Appendix 5-A

THE IMPERVIOUS COVER MODEL: AN EMERGING FRAMEWORK FOR URBAN STORMWATER MANAGEMENT

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5-A.1 INTRODUCTION

Impervious cover (IC) has unique properties as a watershed metric in that it can be measured, tracked, forecasted, managed, priced, regulated, mitigated and, in some cases, even traded. In addition, IC is a common currency that is understood and applied by watershed planners, stormwater engineers, water quality regulators, economists and stream ecologists alike. IC can be accurately measured using either remote sensing or aerial photography (Goetz et al. 2003 and Jantz et al. 2005). IC is also strongly correlated with individual land use and zoning categories (Cappiella and Brown 2001; Slonecker and Tilley 2004) which allows planners to reliably forecast how it changes over time in response to future development. Consequently, watershed planners rely on IC (and other metrics) to predict changes in stream health as a consequence of future development (CWP 1998).

Schueler (2004) has utilized IC to classify and manage urban streams, and economists routinely use IC to set rates for stormwater utilities and off-site mitigation (Parikh et al. 2005). Regulators and engineers utilize IC as a key input variable to predict future downstream hydrology and design stormwater management practices (MPCA 2005). A number of localities have modified their zoning to establish site-based or watershed-based IC caps to protect streams or drinking water supplies. In recent years, IC has been used as a surrogate measure to ensure compliance with water quality standards in impaired urban waters (Bellucci 2007).

Another noteworthy aspect of IC has been its use as an index of the rapid growth in land development or sprawl at the watershed, regional and national scale. For example, Jantz et al. (2005) found that IC increased at a rate five times faster than population growth between 1990 and 2000 in the Chesapeake Bay watershed – over 76,000 acres of impervious cover and over 232,000 acres of turf cover are created each year, or nearly 1 percent of the watershed per year. At a national level, several recent estimates of IC creation underscore the dramatic changes in many of our nation's watersheds as a result of recent or future growth. Elvidge et al. (2004) estimated that about 112,665 km^2 (43,500 mi^2) of IC had been created in the lower 48 states as of 2000. Forecasts by Beach (2002) indicate that IC may nearly double by the year 2025 to about 213,837 km^2 (82,563 mi^2), given current development trends. Although care must be taken when extrapolating from national estimates, it is clear that several hundred thousand stream miles are potentially at risk. For example, a detailed GIS analysis by Exum et al. (2006) indicates that 14% of the total watershed area in eight Southeastern states had exceeded 5% IC as of 2000.

Given growth in IC, watershed managers are keenly interested in the relationship between subwatershed IC and various indicators of stream quality. The Impervious Cover Model (ICM) was first proposed by Schueler (1994) as a management tool to diagnose the severity of future stream problems in urban subwatersheds. The ICM projects that hydrological, habitat, water quality and biotic indicators of stream health decline at around 10% total IC in small subwatersheds (i.e., 5 to 50 km^2) (CWP 2003). The ICM defines four categories of urban streams based on how much impervious cover exists in their subwatershed:

- Sensitive (high-quality) streams
- Impacted streams
- Non-supporting streams, and
- Urban drainage.

The ICM is then used to develop specific quantitative or narrative predictions for stream indicators within each stream category (see **Figure 5-A.1**). These predictions define the severity of current stream impacts and the prospects for their future restoration. Predictions are made for five kinds of urban stream impacts: changes in stream hydrology, alteration of the stream corridor, stream habitat degradation, declining water quality, and loss of aquatic diversity. The model is intended to predict the average behavior of this group of indicator responses over a range of IC, rather than predicting the precise score of an individual indicator.

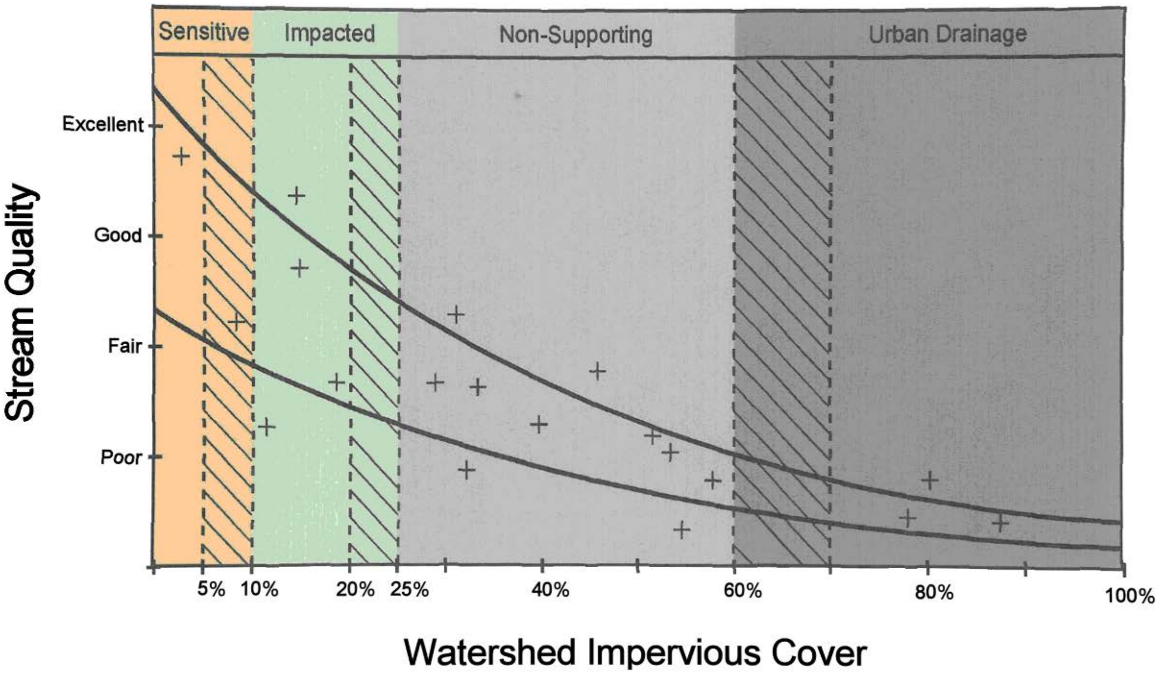

Figure 5-A.1. Reformulated Impervious Cover Model Reflecting Changes in Stream Quality in Response to Percent Impervious Cover in the Contributing Watershed.
(Source: Chesapeake Stormwater Network, 2008)

5-A.2 THE REFORMULATED IMPERVIOUS COVER MODEL

The reformulated ICM includes three important changes to the original conceptual model proposed by Schueler (1994). First, the IC/stream quality relationship is no longer expressed as a straight line, but rather as a “cone” that is widest at lower levels of IC and progressively narrows at higher IC. The cone represents the observed variability in the response of stream indicators to urban disturbance and also the typical range in expected improvement that could be attributed to subwatershed treatment. In addition, the use of a cone rather than a line is consistent with the findings that exact, sharply defined IC thresholds are rare, and that most regions show a generally continuous but variable gradient of stream degradation as IC increases.

Second, the cone width is greatest for IC values less than 10%, which reflects the wide variability in stream indicator scores observed for this range of streams. This modification prevents the misperception that streams with low subwatershed IC will automatically possess good or excellent quality. As noted earlier, the expected quality of streams in this range of IC is generally influenced more by other watershed metrics such as forest cover, road density, riparian continuity, and cropping practices. This modification suggests that IC should not be the sole metric used to predict stream quality when subwatershed IC is very low.

Third, the reformulated ICM now expresses the transition between stream quality classifications as a band rather than a fixed line (e.g., 5 to 10% IC for the transition from sensitive to impacted, 20 to 25% IC for the transition from impacted to non-supporting, and 60 to 70% IC for the transition from non-supporting to urban drainage). The band reflects the variability in the relationship between stream hydrologic, physical, chemical, and biological responses and the qualitative endpoints that determine stream quality classifications. It also suggests a watershed manager's choice for a specific threshold value to discriminate among stream categories should be based on actual monitoring data for their ecoregion, the stream indicators of greatest concern and the predominant predevelopment regional land cover (e.g., crops or forest).

5-A.3 GENERAL PREDICTIONS OF THE IMPERVIOUS COVER MODEL

The ICM is similar to other models that describe ecological response to stressors from urbanization in that the stream quality classifications are value judgments relative to some endpoint defined by society (e.g., water quality criteria). The ICM differs from most other models in that it provides a broader focus on a group of stream responses, yet focuses on only one stressor, impervious cover. The focus on IC allows watershed managers to use the ICM both to predict stream response and to manage future impacts by measuring and managing IC.

The general predictions of the ICM are as follows:

- Stream segments with less than 10 percent impervious cover (IC) in their contributing drainage area continue to function as Sensitive Streams, and are generally able to retain their hydrologic function and support good-to-excellent aquatic diversity.
- Stream segments that have 10-25 percent IC in their contributing drainage area behave as Impacted Streams and show clear signs of declining stream health. Most indications of stream health will fall in the fair range, although some segments may range from fair to good, as riparian cover improves. The decline in stream quality is greatest toward the higher end of the IC range.
- Stream segments with subwatershed IC that ranges from 25-60 percent are classified as non-supporting streams (i.e., no biological diversity). These stream segments become so degraded that any future stream restoration or riparian cover improvements are insufficient to fully recover stream function and diversity (i.e., the streams are so dominated by subwatershed IC that they cannot attain pre-development conditions).
- Stream segments whose subwatersheds exceed 60 percent IC are physically altered so that they merely function as a conduit for flood waters. These streams are classified as Urban Drainage and consistently have poor water quality, highly unstable channels, and very poor habitat and biodiversity scores. In many cases these urban stream segments are eliminated altogether by earthworks and/or storm drain enclosures. **Table 5-A.1** shows in greater detail how stream corridor indicators respond to greater subwatershed impervious cover.

Table 5-A.1. General ICM Predictions Based on Urban Subwatershed Classification

Prediction	Impacted (IC = 11-25%) [8]	Non-Supporting (IC = 26-60%)	Urban Drainage (IC = ≥ 60%)
Runoff as a fraction of annual rainfall [1]	10 to 20%	25 to 60%	60 to 90%
Frequency of bankfull flow per year [2]	1.5 to 3 per year	3 to 7 per year	7 to 10 per year
Fraction of original stream network remaining	60 to 90%	25 to 60%	10 to 30%
Fraction of riparian forest buffer intact	50 to 70%	30 to 60%	Less than 30%
Crossings (roads/utilities, etc.) per stream mile	1 to 2	2 to 10	None left
Ultimate channel enlargement ratio [3]	1.5 to 2.5 times larger	2.5 to 6 times larger	6 to 12 times larger
Typical stream habitat score	Fair, but variable	Consistently poor	Poor, often absent
Increased stream warming [4]	2 to 4 °F	4 to 8 °F	8+ °F
Annual nutrient load [5]	1 to 2 times higher	2 to 4 times higher	4 to 6 times higher
Wet weather violations of bacteria standards	Frequent	Continuous	Ubiquitous
Fish advisories	Rare	Potential risk of accumulation	Should be presumed
Aquatic insect diversity [6]	Fair to good	Fair	Very poor
Fish diversity [7]	Fair to good	Poor	Very poor

[1] Based on annual storm runoff coefficient ranges from 2 to 5% for undeveloped systems.
[2] Predevelopment bankfull flood frequency is about 0.5 per year, or about one bankfull flood every two years.
[3] Ultimate stream channel cross-section compared to typical predevelopment channel cross section.
[4] Typical increase in mean summer stream temperature in degrees Fahrenheit compared with shaded rural stream.
[5] Annual unit area stormwater phosphorus and/or nitrogen load produced from a rural subwatershed.
[6] As measured by benthic index of biotic integrity. Scores for rural streams range from good to very good.
[7] As measured by fish index of biotic integrity. Scores for rural streams range from good to very good.
[8] IC is not the strongest indication of stream health below 10% IC, so the sensitive streams category is omitted from this table

Source: CWP, 2004

5-A.4 SCIENTIFIC SUPPORT FOR THE ICM

The ICM predicts that hydrological, habitat, water quality, and biotic indicators of stream health first begin to decline sharply at around 10 percent total IC in smaller catchments (Schueler, 1994). The ICM has since been extensively tested in ecoregions around the United States and elsewhere, with more than 200 different studies confirming the basic model for single stream indicators or groups of stream indicators (CWP, 2003; Schueler, 2004). Several recent research studies have reinforced the ICM as it is applied to 1st-to-3rd order streams (Coles et al., 2004; Horner et al., 2004; Deacon et al., 2005; Fitzpatrick et al., 2005; King et al., 2005; McBride and Booth, 2005; Cianfrina et al, 2006; Urban et al., 2006; Schueler et al., 2008).

Researchers have focused their efforts to define the specific thresholds where urban stream degradation first begins. There is robust debate as to whether there is a sharp initial threshold or merely a continuum of degradation as IC increases, although the latter view is more favored. There is much less debate, however, about the dominant role of IC in defining the hydrologic, habitat, water quality, and biodiversity expectations for streams with higher levels of IC (15 to 60 percent).

5-A.5 CAVEATS TO THE ICM

The ICM is a powerful predictor of urban stream quality when used appropriately. The first caveat is that subwatershed IC is defined as total impervious area (TIA, which includes *all* impervious cover) and *not* the effective impervious area (EIA, which is the portion of the TIA that is directly connected to the drainage collection system). Second, application of the ICM should be restricted to 1^{st}-to-3^{rd} order alluvial streams with moderate gradient and no major point sources of pollutant discharge. The ICM is most useful in projecting the behavior of numerous stream health indicators, and it is not intended to be accurate for every individual stream indicator. In addition, management practices in the contributing catchment or subwatershed must *not* be poor (e.g., no deforestation, acid mine drainage, intensive row crops, etc.); just because a subwatershed has less than 10 percent IC does not automatically mean that it will have good or excellent stream quality, if past catchment management practices were poor.

ICM predictions are general and may not apply to every stream within the proposed classifications. Urban streams are notoriously variable, and factors such as gradient, stream order, stream type, age of subwatershed development, and past land use can and will make some streams depart from these predictions. Indeed, these atypical streams are extremely interesting from the standpoint of restoration. In general, subwatershed IC causes a continuous but variable decline in most stream corridor indicators. Consequently, the severity of individual indicator impacts tends to be greater at the upper end of the IC range for each stream category.

5-A.6 EFFECTS OF CATCHMENT TREATMENT ON THE ICM

Most studies that investigated the ICM were done in communities with some degree of catchment treatment (e.g., stormwater management or stream buffers). Detecting the effect of catchment treatment on the ICM involves a very complex and difficult paired watershed design. Very few catchments meet the criteria for either full treatment or the lack of it; no two catchments are ever really identical, and individual catchments exhibit great variability from year to year. Not surprisingly, the first generation of research studies has produced ambiguous results. For example, seven research studies showed that ponds and wetlands are unable to prevent the degradation of aquatic life in downstream channels associated with higher levels of IC (Galli, 1990; Jones et al., 1996; Horner and May, 1999; Maxted, 1999; MNCPPC, 2000; Horner et al., 2001; Stribling et al., 2001). The primary reasons cited are stream warming (amplified by the presence of ponds), changes in organic matter processing, the increased runoff volumes delivered to downstream channels, and habitat degradation caused by channel enlargement.

Riparian forest cover is defined as canopy cover within 100 meters of the stream, and is measured as the percentage of the upstream network in this condition. Numerous researchers have evaluated the relative impact of riparian forest cover and IC on stream geomorphology, aquatic insects, fish assemblages, and various indices of biotic integrity. As a group, the studies suggest that indicator values for urban streams improve when riparian forest cover is retained over at least 50 to 75 percent of the length of the upstream network (Booth et al., 2002; Morley and Karr, 2002; Wang et al., 2003; Allan, 2004; Sweeney et al., 2004; Moore and Palmer, 2005; Cianfrina et al., 2006; Urban et al., 2006). The studies also indicate that downstream improvements in some stream quality indicators may still be observed when an unforested stream segment flows into a long segment of extensive riparian forest or wetland cover.

5-A.7 APPLICATION OF THE ICM TO OTHER RECEIVING WATERS

Recent research has focused on the potential value of the ICM in predicting the future quality of receiving waters such as tidal coves, lakes, wetlands and small estuaries. The primary work on small estuaries by Holland et al. (2004) [references cited in CWP (2003), Lerberg et al. (2000)] indicates that adverse changes in physical, sediment, and water quality variables can be detected at 10 to 20 percent subwatershed IC, with a clear biological response observed in the range of 20 to 30 percent IC. The primary physical changes involve greater salinity fluctuations, greater sedimentation, and greater pollutant contamination of sediments. The biological response includes declines in diversity of benthic macroinvertebrates, shrimp, and finfish.

More recent work by King et al. (2005) reported a biological response for coastal plain streams at around 21 to 32 percent urban development (which is usually about twice as high as IC). The thresholds for important water quality indicators, such as bacterial counts that exceed regulatory limits in shellfish beds and beaches, appears to begin at about 10 percent subwatershed IC, with chronic violations observed at 20 percent IC (Mallin et al., 2001). Algal blooms and anoxia resulting from nutrient enrichment by stormwater runoff also are routinely noted at 10 to 20 percent subwatershed IC (Mallin et al., 2004).

The primary conclusion to be drawn from the existing science is that the ICM does apply to tidal coves and streams, but the impervious levels associated with particular biological responses appear to be higher (20 to 30 percent IC for significant declines) than for freshwater streams, presumably due to their greater tidal mixing and inputs from near-shore ecosystems. The ICM may also apply to lakes (CWP, 2003) and freshwater wetlands (Wright et al., 2007) under carefully defined conditions. The initial conclusion is that the application of the ICM shows promise under special conditions, but more controlled research is needed to determine if IC (or other watershed metrics) is useful in forecasting receiving water quality conditions.

5-A.8 UTILITY OF THE ICM IN URBAN STREAM CLASSIFICATION AND WATERSHED MANAGEMENT

The ICM is best used as an urban stream classification tool to set reasonable expectations for the range of likely stream quality indicators (e.g., physical, hydrologic, water quality, habitat, and biological diversity) over broad ranges of subwatershed IC. In particular, it helps define general thresholds where water quality standards or biological narrative conditions cannot be consistently met during wet weather conditions (**Table 5-A.2**). These predictions help stormwater managers and regulators to devise appropriate and geographically explicit stormwater management and subwatershed restoration strategies for their catchments as part of MS4 permit compliance. More specifically, assuming that local monitoring data are available to confirm the general predictions of the ICM, it enables managers to manage stormwater within the context of current and future watershed conditions.

Table 5-A.2. Expectations for Different Urban Subwatershed Classes

Condition	Expectation
Sensitive Streams (2 to 10% IC) [1]	• Maintain or restore ecological structure, function and diversity so streams provide a "rural" benchmark with which to compare other stream categories • Specific stream quality indicators for sensitive streams should be compared to streams whose entire subwatersheds are fully protected (e.g., national parks, etc.)
Impacted Subwatersheds (11 to 25% IC)	• Consistently attain "good" stream quality indicator scores to ensure enough stream function to adequately protect downstream receiving waters from degradation. • Function is defined in terms of flood storage, in-stream nutrient processing, biological corridors, stable stream channels, and other factors.
Non-Supporting Subwatersheds (26 to 59% IC)	• Consistently attain "fair to good" stream quality indicator scores. • Meet bacteria standards during dry weather and trash limits during wet weather. • Maintain existing stream corridor to allow for safe passage of fish and floodwaters.
Urban Drainage Subwatersheds (60 to 100% IC)	• Maintain "good" water quality conditions in downstream receiving waters. • Consistently attain "fair" water quality scores during wet weather and "good" water quality scores during dry weather. • Provide clean "plumbing" in upland land uses such that discharges of sewage and toxics do not occur.
[1] The specific ranges in IC that define each management category should always be derived from local or regional monitoring data.	

5-A.9 REVIEW OF MANAGEMENT RESPONSES TO THE ICM

The diversity in management responses to the ICM is fairly impressive. **Table 5-A.3** classifies the nearly 20 different planning, engineering, regulatory and economic tools that have been used (or proposed) to respond to the ICM. In general, each of these individual professional disciplines has adopted their own tools and methods to mitigate the effect of land development on water quality, and has rarely coordinated with other disciplines. This section reviews the strengths and weaknesses of the many different approaches to managing IC at the watershed and community scale.

5-A.9.1 Planning and Zoning Responses to the ICM

Planning responses are handicapped by the fact that that nearly all rural and suburban zoning categories produce more than 10% IC. This can be seen in **Figure 5-A.2,** which portrays data from Cappiella and Brown (2001) on the IC produced by different rural and suburban zones in four Chesapeake Bay communities. Only agricultural preservation zones and open urban land (e.g., parks, cemeteries and golf courses) produced less than 10% IC. This suggests that even low levels of new land development in a subwatershed will degrade streams and receiving waters to some degree.

Table 5-A.3. Range of Management Responses to the ICM

Planning and Zoning Tools	Engineering Tools
• Better (Environmental) Site Design • Large-Lot Zoning • Site-Based IC Caps • Watershed-Based IC Caps • Development Intensification • Watershed-Based Zoning • Watershed Planning	• Traditional Stormwater Treatment Requirements • Runoff Volume Reduction Practices • Special Subwatershed Stormwater Criteria • Watershed Restoration Plans
Regulatory Tools	**Economic Tools**
• Anti-Degradation Provisions • IC-Based TMDLs • Watershed-Based Permitting	• IC-Based Stormwater Utilities • Excess IC Fees • IC Mitigation Fees • Subwatershed IC Trading

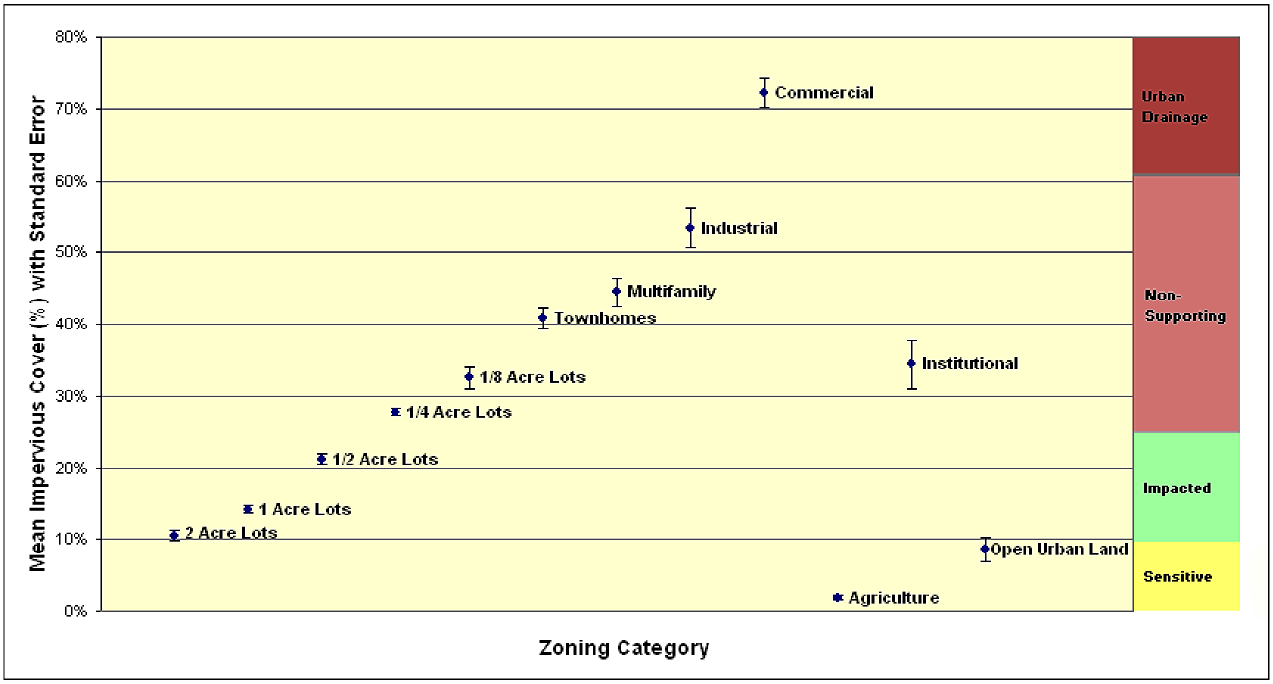

Figure 5-A.2. Relationship between impervious cover and zoning category
(Adapted from Cappiella and Brown, 2001)

This creates a difficult choice for land planners. On one hand, low density development reduces the extent of stream damage but spreads it out over a wider geographic area and thereby accentuates sprawl. More intense development, on the other hand, greatly increases local stream degradation to the point that many urban communities cannot meet water quality standards and may be subject to an uncertain future restoration liability. Communities have responded to this dilemma by pursuing several planning and zoning responses, as described below.

Environmental Site Design. This strategy relies on the fact that nearly 65% of new impervious cover can be classified as car habitat (Cappiella and Brown 2001) and focuses on changing local development codes to minimize the geometry of roads, parking lots, sidewalks, cul-de-sacs and other new development infrastructure. These techniques, which are collectively referred to as Environmental Site Design (ESD) or Better Site Design (BSD), can also include greater use of swales, relaxed lot geometry, natural area conservation, open-space subdivisions, pervious paving and other site design techniques (CWP 1998a). Several dozen communities across the country have changed their local codes and ordinances to promote ESD through a roundtable process to gain consensus among development stakeholders. The strength of the ESD approach is that numerous modeling studies have demonstrated it can reduce IC, pollutants and development costs by as much as 10 to 40% at individual development sites (Kloss and Calarusse 2006; CWP 1998b). The weakness of ESD is that it lacks a watershed context and therefore reductions in site IC may not be enough to meet subwatershed objectives.

Extremely Large Lot Zoning. Several communities have adopted extremely large lot zoning to protect sensitive streams in designated planning areas. Often, these zones are accompanied by decisions to restrict or exclude public water and sewer service. This form of very low-density residential development often involves densities ranging from 0.5 to 0.05 dwelling units per acre, and may also involve conservation easements to protect existing forests, buffers and other natural areas. Large lot zoning has been most frequently applied to protect drinking water reservoirs and trout streams, or generally maintain rural character.

The strength of large lot zoning is that it is relatively easy to implement in the context of existing zoning, and provides some measure of permanent protection for sensitive watersheds. The weakness is that the extensive road networks used to connect individual lots produce more IC area per dwelling unit than any other zoning category. When growth pressures are high, large lots tend to spread development over a wide geographic area and contribute to regional sprawl (U.S. EPA 2006). In addition, large lot zoning does not regulate how future property owners will manage their land, which can result in tree clearing, extensive turf or high density hobby farms. Lastly, large lot zoning obviously has no application in the more urban subwatersheds where the impacts of IC are the greatest.

Site-based IC Caps. Several communities have established IC caps within the context of a comprehensive land use plan or functional master plan for the express purpose of protecting drinking water or sensitive streams. Numerical IC caps are imposed on individual residential lots in order to stay below a designated IC threshold for the watershed as a whole. Individual development proposals are closely scrutinized to ensure the development footprint is below the IC cap, or is otherwise mitigated, disconnected or treated. For example, Montgomery County, MD has designated four sensitive watersheds as special protection areas that have an 8 to 10% IC cap for all new development (MCDEP, 2003). The strengths and weaknesses of IC caps are generally similar to those for large lot zoning. IC caps also have the added weakness that they require frequent monitoring to ensure that individual owners do not add more IC in the post-construction phase.

Watershed IC Caps. Direct watershed IC caps have been considered in a number of communities but seldom have been implemented. The caps can be used to protect both sensitive and impacted watersheds. The main drawback is the difficulty in measuring the aggregate change in a subwatershed IC cap over time as a result of many individual zoning and development decisions. A more indirect way to implement a watershed IC cap is through the watershed-based zoning approach.

Development Intensification. Higher density development generates less runoff and pollution per capita, per household or per increment of job growth (U.S. EPA 2006). Therefore, many urban planners and smart growth advocates have suggested that density be intensified within certain subwatersheds or designated planning areas in order to reduce development pressure in sensitive subwatersheds elsewhere. Intensification often involves high rise development, parking garages, mass transit, mixed uses and other features to decrease per-capita IC creation. Intensification is often created by drawing urban growth boundaries and then using incentives and public infrastructure investments to attract redevelopment. Portland (OR) and Toronto (ONT) are two well-known examples where urban growth boundaries were used to promote intensification.

The strength of intensification is that it confers numerous social, community and economic benefits and should result in less dramatic change to stream quality if the area is already developed (e.g., shifting from non-supporting to urban drainage). The weakness of intensification is that it cannot directly protect sensitive or impacted watersheds when multiple communities are involved. At the regional scale, it is often possible for both intensification and low density sprawl to occur at the same time, in response to different market forces and consumer preferences (e.g. land prices, affordable housing, commuting distances, employment centers and the like).

Watershed-based Zoning. Watershed-based zoning is a planning technique that directly ties comprehensive planning or zoning to the ICM. Local planners evaluate current zoning within individual subwatersheds present in their community (Schueler 1994). Current and future IC are forecasted for each subwatershed as a result of build-out of existing zoning. Land is then rezoned within each subwatershed to either increase or decrease IC to achieve the desired ICM classification, which is then incorporated into the local land use master plan or comprehensive plan. The process may also involve special overlay zones that set forth more specific buffer, stormwater and land conservation requirements within each subwatershed management category. To date, several communities have directly or indirectly utilized elements of watershed-based zoning, but none have fully implemented the entire process. The primary reason has been the inherent disconnect between local watershed planning and comprehensive land use planning in most communities.

Watershed Planning. Watershed plans can guide land use decisions to change the location or quantity of IC created by new development. Numerous techniques exist to forecast future watershed impervious cover and its probable impact on the quality of aquatic resources (CWP, 1998 and MD DNR 2005). The level of control that can be achieved by watershed planning is theoretically high, but relatively few communities have aggressively exercised it. In particular, few communities have fully integrated their watershed planning efforts into their comprehensive planning and zoning process. Consequently, many watershed plans contain recommendations for implementation of watershed practices, but few substantive changes in zoning or land use decisions. Powerful consumer and market forces often drive low-density sprawl development, regardless of the recommendations of the watershed plan.

Even when land use is an explicit component of local watershed plans, these local decisions are reversible and often driven by other community concerns such as economic development, adequate infrastructure, and transportation. Schueler (1996) has explained the primary reasons why local watershed plans are not fully implemented. Many of these reasons still exist today. Consequently, many communities continue to struggle with how to influence the optimal location and intensity of subwatershed IC in their watershed plans. Furthermore, they often lack an effective accountability mechanism (such as a watershed-based permit) to fully implement these plans.

5-A.9.2 Engineering Responses to the ICM

Traditional Stormwater Treatment Requirements. Many communities have relied on engineering rather than planning solutions to address ICM impacts. The major trend has been to adopt stormwater management requirements to treat both the quality and quantity of runoff from individual development sites. The most common practice has been to pipe runoff into a stormwater detention or retention pond. Performance research studies indicate that ponds do have modest flood control and pollutant removal capability (ASCE, 2007 and CWP 2007). Traditional stormwater ponds, however, have not been shown to improve stream quality indicator scores. For example, seven research studies have concluded that stormwater ponds are incapable of preventing the degradation of aquatic life in downstream channels (MNCPPC 2000; Maxted 1999; Stribling et al. 2001; Galli 1990; Horner and May 1999; Horner et al. 2001; Jones et al. 1996). Given that current stormwater technology cannot fully mitigate land development impacts, the engineering community has explored new sizing criteria and stormwater technology to improve their performance.

Runoff Reduction Approach. The prevailing stormwater paradigm has recently shifted to what is known as the Runoff Reduction Approach (Schueler 2008). The goal is to mimic natural systems as rain travels from the roof to the stream through combined application of a series of small practices distributed throughout the entire development site. Runoff reduction is operationally defined as the total runoff volume reduced through canopy interception, soil infiltration, evaporation, rainfall harvesting, engineered infiltration, extended filtration or evapotranspiration. The overall site design objective is to replicate the runoff coefficient for all storms up to a certain design storm event for the native predevelopment land cover.

Runoff reduction practices include rain tanks, rain gardens, infiltration, bioretention, dry swales and linear wetlands, among others. The comparative runoff reduction rate achieved by various stormwater practices varies greatly, as shown in **Table 5-A.4**. Several traditional stormwater practices, such as ponds and sand filters have little or no capability to reduce incoming stormwater runoff volume (Strecker et al. 2004), whereas other practices can achieve annual runoff reduction rates ranging from 40 to 90%, depending on their design. Typically, multiple practices are needed at each site to incrementally reduce the total stormwater runoff volume delivered to the stream. The major challenge with runoff reduction is how to size and arrange the individual practices to meet the appropriate stream protection objective with a subwatershed. The most recent approach is to define a variable runoff reduction volume based on the subwatershed management designation. The shift to runoff reduction is quite recent, so monitoring efforts to demonstrate its effect on improving stream quality indicator scores at the subwatershed scale have yet to be completed. Several recent studies have shown that LID or runoff reduction approaches can be effective at the scale of the individual site (Phillips et al, 2003, Selbig and Bannerman, 2008).

Table 5-A.4. Comparative Runoff Volume Reduction Rates of Selected Stormwater Control Measures in the Chesapeake Bay Region

SCM	Level 1 RR [1]	Level 2 RR [1]
Infiltration	50	90
Bioretention	40	80
Soil Amendments	50	75
Permeable Pavement	45	75
Green Roof	45	60
Dry Swale	40	60
Rain Tanks/Cisterns	Actual holding volume x 0.75	
Filter Strip	25-50	50
Rooftop Disconnection	25	50
Grass Channel	10	20
Extended Detention Pond	0	15
Wet Pond	0	0
Constructed Wetland	0	0
Wet Swale (Linear Wetland)	0	0
Filters	0	0

[1] BMP Level 1 and Level 2 designs are explained in CWP/CSN (2008)

Source: CWP/CSN (2008)

Special Subwatershed Stormwater Criteria. Another approach has been to define special subwatershed design criteria that govern the size, selection and location of the structural and non-structural practices needed to protect aquatic resources in sensitive subwatersheds. Several recent state stormwater manuals have established more prescriptive criteria to protect sensitive waters, such as wetlands, lakes, and trout streams (see Wenger at al 2008 and MPCA 2005) or to focus on increasing the removal of a specific pollutant of concern in a more developed situation (see Schueler 2008).

Watershed Restoration Practices. Stormwater retrofits, stream repair, riparian and upland reforestation, discharge prevention and pollution source controls have all been applied to restore stream quality in urban subwatersheds. A full description of their strengths and weaknesses can be found in the Small Watershed Restoration Manual Series produced by the Center for Watershed Protection. The individual and aggregate effectiveness of restoration techniques appears to be inversely related to the amount of IC present in a subwatershed (Schueler 2004). The best prospects for improving stream quality indicator scores occur in sensitive and impacted watersheds, whereas the cost and feasibility of restoration climbs rapidly in non-supporting and urban drainage subwatersheds (Schueler et al. 2007).

Most communities assemble individual restoration practices within the context of a larger watershed restoration plan to achieve defined stream quality objectives. The key problem of watershed planning tends to be one of implementation. Many communities have fine plans, but have only implemented a handful of actual restoration projects. The poor track record in implementation is created by the inherent difficulty of delivering dozens or hundreds of restoration projects over time, their high cost, and the lack of dedicated financing to build them. In addition, most local watershed restoration plans lack accountability mechanisms to ensure progress is maintained over the 10-15 years required for full implementation.

5-A.9.3 Regulatory Responses to the ICM

Beneficial uses and related water quality standards are frequently exceeded in most urban subwatersheds, so regulatory agencies continue to grapple with the ICM as it relates to the many complex provisions of the Clean Water Act. Some recent trends include the following:

Anti-Degradation, Tiered Uses and Wet Weather Standards. Several sections of the Clean Water Act could potentially protect sensitive and impacted streams, or allow greater flexibility in meeting standards in non-supporting streams. For example, anti-degradation provisions can protect waters that currently achieve or exceed water quality standards or their designated use, but are threatened by future watershed development. States such as Ohio and Maine have crafted anti-degradation rules to regulate discharges or activities by NPDES permittees in the watershed to protect healthy waters. States also have the capability to designate tiered uses and wet weather standards to set more realistic water quality goals for non-supporting and urban drainage subwatersheds, although, to date, few have exercised this option.

Impervious cover based TMDLs. Total Maximum Daily Loads or TMDLs are the primary tool to document how pollutant loads will be reduced to meet water quality standards. Maine, Vermont and Connecticut have recently issued TMDLs that are based on IC rather than individual pollutants of concern (Bellucci 2007). In an IC- based TMDL, IC is used as a surrogate for increased runoff and pollutant loads as a way to simplify the urban TMDL implementation process. IC-based TMDLs have been issued for small subwatersheds that have biological stream impairments associated with stormwater runoff but no specific pollutant listed as causing the impairment (in most cases, these subwatershed are classified as impacted according to the ICM).

A specific subwatershed threshold is set for effective IC, which means IC reductions are required through removal of IC, greater stormwater treatment for new development, offsets through stormwater retrofits or other means. Since IC-based TMDLs have only appeared in the last year, communities have little or no experience in actually implementing them. Traditional pollutant-based TMDLs continue to be appropriate for non-supporting and urban drainage subwatersheds, although they could be modified to focus compliance monitoring on priority urban source areas or subwatersheds that produce the greatest pollutant loads.

Watershed-Based Permitting. U.S. EPA (2007) has issued technical guidance to promote watershed-based permitting, which has the potential to integrate the many permits to improve water quality conditions in urban watersheds. States and localities, however, have yet to implement watershed-based permitting at the sub-watershed scale in the context of the ICM. This regulatory tool shows promise, and several recommendations for applying it to urban watersheds as part of the NPDES MS4 stormwater permit program are presented in the Watershed Planning section of **Chapter 5** and in **Appendix 5-B**.

5-A.9.4 Economic Responses to the ICM

Economists have been attracted to IC because it is easy to measure and can act as a common currency that spans and transcends the site and watershed scale. In recent years, economists have tried to value or price IC so as to better use market forces to improve urban watershed management. These efforts are mostly in their infancy and face the twin problems of defining the unit price of IC and how it varies among subwatersheds with different IC. Several economic approaches that utilize IC are described below.

IC-Based Utilities. Several hundred communities have adopted stormwater utilities that charge residents and businesses a monthly or quarterly charge based on their IC. Funds are used to operate stormwater programs, maintain stormwater infrastructure and comply with their stormwater permits. Utility charges typically range from $30 to $120/year/ residential unit and apply only to existing development. In most cases, an average unit IC charge is applied to all homes and businesses, since most communities lack enough GIS or political resolution to estimate IC and charge for individual parcels. The utility fee can be an incentive to reduce site IC by reducing charges for homeowners that install retrofits such as rain gardens.

IC Mitigation Fees. IC mitigation fees can be applied to new development to discourage the creation of excess IC or to pay for off-site restoration when on-site stormwater compliance is not possible. In the first case, communities establish a maximum IC cap within an individual zoning category or for the subwatershed as a whole. New development projects that exceed the cap are charged a unit fee used to finance restoration practices elsewhere in the subwatershed. In the second case, an IC-based fee-in-lieu is charged when an individual site cannot meet stormwater runoff reduction requirements in full or in part. The basic IC pricing mechanism is the same in both cases: the average per IC acre cost to provide an equivalent amount of restoration or stormwater treatment elsewhere in the watershed. The weakness of mitigation fees involves difficulty in accurately matching the fees collected to actual construction of cost-effective restoration projects in the desired subwatershed that needs restoration.

Subwatershed IC Trading and Offsets. Trading of IC among subwatersheds is still a novel concept although its theoretical elements have been outlined by Parikh et al. (2005). Like other water quality trading programs, development sites that face higher pollution control costs can meet their regulatory obligations by purchasing environmentally equivalent (or superior) pollution reductions or “credits” from another subwatershed at lower cost, thus achieving the same water quality improvement at lower marginal cost. IC is a logical currency for stormwater trading, and may be most efficient in shifting costs among different subwatersheds to produce the greatest water quality improvement. For example, the higher compliance cost in an urban drainage subwatershed might be traded to a sensitive subwatershed to provide greater protection by purchasing lower cost conservation easements.

5-A.10 SUMMARY

The preceding review suggests that no single planning, engineering, economic or regulatory tool appears capable of effectively protecting or restoring stream quality over the full range of subwatershed IC. Some individual tools work reasonably effectively across a narrow range of impervious cover, but most have significant weaknesses, particularly when it comes to implementation. In addition, most communities tend to use only one kind of tool to mitigate the impact of IC (i.e. planning approaches versus engineering solutions). As a result, most communities are unsatisfied with the outcomes of their urban watershed protection or restoration efforts to date.

The review also suggests some possible management remedies. The first is that many communities set unrealistically high expectations for stream quality given their development intensity. In this instance, it may be wise to set more realistic and achievable stream quality objectives (several recommendations are made in the ensuing section. Second, communities may wish to apply a combination of planning, engineering, economic or regulatory tools at the same time. Third, communities should classify their subwatersheds to make sure they are applying the most effective and appropriate tools within the prescribed range of subwatershed IC. Finally, communities may need to develop more stringent accountability mechanisms to ensure that the tools they use are fully implemented.

5-A.11 A SUGGESTED URBAN STREAM MANAGEMENT SYSTEM

Once realistic expectations have been set for a subwatershed, the specific combination of planning, engineering, economic and regulatory tools that are needed becomes more obvious. Some potential combinations for each subwatershed management category are detailed in **Tables 5-A.5 through 5-A.7** below. It should be strongly emphasized that these strategies provide a starting point for developing a local watershed management strategy, and that they will always need to be modified for local conditions.

5-A.11.1 Management Strategies to Protect High Quality Streams

One of the more troubling findings of the ICM, and much of the recent urban stream research, is that it does not take very much subwatershed development to degrade high quality streams – depending on the ecoregion, as little as 3 to 7% IC. Many high quality streams have evolved in response to the forest (or native cover) of their subwatersheds, and have unique habitat conditions that support trout, salmon or spawning of anadromous fish. Given the vulnerability of these streams, watershed managers must commit to an aggressive protection strategy to mitigate the impacts of land development (**Table 5-A.5**). The comprehensive strategy involves watershed zoning, land conservation, preservation of the riparian network and stormwater practices that create no net increase of runoff volume or velocity up to the two year design storm event.

Additional regulatory and economic tools are also needed to protect and maintain the quality of exceptional streams, as shown in **Table 5-A.5**. While the proposed strategy is much more stringent than what most communities currently allow, it is technically achievable, and provides greater reliability in meeting the objectives of maintaining exceptional stream biodiversity and function. From the standpoint of implementation, it is important to formally designate these subwatersheds as being exceptional, and then using the anti-degradation provisions of the Clean Water Act to provide regulatory support for the development restrictions.

Table 5-A.5. Management Strategies to Protect High-Quality Streams

Subwatershed Outcomes Need to Protect High Quality Streams
• Restrict subwatershed IC to less than 10% (or a regional IC threshold) • Retain more than 65% forest or native vegetative cover in the subwatershed • Ensure forest or native cover on at least 75% of the stream network • Do not allow more than one crossing per stream mile, and none that create a barrier to migration
Recommended Watershed Planning and Engineering Practices
• Require full runoff volume reduction up to the 2-year storm for all new IC by maximizing the use of runoff reduction practices and discouraging conventional detention ponds and large diameter storm drain pipes • Establish wide stream buffers (100-200 feet) for the entire drainage network, including zero-order streams • Apply conservation practices to all croplands and keep livestock out of streams • Use site or subwatershed IC caps, extremely large lot zoning, watershed-based zoning, farm preservation, or conservation easements to limit subwatershed IC • Use limited stream restoration to restore habitat, remove fish barriers, and correct past mistakes
Recommended Regulatory and Economic Measures
• Protect healthy streams using anti-degradation provisions of the Clean Water Act • Monitor the geomorphic stability and biological diversity of the streams to verify compliance • Reduce public infrastructure investments in the subwatershed to discourage growth • Increase technology and permit requirements for private water and sewer infrastructure • Designate these subwatersheds as receiving areas for IC mitigation fees to finance restoration and secure conservation easements

5-A.11.2 Management Strategies for Suburban Streams

Stream quality in suburban subwatersheds (10 to 25% IC) exhibits a great deal of variability or scatter. Indicator scores can range from poor to fair to good (but not excellent). A reasonable management objective is to achieve both good indicator scores and maximize stream function to adequately protect downstream receiving waters from degradation (e.g., flood storage, in-stream nutrient processing, biological corridors, stable stream channels, etc.). Given the relatively light development intensity of suburban watersheds, there is room to apply a broad range of management practices in the uplands and the stream corridor (**Table 5-A.6** below).

The basic upland management prescription for suburban streams is to maximize tree canopy and minimize both turf and impervious cover across the subwatershed. Stormwater practices that achieve full runoff reduction up to the two year storm event are applied in a roof to stream sequence to reduce channel erosion and maintain recharge. The prescription for the stream corridor is to protect and enhance buffers around streams, wetlands and floodplains, with special emphasis on minimizing the enclosure of zero order streams (i.e., maintaining them as an open stormwater treatment system). Some elements of the stream corridors may require stream repairs, reforestation or wetland creation.

Table 5-A.6 also outlines the regulatory and economic tools needed to implement and maintain watershed practices for suburban streams. The key management challenge is to prevent a gradual

"creep" in IC over time through rezoning, redevelopment and homeowner expansions. Consequently, watershed managers should set clear goals for maximum future IC, and track it over time to ensure it remains within prescribed limits.

Table 5-A.6. Management Strategies to Protect Impacted Suburban Subwatersheds

Recommended Watershed Planning and Engineering Practices
• Require full runoff reduction up to the one year storm for all new IC created in the subwatershed • Minimize subwatershed IC, maximize forest cover and conserve soil quality using runoff reduction practices from roof to stream • Conserve and protect stream buffers, floodplains, wetlands and river corridor in a natural state and in public ownership • Adjust zoning to limit IC to meet 20 to 25% subwatershed IC caps • Use Environmental Site Design roundtable process (CWP, 1998a) to seek 25% reduction in average IC and turf cover produced by each zoning category • Implement selected stream restoration and storage retrofits to mitigate effect of existing development in the watershed • Establish an ultimate subwatershed tree canopy goal of 40 to 45%
Recommended Regulatory and Economic Measures
• Utilize IC-based TMDLs to set specific targets for runoff reduction and removal of pollutants of concern • Invest in public infrastructure to enhance the quality of drinking water, wastewater and stormwater • Designate these subwatersheds as receiving areas for IC mitigation fees to finance retrofits and other restoration practices • Impose IC mitigation fees for both new and existing development to discourage creation of needless impervious cover, finance restoration and maintain stream protection and stormwater infrastructure

5-A.11.3 Strategies to Manage Highly Urban Streams

The quality of highly urban subwatersheds will be inevitably degraded by the combination of IC creation, soil compaction and stream alteration. Highly urban streams can have one of two management designations – non-supporting (25 to 60% IC) and urban drainage (60 to 100% IC). Urban drainage subwatersheds generally have little or no remaining surface stream network, whereas non-supporting streams still have some surface streams, although they are often highly degraded and fragmented. The management goal for both stream classes is to limit the extent of degradation, while at the same recognizing these subwatersheds are an intense human habitat, both in the uplands and the remaining stream corridor. The proposed management strategies for non-supporting and urban drainage subwatersheds are presented in **Table 5-A.7**.

The basic approach is to protect public health and safety through stormwater management, pollution prevention and discharge prevention practices in the uplands, and to use the stream corridor as a greenway and a conduit for floodwaters. While it is not possible to achieve high levels of aquatic diversity, the watershed practices can reduce pollutant export to downstream receiving waters, and ensure safe water contact during dry weather periods. The land use planning strategy for these subwatersheds encourages both intensification and redevelopment. The impacts from increased IC can be ameliorated by green buildings, expanded urban tree canopy, and selected stormwater retrofits and watershed restoration projects.

Table 5-A.7. Strategies for Non-Supporting and Urban Drainage Subwatersheds [1]

Recommended Watershed Planning and Engineering Practices
• Encourage intensification and redevelopment • Require runoff reduction for the 90th percentile storm as part of the redevelopment process (NS subwatersheds) or a fraction thereof (UD subwatersheds) • Provide sufficient upland retrofit, discharge prevention, and pollution prevention practices to treat stormwater hotspots • Utilize street cleaning and storm drain inlet cleanouts to remove gross pollutants from the dirtiest source areas. • Maintain a forest canopy goal of at least 25% and 15% for NS and UD subwatersheds, respectively • Manage the remaining stream corridor as a greenway and protect/restore large natural area remnants
Recommended Regulatory and Economic Measures
• Utilize conventional TMDLs to reduce pollutants of concern at the most polluted subwatersheds and urban source areas. • Conduct dry weather water quality monitoring in streams (NS) or receiving waters (UD) to assure progress towards goals • Designate these subwatersheds as sending areas for IC mitigation fees to finance retrofits and other restoration practices in less dense subwatersheds • Impose IC mitigation fees for redevelopment when full site compliance with runoff reduction targets cannot be attained.
[1] For space purposes, the strategies for non-supporting (NS) and urban drainage (UD) have been combined together since they differ primarily in the scope or extent of treatment, except where noted

For some, this strategy sacrifices urban streams, and enables municipalities to violate existing water quality standards. The key point, however, is that IC and associated infrastructure has such a dominant influence on these streams that aquatic diversity and water quality standards could never be met, regardless of the investment. Implementation of the stringent measures outlined in **Table 5-A.7** can result in incremental improvements in local waters and substantial pollutant reduction to downstream waters.

5-A.12 CONCLUSIONS

The reformulated ICM organizes and simplifies a great deal of complex stream science into a model that can be readily understood by watershed planners, stormwater engineers, water quality regulators, economists and policy makers. More information is needed to extend the ICM as a method to classify and manage small urban watersheds and organize the optimum combination of best management practices to protect or restore streams within each subwatershed classification.

The challenge for scientists and watershed managers is no longer proving the hypothesis that increasing levels of land development will degrade stream quality along a reasonably predictable gradient – the majority of studies now support the ICM. Rather, researchers may shift to testing a hypothesis that widespread application of multiple management practices at the catchment level can improve the urban stream degradation gradient that has been repeatedly observed. The urgency for testing the catchment effect of implementing best management practices is underscored by the rapid and inexorable growth in IC across the country.

5-A.13 REFERENCES

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