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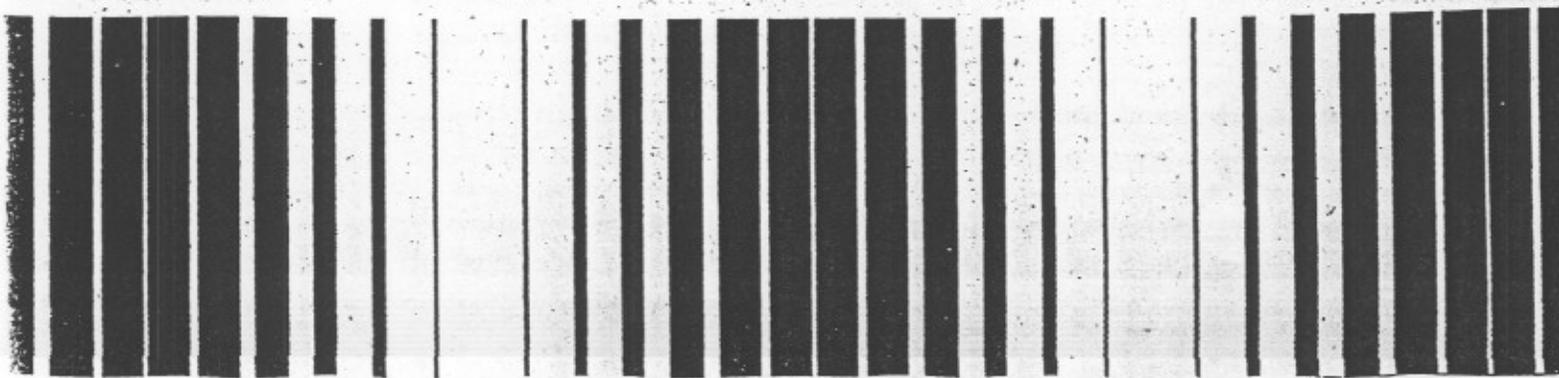
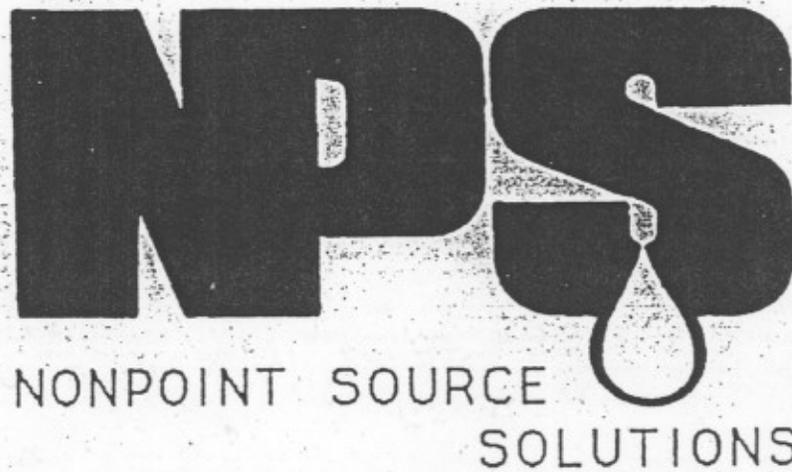
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## Nonpoint Source Watershed Workshop



## MITIGATING THE ADVERSE IMPACTS OF URBANIZATION ON STREAMS: A COMPREHENSIVE STRATEGY FOR LOCAL GOVERNMENT

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### INTRODUCTION

Urban streams are arguably the most extensively degraded and disturbed aquatic systems in North America. In general, stream systems tend to reflect the character of the watershed in which they drain. Given the massive physical conversion in a watershed that accompanies urbanization, the degraded nature of urban streams is not surprising.

Over the last two decades, substantial evidence has accumulated regarding the pervasive impacts of urbanization on stream hydrology, geomorphology, water quality, habitat, and ecology (Table 1). In response, local governments within the rapidly growing Washington metropolitan area have developed an increasing number of stringent measures to mitigate the impact of new development on streams. The effectiveness of these measures has varied considerably, in large part because they have not been applied in a coordinated and comprehensive manner.

This paper outlines a watershed approach for urban stream protection that incorporates the most useful and effective planning and engineering techniques that have evolved in the Washington metropolitan area. The stream protection strategy is based on comprehensive and continuous regulation of the development process from the master planning stage until it is ultimately realized.

### THE IMPACTS OF URBANIZATION ON STREAMS

Urbanization has a profound influence on stream quality. The extent of this influence is obvious when an urban stream is compared with another in a rural or natural watershed. Impacts on urban streams can be loosely grouped into four categories: changes to stream hydrology, geomorphology, water quality, and aquatic ecology. The intensity of the impacts is typically a function of the intensity of urbanization. A convenient measure of development intensity is the percentage of watershed

area devoted to impervious surfaces (roads, parking lots, rooftops, sidewalks, compacted fill, etc.). Operationally, watershed imperviousness can be simply defined as the fraction of watershed area that is unvegetated.

### Changes In Stream Hydrology

The hydrology of urban streams changes immediately in response to site clearing. The natural runoff storage capacity is quickly lost with the removal of the protective canopy of trees, the grading of natural depressions, and the elimination of spongy topsoil and wetland areas. As the soil is further compacted and resurfaced by impervious materials, rainfall can no longer percolate into the soil and is rapidly and effectively converted into surface runoff. Thus, the net effect of development is to dramatically change the hydrologic regime of the urban streams such that:

- **The magnitude and frequency of severe flood events increases.** In extremely developed watersheds (impervious >50 percent), the postdevelopment peak discharge rate may increase by a factor of five from the predevelopment rate. These more severe floods reshape the dimensions of the stream channel and its associated floodplain.

In addition, watershed development increases the frequency of bankfull and sub-bankfull flooding events. Bankfull floods are defined as floods that completely fill the stream channel to the top of its banks, but do not spill over into the floodplain. Schueler (1) estimated that the number of bankfull floods increases from one every other year (prior to development) to over five each year (for a 50 percent impervious watershed). In practical terms, this means that a short but intense summer thunderstorm that scarcely raised water levels prior to development may turn an urban stream into a raging torrent. The greater number of bankfull floods subject the stream channel to continual disturbance by channel scour and erosion.

- **More of the stream's annual flow is delivered as surface storm runoff rather than baseflow or interflow.** In natural undeveloped watersheds, anywhere from 5 to 15 percent of the annual streamflow is delivered during storm events, depend-

Table 1. Major Stream Impacts Caused by Urbanization

**Changes in Urban Stream Hydrology**

- Increase in Magnitude and Frequency of Severe Floods
- Increased Frequency of Erosive Bankfull Floods
- Increase in Annual Volume of Surface Runoff
- More Rapid Stream Velocities
- Decrease in Dry-Weather Baseflow on Stream

**Changes in Urban Stream Morphology**

- Stream Channel Widening and Downcutting
- Increased Streambank Erosion
- Shifting Bars of Coarse-Grained Sediments
- Elimination of Pool/Riffle Structure
- Imbedding of Stream Sediments
- Stream Relocation/Enclosure or Channelization
- Stream Crossings Form Fish Barriers

**Changes in Urban Stream Water Quality**

- Massive Pulse of Sediment During Construction Stage
- Increased Washoff of Pollutants
- Nutrient Enrichment Leads to Benthic Algal Growth
- Bacterial Contamination During Dry and Wet Weather
- Increase in Organic Carbon Loads
- Higher Levels of Toxics, Trace Metals, and Hydrocarbons
- Water Temperature Enhancement
- Trash/Debris Jams

**Changes in Stream Habitat and Ecology**

- Shift from External to Internal Stream Production
- Reduction in Diversity of Aquatic Insects
- Reduction in Diversity and Abundance of Fish
- Destruction of Wetlands, Riparian Buffers, and Springs

ing on watershed vegetative cover, soils, and geology. By contrast, in developed watersheds, the majority of annual streamflow occurs as surface runoff. As a general rule, the amount of storm runoff increases in direct proportion to the amount of watershed imperviousness. For example, surface runoff typically comprises half the annual streamflow in a watershed that is 50 percent impervious (1).

Consequently, the amount of baseflow and interflow available to support streamflow during extended periods of dry weather is greatly reduced. In smaller headwater streams, the reduction in dry-weather flow can cause a perennial stream to become seasonally dry. In larger urban streams, the reduced dry-weather flow can significantly restrict the wetted perimeter of the stream that is available for aquatic habitat.

- The velocity of flow during storms becomes more rapid. This is due to the combined effect of greater discharge, rapid time of concentration, and smoother hydraulic surfaces. In a 50 percent impervious watershed, postdevelopment runoff velocities exceed thresholds for erosivity, requiring channel protection measures or even stream enclosure. In addition, streamflow becomes extremely flashy, with sudden and sharp increases in discharge followed by an equally abrupt return to prestorm discharge levels.

**Changes in Urban Stream Morphology**

Stream channels in urban areas must respond and adjust to the altered hydrologic regime that accompanies urbanization. The severity and extent of stream adjustment is a function of the degree of watershed imperviousness, and can be summarized as follows:

- The primary adjustment to the increased stormflow is channel widening, and to a lesser extent, down-cutting. Stream channels in moderately developed watersheds may become four times wider than after development (1). The channel-widening process is primarily accomplished by lateral cutting of the streambanks. As a consequence, the riparian zone adjacent to the channel is severely disturbed by undercutting, tree-fall, and slumping.
- Sediment loads to the stream increase sharply due to streambank erosion and upland construction site runoff. The coarser-grained sediments are deposited in the new wider channels and may reside there for years until the stream can export them from the watershed. Much of the sediment remains in temporary storage, in the form of constantly shifting sandbars and silt deposits. The shifting bars often accelerate the streambank erosion process by deflecting runoff into sensitive bank areas.
- Together, the massive sediment load and channel widening produce a major change in the morphology of urban streams. The series of pools and riffles so characteristic of natural streams is eliminated, as the gradient of the stream adjusts to accommodate the frequent floods. In addition, the depth of flow in the channel becomes shallower and more uniform during dry-weather periods. The loss of pool and riffle structure in urban streams greatly reduces the availability and diversity of habitat for the aquatic community.
- The nature of the streambed is also modified by the urbanization process. Typically, the grain size of the channel sediments shifts from coarse-grained particles towards a mixture of fine- and coarse-grained particles. This results in a phenomenon known as imbedding, whereby sand, silt, and even clay fill up the interstitial voids between

larger cobbles and gravels. Imbedding reduces the circulation of water, organic matter, and oxygen to the filter-feeding aquatic insects that live among and under the bed sediments. These insects are the basic foundation of the stream food chain. In addition, imbedding of the stream sharply limits the quality and availability of fish spawning areas, particularly for trout.

- **In intensively urbanized areas, many streams are totally modified by man to "improve" drainage and reduce flooding risks.** Headwater streams tend to suffer disproportionately from enclosure. Quite simply, the headwater stream is entirely destroyed, and is replaced by an underground network of storm drainpipes. In the past, larger urban streams have been engineered and channelized to more efficiently and safely convey floodwaters. Although large-scale stream channelization is now discouraged, some form of future channel "improvement" is inevitable if development is allowed within the postdevelopment floodplain.
- **Another inevitable consequence of urbanization is stream crossings by roads and pipelines.** These structures must be heavily armored to withstand the down-cutting power of stormwater. Many engineering techniques utilized for this purpose (drop structures, gabion mats, culverts, etc.) create barriers to the migration of both resident and anadromous fish. Even a 6 in. drop can block the upstream movement of many fish species, making recolonization of upstream areas impossible after a disturbance event.

#### Changes in Stream Water Quality

During the initial phase of development, an urban stream receives a massive pulse of sediment eroded from upland construction sites. Unless erosion and sediment controls are used, sediment loads and turbidity levels increase by two to three orders of magnitude from predevelopment levels. Sediment levels often decline once upland development stabilizes but never return to predevelopment levels, because of increased stream-bank erosion.

Once construction is complete, the dominant pathway of pollutants to a stream is the washoff of accumulated deposits from impervious areas during storms (2). Substantial quantities of nitrogen, phosphorus, carbon, solids, and trace metals are deposited on urban surfaces as both dry and wet atmospheric deposition, and are rapidly and directly conveyed to the stream via storm drains. Other non-atmospheric sources of pollutant accumulation are also important, such as pet droppings, leaf litter, vehicle leakage, and deterioration of urban surfaces.

In general, the pollutant levels in urban streams are one to two orders of magnitude greater than those reported in forested watersheds. The degree of pollutant loading has been shown to be a direct function of the percentage of watershed imperviousness (1). In urban streams, the higher pollutant loadings translate into water-quality problems, such as:

- **Nutrient enrichment.** Nitrogen and phosphorus concentrations in urban runoff stimulate excessive algal growth, particularly in shallow, unshaded stream reaches. Most algal growth is benthic in nature, attaching on rocks or growing within the slime coating that surrounds rock surfaces in urban streams.
- **Bacterial contamination.** Bacterial levels in urban streams routinely exceed U.S. Public Health standards during both wet and dry weather, rendering them unsuitable for water contact recreation. The sources of bacterial contamination are complex, but include the washoff of pet feces and leakage from sanitary sewer lines.
- **Organic matter loads.** Loads of organic matter delivered during storm events are equivalent in strength to primary wastewater effluent. When the organic matter eventually settles out in slower moving lakes and estuaries, the oxygen demand exerted during their decomposition depletes oxygen from the water column.
- **Toxic compounds.** A large number of potentially toxic compounds are routinely detected in urban stormwater. These include trace metals (lead, zinc, copper, cadmium, and zinc), pesticides, and hydrocarbons (derived from oil/grease and gasoline runoff), among others. While the duration of exposure to these toxic chemicals is limited during storms, they tend to accumulate in benthic sediments of urban streams, lakes, and estuaries. Not much is known about the individual or collective toxicity of these compounds to the stream community. However, some degree of impact is likely, given the consistently poor aquatic diversity noted in these ecosystems.
- **Temperature enhancement.** Impervious areas act as heat collectors. Heat is then imparted to stormwater runoff as it passes over the imperviousness. Recent data indicate that intensive urbanization can increase stream water temperatures by as much as 5 to 10°C during storms (3). A similar temperature increase may occur during dry weather periods, if a stream's protective riparian forest canopy has been eliminated or if ponds and lobes are created upstream.

The thermal loading severely disrupts aquatic organisms that have finely tuned temperature limits.

Cold-water organisms such as trout and stoneflies are particularly sensitive, and often become locally extinct in intensively developed streams.

- **Trash/debris.** A conspicuous and diagnostic feature of urban streams is the presence of large debris jams in the stream and floodplain, composed of litter, leaves, and trash that have washed through the storm drain system. The debris jams greatly detract from the scenic appearance of the stream.

### Changes In Stream Habitat and Ecology

The ecology of urban streams is shaped and molded by the extreme shifts in hydrology, morphology, and water quality that accompany the development process. The stresses on the aquatic community of urban streams are both subtle and profound, and are often manifested in the following ways:

- **Shift from external to internal stream production.** In natural streams, the primary energy source driving the entire aquatic community is the import and decomposition of terrestrial detritus, namely leaf litter and woody debris. However, in many urban streams, internal benthic algal production becomes a major energy source supporting the aquatic community, due to the combined effect of increased light penetration and nutrients (and the rapid washout of terrestrial detritus through the stream system). This shift is often manifested in changes in the mix of species found in the stream community. For example, environmental conditions are more favorable for species that graze algae from rocks (e.g., snails) than for species that shred leaves or filter coarse-grained detritus (e.g., caddis flies, stoneflies).
- **Reduction in diversity in the stream community.** The cumulative impact of the loss of habitat structure (pools/riffles), the imbedding of the streambed, greater flooding frequency, higher water temperatures, extreme turbidity, lower dry-weather flows, eutrophication, and toxic pollutants conspire to greatly reduce the diversity and richness of the urban stream community. In intensively developed areas, streams support only a fraction of the fish and macroinvertebrates that exist in natural reference streams.
- **Destruction of freshwater wetlands, riparian buffers, and springs.** In the past decade, it has been necessary to abandon the notion that a stream ecosystem is defined solely by its channels. It is now understood that a stream ecosystem extends to include the extensive freshwater wetlands, floodplains, riparian buffers, seeps, springs, and ephemeral channels that are linked to the stream. These areas contribute, in varying ways, many of the ecological functions and processes upon which the stream community depends. Unfortunately, these areas are

frequently destroyed or altered by indiscriminate clearing and grading during the construction phase of development.

### COMPREHENSIVE URBAN STREAM PROTECTION STRATEGY

For the past two decades, governments in the Washington metropolitan area have attempted to deal with the complex impacts of urban growth on streams by creating an equally complex series of regulations, programs, and controls on the urban development process. The success of these measures in mitigating the impacts on streams, however, has been less than anticipated. The primary reason has been that individual measures are developed in response to a single impact that occurs during a unique phase of the development cycle. Until recently, little effort has been made to craft a comprehensive stream protection strategy throughout the entire development cycle, from development of watershed master plans to the ultimate realization of that development.

What follows is an attempt to outline the elements of an effective local stream protection strategy that can minimize the impacts of growth on urban streams (see Table 2). It is hoped that this strategy can be further refined and adjusted to aid local governments in developing effective programs to maintain stream quality.

The comprehensive stream protection strategy has six primary components that roughly relate to various stages of the development cycle. They are:

1. Watershed Master Planning
2. General Development Restrictions
3. Environmental Site-Planning Techniques
4. Sediment and Erosion Control During Construction
5. Urban Stormwater Best Management Practices
6. Community Stream Restoration Programs

#### Watershed Master Planning

The future quality of an urban stream is fundamentally determined by the broad land-use decisions made by a community. It is therefore essential that the impact of future development on streams be assessed during the master planning process. The appropriate planning unit for this assessment is the watershed. The location and intensity of future development within the watershed should be carefully examined from the following perspectives:

- **Evaluating stream resources.** The first step in the planning process is to survey the stream resources within a jurisdiction to obtain basic information on their use, quality, and value. It is also useful to survey and delineate floodplains, wetlands, and other environmentally sensitive areas during this stage.

Table 2. Six Elements of a Comprehensive Stream Protection Strategy

<p><b>1. Watershed Master Planning</b></p> <ul style="list-style-type: none"> <li>Evaluation and Mapping of Stream Resources</li> <li>Designating Stream Quality Classes</li> <li>Zoning to Protect Unique and Sensitive Stream Systems</li> <li>Evaluation of Adequacy of Current Stream Protection Programs</li> <li>Regional Stormwater Management Planning</li> </ul> <p><b>2. Adoption of General Development Restrictions</b></p> <ul style="list-style-type: none"> <li>Variable-width Stream Buffer Requirements</li> <li>Floodplain Development Restrictions</li> <li>Steep Slope Restrictions</li> <li>Nontidal Wetland Protection</li> <li>Protection of Environmentally Sensitive Areas</li> <li>Upland and Riparian Tree Cover Requirements</li> <li>Waterway Disturbance Permits</li> <li>Community Open-Space Requirements</li> </ul> <p><b>3. Environmental Site Planning Techniques</b></p> <ul style="list-style-type: none"> <li>Cluster Development</li> <li>Transferable Development Rights</li> <li>Planned Unit Developments</li> <li>Flexible Road Width Requirements</li> <li>Fingerprinting of Site Layout</li> </ul>	<p><b>4. Sediment and Erosion Control During Construction</b></p> <ul style="list-style-type: none"> <li>Limit Area and Time of Construction Disturbance</li> <li>Immediate Vegetative Stabilization of Disturbed Areas</li> <li>Use of Super-basins for Sediment Control</li> <li>Frequent Inspection of Erosion and Sediment Controls</li> <li>Strong Civil Enforcement Authority for Violations</li> </ul> <p><b>5. Urban Stormwater Best Management Practices</b></p> <ul style="list-style-type: none"> <li>BMP Performance and Maintenance Criteria</li> <li>First Flush Treatment Requirements</li> <li>Use of Extended Detention Wet Pond Marsh Systems</li> <li>Use of Infiltration Systems with Pretreatment</li> <li>BMP Landscaping, Safety, and Appearance Guidelines</li> <li>Careful Environmental Review of Urban BMPs</li> <li>Strong Local BMP Plan Review and Inspection</li> <li>Public BMP Maintenance Responsibility and Financing</li> </ul> <p><b>6. Community Stream Restoration Programs</b></p> <ul style="list-style-type: none"> <li>Long-term Stream Trends Monitoring</li> <li>Watershed Assessment of Restoration Opportunities</li> <li>Retrofitting of Older Urban BMPs</li> <li>Construction of New Urban BMPs</li> <li>Riparian and Upland Reforestation Programs</li> <li>Instream Fish Habitat Improvements</li> <li>Urban Wetland Restoration and Creation</li> <li>Removal of Fish Barriers</li> <li>Urban Stream Stewardship</li> </ul>
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- **Designating stream quality classes.** The next step is to rank and prioritize the stream systems within a locality, based on the stream resource surveys. Stream use classes are designated to set forth the appropriate targets for stream quality that will be maintained during the development process. Unique areas, such as cold-water trout streams, warmer water stream fisheries, scenic reaches, and extensive stream/wetland/floodplain complexes should be targeted for special protection. The upland watersheds draining to these unique areas can only be protected through a combination of low-density zoning, open space preservation, and stream valley park acquisition (as well as strict subdivision, sediment, and stormwater controls during the low-density development process). Based on experience in the Washington area, it is almost impossible to maintain the quality of these unique systems if upland watershed imperviousness exceeds 10 to 15 percent.
- **Evaluating the adequacy of stream protection programs.** The watershed master planning stage

provides an excellent opportunity for a community to critically review the adequacy of its stream protection measures before development begins. This requires a thorough analysis of whether the community has the authority, criteria, review staff, and enforcement capability to maintain its stream protection programs in the areas of environmental subdivision review, construction sediment controls, stormwater management, and stream restoration. If a community is unwilling to commit the financial and staff resources to stream-protection programs, watershed master planning becomes a meaningless exercise.

- **Regional stormwater management planning.** An important component of watershed master planning is the use of hydrologic and hydraulic simulation models to project a stream's future hydrologic regime. Models are a useful (but not sufficient) means of evaluating the impact of future development scenarios on stream quality. The models also can be used to identify the most effective locations in the watershed to construct regional stormwater

management facilities, thereby enabling a community to acquire the sites to construct regional facilities before development begins.

#### Development Restrictions

The second phase in a community stream protection plan is the adoption of a comprehensive and integrated set of environmental restrictions to govern the development process. The greatest level of stream protection is afforded when a single development ordinance is adopted by a community and administered by a single planning authority. In short, the ordinance mandates a minimum level of environmental site planning during development and includes, but is not limited to, the following items. Several innovative local regulations from the Washington metropolitan area are referenced.

- **Stream buffer requirement.** Development is not allowed within a variable width buffer strip on each side of ephemeral and perennial stream channels. The minimum width of the buffer strip is 50 ft for low-order headwater streams, but expands to as much as 200 ft in larger streams (4). The stream buffer further expands to include floodplains, steep slopes, wetlands, and open space areas to form a contiguous system, according to prescribed rules.
- **Floodplain restrictions.** No development is allowed within the boundaries of the post-development 100-year floodplain, as designated in the watershed masterplan. This eliminates the need for future flood protection measures for these properties, and forms an essential component of the stream buffer system.
- **Steep slope restriction.** No clearing and grading is permitted on slopes in excess of 25 percent (5). These areas may be tied into the stream buffer system, or may exist as isolated open space reserves.
- **Nontidal wetland protection.** No development is permitted within nontidal wetland areas and a perimeter buffer area (25 to 50 ft). In many cases, the establishment of the stream buffer system will have already protected these important areas (6).
- **Protection of environmentally sensitive areas.** Development is not allowed within unique habitat areas and plant communities and protective perimeter buffers, as identified in the watershed master planning study (7). It is critically important to provide corridors from upland environmentally sensitive areas to the stream buffer system.
- **Upland and riparian tree cover requirements.** An allotted percentage of upland pre-development tree cover must be maintained after site development (8). In addition, the riparian tree cover (which should be

entirely contained within the stream buffer system) must also be retained, or reforested (if no tree cover currently exists). Where possible, tree-save areas should be lumped into large blocks tied into the buffer system rather than small and isolated stands. Numerous studies have confirmed that local wildlife diversity cannot be maintained in small islands of trees surrounded by urbanization (9).

- **Waterway disturbance permits.** Certain forms of development such as roads and utilities, must, by their very nature, cross through the stream buffer system and thereby reduce its effectiveness. Linear developments must be closely scrutinized to locate them in the narrowest portions of the buffer system, and ensure that they do not form barriers to either fish or riparian migration. In addition, the time "window" during which the stream and buffer system can be disturbed by construction activity should be limited to exclude critical fish spawning seasons.
- **Community open-space requirements.** Once the stream buffer system has been delineated, the developer is still required to preserve an additional percentage of open space at the site to accommodate the residents, future requirements for parks, playgrounds, ballfields, and other community needs. If an acceptable amount of community open space is not reserved for this purpose, it is extremely difficult to maintain the integrity of the stream buffer in the future.

#### Environmental Site Planning at the Site Level

Significant opportunities still remain to protect streams during the site planning stage. The major objective is to minimize the total amount of site imperviousness at the site, and cluster development into centralized areas where stormwater can be effectively treated. The best tools at this stage are incentive methods, such as transferable development rights, cluster zoning, site "fingerprinting," planned unit development, and flexible site and road width layout. An excellent review of how these site-planning methods can be applied to protect streams is contained in Yaro et al. (10).

#### Erosion and Sediment Control During Construction

The fourth objective of an effective stream protection strategy is to reduce the massive pulse of sediment that inevitably occurs during the construction stage of development. To accomplish this goal, it is necessary to both minimize the degree of erosion within the construction site (erosion control) and to remove sediments borne in construction site runoff as they leave the site (sediment control). An excellent design manual of state-of-the-art erosion and sediment control techniques is the forthcoming Maryland Standards and Specifications (11).

Several strategies have been shown to be very effective in reducing downstream sediment concentrations during the construction phase. These include:

- **Reduce the area and length of time that a site is cleared and graded.** This reduces the potential for erosion and can be done by prohibiting clearing and grading from all postdevelopment buffer zones at the site, configuring the site plan to retain as much undisturbed open space as possible (e.g., cluster zoning and the environmental site planning techniques noted earlier); and phased construction sequencing to limit the amount of disturbed area exposed at any given time.
- **Immediate vegetative stabilization of disturbed areas.** Recent studies in the Washington metropolitan area indicate that the rapid establishment of a grass or mulch cover on cleared and graded areas in construction sites can result in a six-fold reduction in downstream suspended sediment levels (12).
- **Use of "super" sediment control basins.** Superbasins have wet and dry storage equivalent to 1 in. of sediment per acre of upland watershed area. If properly designed and maintained, superbasins can provide reliably high rates of sediment removal for most of the storms during the year (12). Smaller, conventionally designed sediment basins and sediment traps exhibit highly variable sediment removal rates, and are often overwhelmed during larger storms.
- **Frequent onsite inspection of erosion and sediment controls.** The landscape at a construction site often changes dramatically from week to week. Consequently, it is critically important that sediment inspectors visit the site at least every two weeks to ensure that the sediment control plan is working and that all control measures are being properly initiated and maintained. In particular, inspections should be concentrated during the latter stages of construction, when the sediment delivery potential from the site is at its highest.
- **Provide sediment control inspectors with strong enforcement authority.** This authority is needed to allow inspectors to direct contractors to promptly correct violations of the sediment control plan in the field. The best success has been enjoyed in communities where inspectors are empowered to issue automatic and costly civil fines for sediment control violations. These strong enforcement tools are critical in forcing construction contractors to make erosion and sediment control a part of their daily operations.

### Urban Best Management Practices and Stormwater Control

The fifth objective of an effective stream protection strategy is establishing local requirements to install urban stormwater best management practices (BMPs) to control postdevelopment stormwater runoff. Urban BMPs try to replicate the natural, predevelopment hydrologic regime of a stream by infiltrating, retaining, or detaining the increased quantity of urban stormwater produced by development. In addition, urban BMPs may partially reduce the increased load of pollutants generated from developed areas.

In recent years, major advances have been made in urban BMP planning and design. While a thorough discussion of current urban BMP techniques is outside the scope of this paper, several reviews are available on the subject (1,13). In addition, area local governments have prepared model ordinances to implement effective urban stormwater programs (14).

Several important points should be kept in mind about urban BMPs. First, urban BMPs can never fully mitigate the wide spectrum of hydrologic and water-quality impacts that accompany urbanization. That is, they can never compensate for poor watershed master planning, an inadequate stream buffer network, or sloppy site planning. Second, urban BMPs are a simple technological solution to a complex problem, and in some cases may create as many environmental problems as they eliminate. For example, pond BMPs have been shown to increase water temperatures and stress cold-water organisms (3), to be a significant cause of destruction of freshwater wetlands, and to represent a local interruption to the stream continuum. Similarly, infiltration BMPs may increase the risk of ground-water contamination and have a high rate of failure (13).

Third, urban BMPs are a significant feature of the community, and can become a locally unwanted land use (LULU) if careful attention is not paid to concerns such as landscaping, appearance, safety, stagnation, and maintenance. Finally, urban BMPs must be maintained if they are to continue to protect streams in the future. Communities must recognize, accept, and finance the maintenance burden of stormwater management.

### Stream Restoration Techniques

The final element of an effective stream protection strategy is a community stream restoration program. The primary purpose of stream restoration is to enhance the aquatic habitat and ecological functions of urban streams that have been lost or degraded during the urbanization process. In a sense, stream restoration programs are an attempt to fix the mistakes made during the development process. The best way to identify these mistakes is to

look at the postdevelopment stream from the perspective of a fish. That is, what are the dominant changes in the postdevelopment stream that have contributed most to the decline of a healthy stream community?

- **Long-term stream trends monitoring.** The first step is to conduct systematic biological surveys throughout the stream system every five to ten years to identify reaches where the aquatic community has shown the greatest decline. These reaches indicate that some aspect of the stream protection effort has failed, and they become the first candidates for stream restoration.
- **Watershed assessment of restoration opportunities.** The second step is to walk the stream and its upland watershed to determine the dominant impacts that have degraded the aquatic community, and identify feasible opportunities for restoring stream habitat or water quality. Stream assessments are best done on 1 to 10 mi<sup>2</sup> sub-watersheds, where a team of aquatic biologists and engineers can identify possible restoration opportunities within urban BMPs, the stream buffer network, and the stream itself.
- **Retrofitting of urban BMPs.** The best restoration opportunities often involve the improvement of existing urban BMPs. Unfortunately, many urban BMPs never achieve in the field what was hoped for at the drafting table. In addition, since urban BMP design is constantly changing and improving, most older urban BMPs do not have the pollutant removal capability of current designs (e.g., the dry stormwater management pond).

These older urban BMPs offer great opportunities for retrofitting at relatively modest investment. Pond retrofitting has been the primary focus of restoration efforts in the Washington metropolitan area (15), and has typically involved converting older dry stormwater ponds into extended wet pond marsh systems.

- **Construction of additional urban BMPs.** In watersheds where development has occurred prior to the implementation of a community stream protection strategy, it is often necessary to retrofit new urban BMPs into the urban landscape. This is not an easy task, given the limited amount of space available. However, surveys have shown that acceptable sites can be found in a developed watershed, and that public land agencies will participate in a retrofit program, particularly if it is demonstrated that the proposed urban BMPs will improve the amenity value on those public lands (5,16). Innovative retrofit techniques are currently being developed for these areas, including the peat-sand filter (17), oil grit separator inlets (18), and extended detention lake/wetland systems (19).

- **Riparian reforestation programs.** A common problem encountered in urban streams is that the riparian stream buffer zone has been cleared. Fortunately, the buffer zone can be gradually reforested within a matter of years, through cooperative community tree-planting programs at a relatively low cost. These volunteer programs have become extremely popular in the Washington area, and are most effective when local governments arrange the logistics, assemble the sites, and secure the plant stock according to a long-term watershed plan.
- **Upland reforestation programs.** A useful method for reducing the adverse impact of watershed imperviousness on urban streams is to reforest upland areas. Quite simply, impervious areas are converted into pervious, forested areas. Again, a community reforestation program, that utilizes native tree species and citizen volunteers, is a useful tool. These programs have the additional benefits of increasing citizen awareness about environmental stewardship and improving the appearance of the urban landscape.
- **Instream fish habitat improvement.** From the perspective of a fish, the dominant impact associated with urbanization is probably the degradation of stream habitat structure, most notably the loss of pools, riffles, and clean spawning areas. These habitat features can be re-created within urban streams by adapting habitat improvement techniques developed by stream biologists to increase fish production in more natural stream systems. These techniques include the use of boulder and log deflectors, log drop structures, brush bundles, willow wattles, boulder placement, and imbricated rip-rap. These stream restoration techniques are being applied in several highly degraded stream reaches of the urbanized Anacostia watershed to test the hypothesis that an improvement in stream habitat can improve local fish diversity and abundance in urban streams (3).
- **Urban wetland creation/restoration.** Despite recent regulatory protections, it is likely that most watersheds have lost, and will continue to lose, large areas of freshwater and tidal wetlands to the development process. This is because urban stormwater runoff exerts the same series of pervasive and adverse impacts to urban wetlands as it does to urban streams. It is therefore critical to actively restore and manage urban wetlands, rather than merely conserve them. Otherwise, the ecological value and functions of urban wetlands will gradually diminish over time. It is equally critical to create new urban stormwater wetland areas that partially substitute for the lost ecological functions of the destroyed or degraded wetland system.

A series of urban wetland restoration and creation projects are currently being performed in the Anacostia River basin (20). At present, the goal of these programs is to augment the total acreage and environmental function of urban wetlands at the scale of the sub-watershed.

- **Identification and removal of fish barriers.** The urban stream network should be periodically surveyed to detect possible barriers to anadromous and resident fish migration. Fish barriers can be detected through systematic upstream/downstream fish collections at suspected structures during spring runs (21), or in some cases, by visual surveys. In many cases, urban fish barriers are created by relatively low-drop structures that can be rather easily modified to allow migration. In the Anacostia, simple and low-cost modifications to two-drop structures are planned that are expected to open up several miles of spawning habitat to anadromous fish (22).
- **Stream stewardship.** The foundation of effective community stream restoration programs are citizens who take an active and personal interest in maintaining urban stream quality. Local governments should recognize these individuals, and encourage them to adopt a stream and participate in streamwalks, tree-plantings, and other volunteer programs. These urban stream stewards can also be of great value in reporting oil spills, sediment control violations, pollution problems, and sewer overflows. Most of all, stewards can act as effective advocates for urban streams.

## SUMMARY

Protecting urban streams from development is obviously a difficult task. The six-step strategy outlined in this paper requires an extensive commitment of knowledge, resources, and staff on the part of a community. To be successful, a community must be willing to place the protection of urban streams on a par with economic growth and the creation of urban infrastructure. If these conditions can be met, it is possible to mitigate the impact of development, and to maintain a quality stream system for the future generations that will live and work within them.

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