping to control fire, flooding, and local weather fluctuations; and
- cost savings through reduction of downstream remediation of effects of hydrologic disruption and contaminant concentration by systems.

Runoff and Fugacity Models As previously described, an aggregate stormwater runoff model has been developed to estimate annual hydrologic flows and storages resulting from a user-defined landscape. The model calculates inflows and outflows based on a hydrologic balance such as: rain + run-in = evapotransporation + shallow recharge + groundwater recharge+ runoff. This type of approach has been shown to estimate long-term runoff volumes and diffuse pollution loads with reasonable accuracy (within 20% of recorded volumes) when the fraction of effective impervious area is known (Chiew and McMahon, 1999). The runoff in this model goes first to wetlands and then the remaining fraction is discharged to an aquatic system (generally a river or lake). This discharge and the aquatic system are modeled using the Mackay and Paterson fugacity-based partitioning models.

The runoff portion of the Cumulative Impact Model requires only two types of input variables: 1) total basin area subdivided into land cover percentages, and 2) annual rainfall (Figure 1). Other variables are built into the model for simplicity but can be altered by the user when site-specific or more detailed data are available. Estimated runoff coefficients for each type of land cover are built into the model and runoff from the total upland area is simply a function of the relative permeability of the land cover, area, and rainfall less losses to evapotranspiration, shallow storage, and groundwater. The first runoff fraction flows to an aggregate area of wetlands and the remaining fraction is discharged to an aquatic system (a river or lake for example). The basic equations are:

- Rainfall Volume = Watershed Area (m^2) * Annual Rainfall (m/yr)
- Runoff Volume for each land use category =
  (Runoff Coefficient * Rain Volume) – (% to ET + % to GW + shallow storage volume)
- Runoff Concentration for each land use category =
  Volume of Run-in * Event Mean Concentration per contaminant per land use category
- Volume to Wetland = (Run-in from Upland + Direct Rainfall) – (% to ET + % to GW + wetland storage)
- Mean Pollutant Load to Wetland or Aquatic System = (Sum of Runoff Concentration – Treatment Removal Fractions) for each land use category, pollutant, treatment type, and area.

The resultant pollutant load is entered into an adapted version of the Mackay and Paterson fugacity-based partitioning models. These models provide a steady-state ‘picture’ of the mass distribution and fate of a given contaminant in a defined environment. This full distribution view is sometimes overlooked but can be essential in the evaluation and ranking of risk and treatment efficiencies. Edwards et al., 1999 compared the ranking of 45 organic chemicals from the EPA’s Toxic Release Inventory using several ranking systems. The rank and relative importance of chemicals changed substantially when viewed from an annual mass release basis (as used in the EPA inventory) versus the mass distribution and persistence in various media (fugacity model results). The relative risk is due not only to the mass released but is also a function of the transport, fate, relative persistence, toxicity, and bioavailablity in the environment (Edwards et al., 1999; Wania and Mackay, 1999).

Briefly, the Mackay and Paterson fugacity models include the following general components (Mackay and Paterson, 1991):

- environmental media such as soil, air, water, and fish are defined in terms of volume and physico-chemical parameters (i.e., porosity, organic carbon content and temperature);
- media flow rates (advective inflow, outflow, and transfer rates);
- chemical contaminant background and inflow concentrations;
- contaminant physical and chemical properties (i.e., partitioning coefficients, solubility, vapor pressure, degradation rates in various media);

The model sets up steady-state mass balance equations accounting for inflows, reactions within a given phase (such as loss or storage via degradation, sorption, or bioaccumulation), transfer of available mass between media, and advective outflow (generally in air, water, or runoff). The generic mass balance equation for the Level III fugacity model is:

$$N_{E,i} + D_{A,,i}\, f_{B,i} - f_i \left[\sum_j D_{i,j} + D_{A,j} + D_{B,I} \right] + \sum_j [D_{j,i}\, f_j] = 0$$

where,
$N_{E,i}$ = emissive inflow in ith phase,
$D_{A,j}$ = transfer coefficient for the ith phase,
$f_{B,i}$ = fugacity in the ith phase,
C_i = concentration in the ith phase ($C_i = f_i Z_i$)
Z_i = fugacity capacity of the ith phase.

The model media and flows for each include stormwater run-in (including suspended sediment load); air advective inflow; runoff from impermeable surfaces; recharge, sorption, degradation, and run-off from semi-permeable surfaces; flow to surface waters (wetland and pond surface waters); and discharge outflows to groundwater, air, and adjoining surface waters.

The model results indicate the relative mass and concentration of the steady-state distribution between the various media phases. For example, results provide the concentrations of a given contaminant persisting in on-site soils and sediments, surface waters and suspended sediments, fish and plants, or air. In tandem, these models and these data can provide a basis for the assessment of the relative efficiency of selected stormwater designs.

BASIN PLANNING, CUMULATIVE IMPACT MODEL

Example 1 – Urban Development with Loss of Wetlands As a hypothetical case, the Urban/Commercial area of the Wekiva River Basin baseline model was proposed to increase 50% with a concomitant decrease in wetland area. This would result in a 17% decrease in the total wetland land area and an approximate 40% increase per year in average pollutant loading to the aquatic system. If permeable pavement was used on approximately 20% of the new urban areas, this increased loading could feasibly be reduced to less than 20% (Figure 2). This is simply for demonstration purposes and is not meant to imply that permeable pavement could replace the many other vital functions of the wetland area. Incorporating wetland areas and extensive vegetated buffer zones into the land design can achieve the same results with the additional benefits of increased stormwater storage capacity, reduced peak flows, maintenance of stream baseflows, and reduced risk of fire. The interest in this scenario is two-fold:

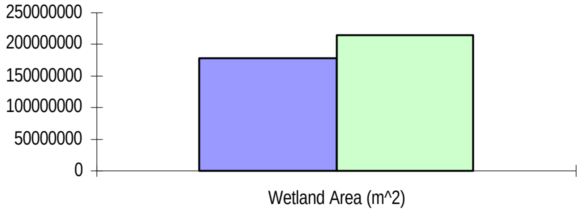
1) the demonstration that a relatively small loss of vegetated area (17%) can result in a disproportionately large, annual, increase in pollutant loading to receiving water bodies, and

2) that there are relatively simple planning methods that can mitigate these cumulative effects.

Figure 2: Results Example 1: Increase Urban 50% - No Permeable Pavement, Decrease Wetland Area

CHANGE IN WETLAND AREA

	Future Use	Baseline	% Change [(F-B}/B]
Wetland Area (m^2)	1.8E+08	2.1E+08	-17%
	Future Use	Baseline	
% of Total Land Area	37%	44%	



CHANGE IN ANNUAL LOAD ENTERING THE AQUATIC SYSTEM

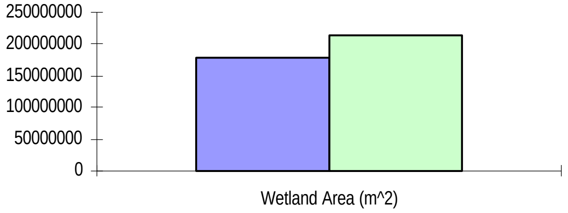
	TN	TP	BOD	SS	Zn	Pb
Wetland Removal Fraction	0.8	0.6	0.7	0.7	0.7	0.7

	Mean Annual Load to Aquatic System (lbs/year)					
	TN	TP	BOD	SS	Zn	Pb
Future: lbs/yr to Aquatic System	1.19E+10	3.40E+09	4.04E+10	5.29E+11	8.28E+08	1.04E+09
Baseline: lbs/yr to Aquatic System	9.01E+09	2.52E+09	2.94E+10	3.85E+11	5.68E+08	7.18E+08
Difference	2.88E+09	8.75E+08	1.10E+10	1.44E+11	2.59E+08	3.27E+08
% Increase or Decrease [(future-baseline)/baseline]	32%	35%	37%	37%	46%	46%

Figure 3: Results Example 1: Increase Urban 50% with Permeable Pavement, Decrease Wetland Area

CHANGE IN WETLAND AREA

	Future Use	Baseline	% Change [(F-B}/B]
Wetland Area (m^2)	1.8E+08	2.1E+08	-17%
	Future Use	Baseline	
% of Total Land Area	37%	44%	



CHANGE IN ANNUAL LOAD ENTERING THE AQUATIC SYSTEM

	TN	TP	BOD	SS	Zn	Pb
Wetland Removal Fraction	0.8	0.6	0.7	0.7	0.7	0.7

	Mean Annual Load to Aquatic System (lbs/year)					
	TN	TP	BOD	SS	Zn	Pb
Future: lbs/yr to Aquatic System	1.02E+10	2.89E+09	3.40E+10	4.45E+11	6.78E+08	8.55E+08
Baseline: lbs/yr to Aquatic System	9.01E+09	2.52E+09	2.94E+10	3.85E+11	5.68E+08	7.18E+08
Difference	1.21E+09	3.68E+08	4.63E+09	6.06E+10	1.09E+08	1.37E+08
% Increase or Decrease [(future-baseline)/baseline]	13%	15%	16%	16%	19%	19%

Example 2 – Urban Development with Stormwater Treatment Ponds In this example, the Urban/Commercial area is again proposed to increase 50% but the land area developed is from the Pine and Oak Uplands and the new development includes conventional stormwater treatment ponds. In this example, treatment pond removal fractions are estimated (SJRWMD, 1998) as ranging from 15% BOD to 80% zinc and lead (Figure 4). This gives no net change in wetland area, assumes conventional stormwater management technology, and still results in an approximate average increase in pollutant loading of 40%.

Figure 4: Results Example 2: Increase Urban 50% with Treatment Ponds, Decrease Pine & Oak Uplands

CHANGE IN WETLAND AREA

	Future Use	Baseline	% Change [(F-B}/B]
Wetland Area (m^2)	2.1E+08	2.1E+08	0%
	Future Use	Baseline	
% of Total Land Area	44%	44%	

CHANGE IN ANNUAL LOAD ENTERING THE AQUATIC SYSTEM

	TN	TP	BOD	SS	Zn	Pb
Wetland Removal Fraction	0.8	0.6	0.7	0.7	0.7	0.7
Treatment Pond Removal	0.3	0.5	0.15	0.55	0.8	0.8

		Mean Annual Load to Aquatic System (lbs/year)					
		TN	TP	BOD	SS	Zn	Pb
Future Use:	lbs/yr to Aquatic System	1.16E+10	3.38E+09	3.99E+10	5.25E+11	8.26E+08	1.04E+09
Baseline:	lbs/yr to Aquatic System	9.01E+09	2.52E+09	2.94E+10	3.85E+11	5.68E+08	7.18E+08
	Difference	2.61E+09	8.52E+08	1.05E+10	1.40E+11	2.57E+08	3.18E+08
	% Increase or Decrease [(future-baseline)/baseline]	29%	34%	36%	36%	45%	44%

Example 3 – Cumulative Impact of Organic Contaminants Several studies have demonstrated that PAHs and select chlorinated pesticides are among the most prevalent and most toxic of common organic stormwater constituents (Boxall and Maltby, 1997; Maltby et al., 1995; Pereira, et al., 1996; Ashley and Baker, 1999). A simple example models a single polynuclear aromatic hydrocarbon (PAH) compound, benzo(a)pyrene, in runoff entering a flowing water body. In one year long study of branches of the Anacostia River watershed in the Chesapeake Bay area, benzo(a)pyrene was measured in stormwater/streamwater samples at total concentrations ranging from 0.4 to 910 ng/l, with a mean concentration of 178 ng/l (Foster, et al., 2000). Dissolved phase concentrations ranged from 0.4 to 6.7 ng/l (mean 2.6 ng/l) and particulate phase concentrations ranged from 0.4 to 903 ng/l (mean 196 ng/l). For illustrative purposes, a mean total concentration of 178 ng/l was entered into the level III fugacity models as advective inflow in water to the receiving water body (Figure 5).

Figure 5 – Mackay and Paterson Level III Fugacity Model Default Input Parameters

Level 3 MODEL RESULTS		
CHEMICAL NAME: Benzo(a)pyrene		
Simulation ID: PAH		
CHEMICAL PROPERTIES		
Chemical Type: 1		
Molecular Mass (g/mol)	252.3000031	The Vapour Pressure is that
Data Temperature °C	20	of the chemical in the state
LogKow	6.039999962	(solid or liquid) corresponding
Water Solubility (g/m³)	0.0038	to the data temperature
Water Solubility (mol/m³)	1.50614E-05	
Henry's Law Constant (Pa.m³/mol)	0.046476316	
Vapour Pressure (Pa)	7E-07	
Melting Point °C	175	
Fugacity Ratio	0.027594417	
Sub-cooled Liquid Vapour Pressure	2.53674E-05	
Half -Lives	(hours)	(days)
Half-Life in Air (gaseous)	170	
Half-Life in Water (no sus. sedmt.)	1700	
Half-Life in Soil	17000	
Half-Life in Bulk Sediment	55000	
Half-Life in Suspended Sediment	1700	
Half-Life in Fish	1700	
Half-Life in Aerosol	170	
PARTITION COEFFICIENTS		All amounts are dimensionless, except where noted
Log Octanol-Water Partition Coefficient	6.039999962	
Octanol-Water Partition Coefficient	1096478.125	
Organic Carbon-Water Partition Coefficient (L/kg)	449556.0313	
Air-Water Partition Coefficient	1.90692E-05	
Soil-Water Partition Coefficient	21578.68853	
Soil-Water Partition Coefficient (L/kg)	8991.120222	
Sediment-Water Partition Coefficient	43157.37706	
Sediment-Water Partition Coefficient (L/kg)	17982.24044	
Suspended Sediment-Water Partition Coefficient	215786.894	
Suspended Sediment-Water Partition Coefficient (L/kg)	89911.20585	
Fish-Water Partition Coefficient	52630.94922	
Fish-Water Partition Coefficient (L/kg)	52630.94922	
Aerosol-Air Partition Coefficient	2.36524E+11	

The resulting steady state (i.e., input rate equals output rate) condition accounts for degradation, advection, and transport between media. In this example, benzo(a)pyrene has a total persistence of 410 days (9836 hours). As might be expected, the highest concentrations are found in sediments (95% or 2598 ng/g), with a steady state concentration of about 88 ng/l in the water (approximately 5%). This persistence and distribution is important in evaluating potential effects and relative toxicity of various stormwater constitutents. On just a mass basis, benzo(a)pyrene may not rank as major constituent but the relative importance changes when the compounds are viewed in terms of persistence, availability, and toxicity. Identifying only total maximum daily loads and focusing expensive rehabilitative measures on maximum concentrations in stormwater samples may not always give the desired result – meaning highest protection for the receiving water body. It may be the lower concentration, persistent, and high toxicity compounds that have the most marginal impact, or it may be a cumulative/interactive effect of any number of combinations.

Cost effective stormwater management might by-pass these complexities all together by focusing on land development designs that preserve sufficient vegetated upland and wetland areas as natural filtration and stormwater storage systems with very high contaminant removal capacities, regardless of individual ranking or presumed significance in the system as a whole. Another approach, defined by Drs. Lee and Lee as 'Evaluation Monitoring', proposes finding consensus among stakeholders defining what are considered water quality use impairments given the use and location of the individual water body in a given watershed. Once defined, Evaluation Monitoring focuses on determining the cause of the use impairments, including finding specific constituents responsible for aquatic life toxicity (Lee and Lee, 1999). This method proposes not monitoring chemical concentrations but focusing more on adverse impacts to the defined beneficial uses of the waterbody; the form and relative toxicity of the contaminant; and the persistence, availability, and duration of exposure.

There are numerous approaches and possibilities for linking land use planning with water quality policy. Incentives for regional planning and conservation-based development designs are not well recognized. The model presented in this paper is an initial attempt at developing an aggregate basin planning model that does more than calculate total load or isolated hydrologic functions. This type of model supports comparative risk evaluation over time and allows rapid scenario testing with minimal input requirements thereby making it useful as an interactive management and conflict resolution tool. Decision tools that are comprehensive and quick may be useful in demonstrating the benefits of such designs and the efficiency of stormwater management options at varying scales.

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