Proceedings of the 4th International Conference on Diffuse Pollution, IWA, Bangkok, Thailand, January 2000

RECONCILING FLOOD AND DIFFUSE POLLUTION CONTROL OBJECTIVES IN URBAN WATERSHED MANAGEMENT

Vladimir Novotny*, Douglas Booth*, David Clark*, Robert Griffin*, Jim Giese*, Alena Bartošová*, and Neal O'Reily**

* *Institute for Urban Environmental Risk Management, Marquette University, Milwaukee, WI 53201-1881,USA*
*** Hey and Associates, Brookfield, WI 53045-6590, USA*

ABSTRACT

Urban watersheds and receiving waters are adversely affected by urbanization that increases risk of flooding and, in the same time, reduces the chemical, physical (habitat) and biological integrity of the affected water bodies. Restoration of ecological integrity and flood control objectives in the past were conflicting, often to a degree that flood control alone lead to ecological degradation of the receiving water bodies by damaging the habitat. The two objectives in today's urban restoration/flood control projects must be reconciled.

This article describes a methodology and research that optimize both objectives. Numeric and flooding risks are will be correlated to the citizens "Willingness to pay" for reduction of either or both risks. Preliminary results of focus group surveys indicate that reduction of ecological risks and restoration of physical, chemical and biological integrity of urban streams is preferred by most citizens while the willingness to pay for flood control is related to the past history of flooding.

KEYWORDS

Flood risks, Stormwater pollution, Watershed management, Ecological risks, Integrity of urban streams, Public opinion surveys, Willingness to pay.

INTRODUCTION

Management of smaller and medium size urban streams today must today consider several objectives such as

I. Flood control
II. Preservation and restoration of ecological integrity of the receiving water body affected by point and nonpoint discharges and changes in hydrology and hydraulics.
III. Providing contact and noncontact recreation to urban population
IV. Other uses such as water supply, navigation, or hydropower production

Some of the objectives are conflicting some other are complementing each other. For example, preservation and restoration of ecological integrity and providing habitat for aquatic life complements recreational objective. As matter of fact, a healthy ecology of the stream is a prerequisite to the contact recreational use. On the other hand, flood control often is in conflict with ecological and recreational objectives. In the context of watershed and water body management these conflicts must be reconciled and uses must be optimal.

The increased magnitude and frequency of high flows caused by urbanization has several major adverse effects on floodplain, stream channel and on the ecology of the urban stream. The hydrologic effects include: (1) floodplain enlargement; (2) increase of the frequency of flooding inside the floodplain; (3) increase of peak flows during storm events; (4) increase of the magnitude and frequency of all runoff events of all sizes; (5) as a result of increased medium floods channels become unstable and more erosive (degrading); (6) imperviousness impedes recharge of shallow groundwater aquifers, which diminishes base flow contributions (after urbanization some streams may become ephemeral or effluent dominated); (7) more flow moves on the surface with a faster velocity which increases the volume of surface runoff contribution.

The most important adverse ecological impacts are: (1) loss of bank habitat by increased stream bank erosion and channel alteration to accommodate increased flows; (2) siltation of the channel by increased sediment loads; (3) water column and sediment contamination by pollutant discharges from point and nonpoint sources; (4) increased temperature due to more warmer surface flows and loss of stream shading by vegetation; (5) loss of pollution intolerant species.

The effects of urbanization are not only limited to the stream channels. The entire stream corridor consisting of the stream channel and floodplain must be considered in a comprehensive analysis of urban streams. Typically, urban developers try to reclaim floodplain and often development that was outside of the floodplain becomes a part of it as the floodplain enlarged as a result of urbanization.

Ecological and hydrological/hydraulic impacts of urbanization

The major impacts of urbanization on integrity of urban streams can be divided into three categories:

I. Hydrologic/hydraulic changes of flow regime and their effect on stream morphology.
II. Water and sediment quality degradation and their effects on composition and survival of aquatic species.
III. Ecological/habitat changes, including modifications of channels and floodplain.

Impervious surface in urban areas dramatically increases surface runoff during storm events. The changes affect both the rate and volume of flow. Schueler (1994) claimed that depending on the degree of imperviousness and soil type, annual volume of runoff of fully developed urban watersheds can increase 2 to 16 times the pre-development rate.

To accommodate the increased high stream flow caused by urbanization, streams themselves respond by increasing their cross sectional area. This is done by stream bed downcutting, stream widening, or a combination of both. Robinson (1976) in a study of eight watersheds in Baltimore, MD found that urban streams have channel cross-sections areas approximately twice those or rural streams and width-to-depth ratios about 1.7 times those of rural streams. Other studies have found that cross-sectional area increases by a factor of 2 to 5, depending on the degree of impervious cover in the watershed and the age of the development (Arnold et al., 1982; Gregory et al., 1992). Stream channels react to increased urban runoff not only by adjusting their widths and depths, but also by changing their gradients and meander pattern (Riley, 1998).

The final modification of urban stream, in the last phase, is again done by man. To constrict the widening stream, control stream bank erosion and contain the flood water in the channel, streams banks and channel are lined with artificial materials such as concrete, stone rip raps and gabions. Such engineering measures downgrade the stream to an open conveyance channel with minimum or no habitat conditions. Table 1 summarizes the hydrological/hydraulic effects of urbanization on urban streams.

RECONCILING THE CONFLICTS OF THE OBJECTIVES OF URBAN STREAM MANAGEMENT

Most of urban watershed management projects in the United States are driven by flood control objectives. On one side, public media pay extraordinary attention to the plight of people affected by flooding that then results in heavy pressure and lobbying of public officials by affected individuals and citizens groups. However, using traditional benefit/cost analysis most urban flood control projects are highly inefficient. In the Milwaukee (Wisconsin) metropolitan area the benefit/cost ratio of flood control drainage projects in which the benefit is the reduction of monetary damages to properties and land within the floodplain, are typically less than 0.2. Consequently, projects that would address flood control only are not feasible. Such projects would represent a massive transfer of benefits from the general taxpayer public to a small number of beneficiaries located in the floodplain. Further more, the *antidegradation rule* of the present regulations in the United States and elsewhere does not allow downgrading the integrity of the receiving water bodies even when the objective is drainage or flood control. Therefore, the sometimes conflicting concurrent objectives of drainage/flood control and restoration of ecological integrity of urban streams of urban stream projects must be reconciled.

Restoration of ecological al integrity of urban streams, on the other hand, benefits much larger segments of population. However, considering the benefits of ecological improvement in the classic economic benefit cost analysis is difficult because such benefits are mostly intangible. On the other hand, such benefits are very desired by the public, especially those living near the water body but in the floodplain. Consequently, another measure of benefits must be defined and substituted. The *Willingness to Pay* of the public for the ecological benefits is a common substitution for strictly monetary flood control benefits in a multi-objective watershed restoration and flood control projects.. In reality, projects that include both flood control benefits and ecological and water quality restoration and improvement may become acceptable to the general public as exemplified in two such projects in the Milwaukee Metropolitan area that are featured in this article.

Table 1 **Summary of impacts of urban stormwater runoff on stream ecosystems**

Potential Stream Ecosystem Change	Disturbance Activity							
	Increased Watershed Imperviousness	Increased Soil Erosion	Vegetative Clearing	Channelization	Streambed Armoring	Woody Debris Removal	Bridges, Culverts and Utility Crossings	Contaminants
Increased peak flood flows	•				•	•		
Increased frequency of bankfull flows	•			•				
Increased duration of flood flows	•							
Increased instream velocities	•		•	•	•			
Increased flood energy	•		•	•	•			
Increased channel bed and bank erosion	•		•	•				
Increased streambed turnover	•				•	•		
Decreased base flow	•							
Embedded streambed sediments	•	•	•					
Loss of fish refuge				•		•	•	
Loss of pool and riffle structure	•	•	•	•	•			
Increased streambed gradient	•		•	•	•			
Changes in meander patterns	•		•	•	•			
Increased stream migration	•		•	•	•			
Channel widening and down-cutting	•		•	•	•			
Loss of riparian vegetation			•	•	•	•	•	
Shift in organic material from external sources (leaves) to internal sources (algae)			•	•	•	•		
Reduction in macroinvertebrate numbers and diversity	•	•		•	•	•		•
Shift in macroinvertebrate community structure	•	•		•	•	•		•
Reduction in fish diversity	•	•	•	•	•	•	•	•
Shift in fishery to more pollutant tolerant species	•	•	•	•	•	•	•	•
Increase in fish disease	•	•						•
Blocked fish passage				•	•		•	
Increased water temperatures	•	•	•	•		•		
Reduced instream oxygen levels	•							•
Reduced gene pool of species for dispersal and colonization	•	•	•	•	•	•	•	•

INVESTIGATED URBAN WATERSHEDS

Oak Creek

The Oak Creek discharges to Lake Michigan in the City of South Milwaukee, WI. About 22 km of the stream is perennial.

TABLE 1. Basic watershed characteristics: Oak Creek watershed.

Area	69.8 km^2 (27.24 mi^2)
Percent urbanized	44.6%
Population (1980)	39,700

The Oak Creek watershed can be characterized as a rural area with a great potential for future development. Agricultural land (cropland and pasture) represents the prevailing type of the land use in the watershed (see Tab. 2). Most of the agricultural land is located in the western and southern portions of the watershed. The soils within the Oak Creek watershed are silty clay loams, loams, and sandy loams, and are developed on gently sloping or rolling morainel topography. Most of the soils are relatively fertile.

TABLE 2. Land use distribution: Oak Creek watershed [GIS].

Land Use	Percent Total
Cropland and Pasture	55.4
Residential	22.8
Other Urban or Built-Up	6.5
Transportation, Commerce, Utilities	6.0
Commercial and Services	5.8
Industrial	3.6

Pollution sources can be categorized as municipal, industrial, agricultural, landfill, and stormwater. A contribution of pollution from the point sources is negligible compared to that from the nonpoint sources. Rural sources dominate among the nonpoint sources (20-50%).

Menomonee River

The Menomonee River discharges into the Milwaukee River about 0.9 mile upstream from where the Milwaukee River enters Lake Michigan.

TABLE 3. Basic watershed characteristics: the Menomonee River watershed.

Area	350.7 km^2 (137 mi^2)
Percent urbanized	52.8%
Population	348,165 (1970)
	964,640 (1990)
	962,570 (1996)

Population density ranges from less than 135 to about 10,000 persons per square kilometer with an average of 980 po./km^2. Channel modifications are concentrated in the urban areas. The 120-km river system contains 42% of minor channelization, 22% of major channelization, and 3% of conduit, accounting for a total of 67% of river length.

Table 4 shows the land use distribution for the Menomonee River watershed. About 46% of the total area is still in rural uses, representing a great potential for nonpoint source pollution. Rural areas prevail in the northern portion of the watershed, while the southern portion of the watershed is mainly urban.

The soils within the Menomonee River watershed are rolling silt loams or gravelly loams. Most of the natural soils are relatively fertile. Where urbanization has occurred, artificial fill materials and paved surfaces have modified the natural character of the soils with regard to drainage and fertility.

TABLE 4. Land use distribution: the Menomonee River watershed [GIS].

Land Use	Percent Total
Commercial and Services	7.6
Confined Feeding Ops	0.1
Cropland and Pasture	42.6
Deciduous Forest Land	2.4
Forested Wetland	0.3
Industrial & Commercial	6.0
Mixed Forest Land	0.2
Mixed Urban or Built-Up	1.1
Silvicultural	0.1
Other Urban or Built-Up	5.2
Reservoirs	0.2
Residential	29.7
Strip Mines (quarries)	0.7
Transportation, Commerce, Utilities	2.4
Transitional Areas	0.1

Ecological Risk Assessment

There are no point sources of pollution discharging in the two investigated water bodies.

The habitat quality and physical parameters were evaluated using Habitat Assessment and Physicochemical Parameters Protocol (Plafkin et al., 1989). The scores at Oak Creek ranged from 45 to 95% of reference score with majority of scores between 53 and 62% (non-supporting). Only one site has habitat conditions comparable to those of the reference site (>90%) and two sites are classified as supporting (75-90%). The scores at Menomonee River ranged from 40 to 97% of reference score. Three sites have conditions comparable to those of the reference site, one site is classified as partially supporting (60-75%) and four sites as non-supporting (<60%).

Biological monitoring was conducted during Summer 1999 in cooperation with Wisconsin Lutheran College. An index of biotic integrity (IBI) based on fish species composition was calculated based on procedures developed by Lyons (1992). A high percentage of tolerant species and low species diversity indicate very poor stream quality. The IBI scores indicate that all three locations do not support a typical fish community for this region.

Macroinvertebrates were collected at 5 sites on Oak Creek and 9 sites on Menomonee River, including 2 sites in headwaters without significant impairment by urbanization (reference sites). Sampling followed protocols for multihabitat using a D-frame dip net. Sampled habitat types included cobble, snags, vegetated banks, submerged macrophytes, sand and other fine sediment.

The chemical integrity monitoring program focused on key locations in the Oak Creek and Menomonee River watersheds. The following parameters were monitored: pH, suspended solids, volatile suspended solids, total solids, hardness, COD, total Kjeldahl nitrogen, nitrate and nitrite nitrogen, total phosphorus, total and dissolved heavy metals (Cd, Cu, Pb, Zn), cyanides (winter sampling only), and PAH (sampled twice). Total of 24 water column samples were analyzed. The sampling covered both low and high flow periods with wide range of flows. Sediment samples were also analyzed.

The data on water quality were used to estimate the ecological risk to aquatic biota by selected heavy metals (Cu, Pb, Zn). The calculation is based on modified methodology summarized in Novotny and Witte, 1997. The ecological risk is estimated as a joint probability of two probability functions: (i) the probability density function of ambient concentration (pdf), and (ii) the probability that an organism will be adversely affected by the exposure to the given concentration (toxic response curve). Ambient concentrations follow log-normal distribution.

Table 5 reports the calculated chemical risks by toxic metals. The risks (both chronic and acute) from copper calculated for the Menomonee River are two orders of magnitude higher than those for the Oak Creek. The risks from lead and zinc are at the same level for both watersheds.

Table 5. Chemical risk to aquatic biota. Oak Creek and Menomonee River.

Station Number	Cu	Pb <1987	Pb >1987	Zn
Oak Creek - acute	1 E-06	1 E-04	7 E-06	9 E-04
Oak Creek - chronic	7 E-05	2 E-02	3 E-03	1 E-03
Menomonee River - acute	1 E-04	2 E-04	2 E-06	6 E-04
Menomonee River - chronic	7 E-04	3 E-02	2 E-03	1 E-03

Flood Risk

The flood risk was defined as a probability at any point of the watershed that a flood will occur in any given year. Flood risks were estimated in the GIS ArcView environment. Two basic approaches were considered. The first is a vector-based approach that employed a custom developed ArcView Avenue scripts program. This approach permits estimation of risks only at specific points rather than for complete areas. The second more general approach works in a grid (raster) environment, and makes use of the Spatial Analyst Extension for ArcView. It permits flood risk to be calculated for the entire watershed, and specified points can be assigned the corresponding value from the underlying polygon. The second approach was selected because of its future applicability in watershed management applications.

RELATION OF THE WILLINGNESS TOP PAY TO THE RISKS OF FLOODING AND ECOLOGICAL DAMAGE TO THE STREAMS

Willingness to pay provides a measure of how much all beneficiaries, not just those living in the flood plain, are willing to spend for flood control and restoration of urban streams. In the research described herein, a hypothesis was advanced that the willingness to pay parameter could be related to the risks of flooding and damage to ecology.

To identify users's (citizen's) preferences for flood control and diffuse pollution control/stream restoration actions a two way survey is being conducted in two watersheds in the Milwaukee metropolitan area. The objectives of the surveys are as follows:

1. Find the extent and nature of physical and emotional connection to the water body;
2. Identify perceptions of the health of the water bodies;
3. Identify perceptions about flooding;
4. Assess understanding of the "Willingness to Pay" questions;
5. Identify salient beliefs about the water bodies and related issues;
6. Identify perceptions about the citizen's capacity to get information on this topic;
7. Identify beliefs about nature and quality of information about this topic from mass media;
8. Find the range of values placed on prevention of flooding and ecological improvement relative to other community issues.

Participants were drawn from a random sample of homeowners and residents of two investigated watersheds ion the Milwaukee metropolitan area.

Findings of the focus groups

Objective 1: There is great variance in people's connection to the river or creek. Some visit the river regularly to enjoy the scenery, walk or bike along the river while others avoid the river because they are too busy, or due to perceptions of pollution or lack of accessibility. Emotionally, some expressed anger at local agencies perceived as responsible for flooding/environmental quality problems.

Objective 2: Most participants felt that the health of the river and creek could be improved and that it had worsened over time. Specific concerns were about fertilizer, chemical runoff and trash and debris left behind by people. Several participants were concerned about the effect that communities upstream may have on the health of the river. A handful felt that some positive changes had taken place to improve the environmental quality. The following were seen as indicators of the health of the river or creek: 1) clarity and quality of water, 2) presence of fish, 3) presence of birds and other wildlife, 4) presence and condition of trees and plants, 5) ability for the water and areas surrounding the river and creek to sustain life, 6) the absence of fertilizers and chemical runoff from farms and homes, 7) the absence of industrial pollution.

Objective 3: Participants from Menomonee River groups perceived a much greater risk of flooding than respondents from Oak Creek. Menomonee River has a recent history of urban flooding. Participants were concerned about a wide range of damage, including flooding of yards and basements, roads and streets, sewer backup, well water contamination, the effects of future development and concern about others living in the flood plain. In general, it was difficult for participants to identify the cause of flooding in their community. Many were unsure whether the flooding they experienced was the result of poor drainage, sewers backing up, heavy rain, or rising water in the river and creek. It was suggested that future research include a set of items that tap into respondent's perceptions about the causes of flooding-- a consideration that is likely to influence WTP estimates.

Objective 4: Oak Creek residents had a hard time providing a WTP dollar amount because they did not believe the river was flooding and was not a problem in their community. Interestingly, flood plain residents gave WTP estimates that were lower than other groups. In fact, 4 out of 9 gave zero bids. Some of the reasons for the lower estimates include: 1) the beliefs that current taxes should be covering these projects; 2) the beliefs that past projects didn't work; 3) anger at and mistrust of public officials and local agencies. Given existing perceptions of minimal to nonexistent flood risks in the Oak Creek watershed, it was concluded that willingness to pay on flooding risk will only be evaluated in the Menomonee River watershed.

Objective 5: A number of salient behavioral beliefs were considered when subjects were formulating a WTP estimate. These appear to be the beliefs that are likely to be positively related to WTP. The most commonly held beliefs:

1. Perception that there is a current risk of flooding
2. Feeling strongly connected to the river/creek.
3. Concern for others in the flood plain.
4. Affordability and personal finances
5. Belief that paying would be making my contribution to solve a community problem
6. Belief that the project would benefit the community.
7. Belief that the project would improve the environmental quality

Some beliefs appear to be negatively related to WTP. These were:

1. Homeowners and developers are responsible for the increased risk and should be held responsible.
2. Belief that the project would be ineffective. General skepticism.
3. Taxes are too high already. Should be paid with current monies.
4. Belief that the project is not a priority for my community
5. Belief that the money would go to administrative costs and studying the problem, not solving the problem.

Objective 6: Participants generated a long list of potential information resources, but a majority of respondents said they would turn to governmental sources for information. (This may have been an artifact of the social context of the focus groups, however.) Some expressed distrust about the accuracy of information coming from government agencies. Many perceived a great difficulty in getting and understanding the information they would need to make a more educated WTP estimate (because of access and interpretability of information). Some felt it was not their responsibility to get information about potential projects.

Objective 7: A majority of participants said they would be unlikely to turn to the mass media for information. Participants varied greatly on the extent to which they held the following beliefs:

Stories with statistics are more believable than those without.
Someone's personal experience is more convincing than statistics.
In-depth features are more informative than single news articles or reports.
In-depth features are more trustworthy.

A number of additional possible items were suggested, designed to tap into people's beliefs about government agencies, experts, environmental groups and elected officials.

Objective 8: Most participants placed the prevention of floods and the environmental improvement of the river/creek as a medium to high priority for their community. Most participants disagreed with the notion that only those who live in the flood plain should be required to pay the cost of flood control. However, results were much more varied when a similar question implied taxation and the participant possibly having to make a contribution ("Taxpayers have a duty to share in the cost of flood control even thought only a minority is affected by floods"). Most participants agreed that we have an obligation to protect nature even if there are not human benefits.

The focus group surveys are being followed by two large surveys of approximately1000 citizems of the two investigated watersheds. Results of the surveys will be available at the end of the year 2000.

CONCLUSIONS

Urban streams are adversely affected by urbanization that increases risk of floods and decreases ecological integrity of urban receiving waters. Reducing both risks may lead to conflicting solutions. In the past emphasis was solely on flood control by using conveyance approaches. Today, efforts are on the way in many communities to restore the ecological integrity and in the same time provide flood control. BY correlating the numeric ecological and flood risks to the citizen's willingness to pay for reduction of the risks it will be possible to find an optimum of the solutions of the dual risks facing today many urban streams.

Focus group surveys by the research team of citizens living in two urban watersheds revealed that citizens value highly ecological integrity of the streams and are willing to support programs that would lead to its restoration. Willingness to pay for flood control may vary depending on the history of the flooding. Education of the public about future flooding potential is crucial because the citizens living in developing watersheds do not anticipate the future increases of the flood risks.

REFERENCES

Arnold, C., P. Boison, and P. Patton. (1983). *Evaluation of Catch Basin Performance for Urban Stormwater Pollution Control: Project Summary*, EPA 600/S2-83-043, Municipal Environmental Research Laboratory, U.S. EPA, Cincinnati, OH.

Gregory, K., R. Davis, and P. Downs. (1992). Identification of River change due to urbanization. *Applied Geography*, 12:299-318.

Lyons, J. (1992). Using the Index of Biotic Integrity (IBI) to Measure Environmental Quality in Warmwater Streams of Wisconsin. Gen. Tech. Rep. NC-149. US Dept. of Agriculture, Forest Service North Central Forest Experiment Station, St. Paul, MN.

Novotny, V., and J. W. Witte (1997). "Ascertaining aquatic ecological risks of urban stormwater discharges," *Water Res.* **31**(10):2573-2585.

Plafkin, J. L., M. T. Barbour, K. D. Porter, S. K. Gross, and R. M. Hughes (1989). Rapid Bioassessment Protocol for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish, EPA/440/4-89/001. U.S. Environmental Protection Agency, Washington, DC.

Riley, A. L. (1998). Restoring Streams in Cities: *A Guide for Planners, Policy-Makers and Citizens*, Ireland Press.

Schueler, R. L. (1994). The importance of imperviousness. *Watershed Protection Techniques*, 1(3):100-111.