Impervious Surface Coverage

The Emergence of a Key Environmental Indicator

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Planners concerned with water resource protection in urbanizing areas must deal with the adverse impacts of polluted runoff. Impervious surface coverage is a quantifiable land-use indicator that correlates closely with these impacts. Once the role and distribution of impervious coverage are understood, a wide range of strategies to reduce impervious surfaces and their impacts on water resources can be applied to community planning, site-level planning and design, and land use regulation. These strategies complement many current trends in planning, zoning, and landscape design that go beyond water pollution concerns to address the quality of life in a community.

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Impervious land cover has long been characteristic of urban areas, but has only recently emerged as an environmental indicator. Natural resource planning using impervious surface coverage as a framework can be a pragmatic and effective way of addressing a host of complex urban environmental issues, particularly those related to the health of water resources.

Water resource protection at the local level is getting more complicated, largely due to the recognition of nonpoint source pollution, or polluted runoff, as a major problem. This diffuse form of pollution, now the nation's leading threat to water quality (Environmental Protection Agency 1994), is derived from contaminants washed off the surface of the land by stormwater runoff, and carried either directly or indirectly into waterways or groundwater. As programs directed at nonpoint source control cascade down from federal to state to local governments, the technical complexities involved with such control are further complicated by regulatory and management considerations.

Stormwater runoff problems are nothing new to local land-use decision-makers. However, the principal concern about runoff has always been safety, with the focus on directing and draining water off of paved surfaces as quickly and efficiently as possible. Once off the road and out of sight, stormwater has been largely out of mind—downstream consequences be damned (or dammed). Regulations have been expanded in recent years to include consideration of flooding and erosion, yet these factors fall far short of a comprehensive and effective approach to mitigating the water quality impacts of development.

How do planners and other local officials get a handle on protecting their local water resources? While no magic bullet exists to simplify all the complexities involved, an indicator is emerging from the scientific literature that appears to have all the earmarks of a useful tool for local planners—the amount of impervious, or impenetrable, surface. This article reviews the scientific underpinning, usefulness, and practical application of impervious surface coverage as an urban environmental indicator.

People, Pavement and Pollution

Impervious surfaces can be defined as any material that prevents the infiltration of water into the soil. While roads and rooftops are the most prevalent and easily identified types of impervious surface, other types include sidewalks, patios, bedrock outcrops, and compacted soil. As development alters the natural landscape, the percentage of the land covered by impervious surfaces increases.

Roofs and roads have been around for a long time, but the ubiquitous and impervious pavement we take for granted today is a relatively recent phenomenon. A nationwide road census showed that in 1904, 93 percent of the roads in America were unpaved (Southworth and Ben-Joseph 1995). This changed with the early twentieth century ascendancy of the automobile over the railways, capped by the mid-century massive construction of the interstate highway system, which served to both stimulate and facilitate the growth of suburbia. From that point on, imperviousness became synonymous with human presence—to the point that studies have shown that an areas's population density is correlated with its percentage of impervious cover (Stankowski 1972).

Impervious surfaces not only indicate urbanization, but also are major contributors to the environmental impacts of urbanization. As the natural landscape is paved over, a chain of events is initiated that typically ends in degraded water resources. This chain begins with alterations in the hydrologic cycle, the way that water is transported and stored.

These changes, depicted in figure 1, have long been understood by geologists and hydrologists. As

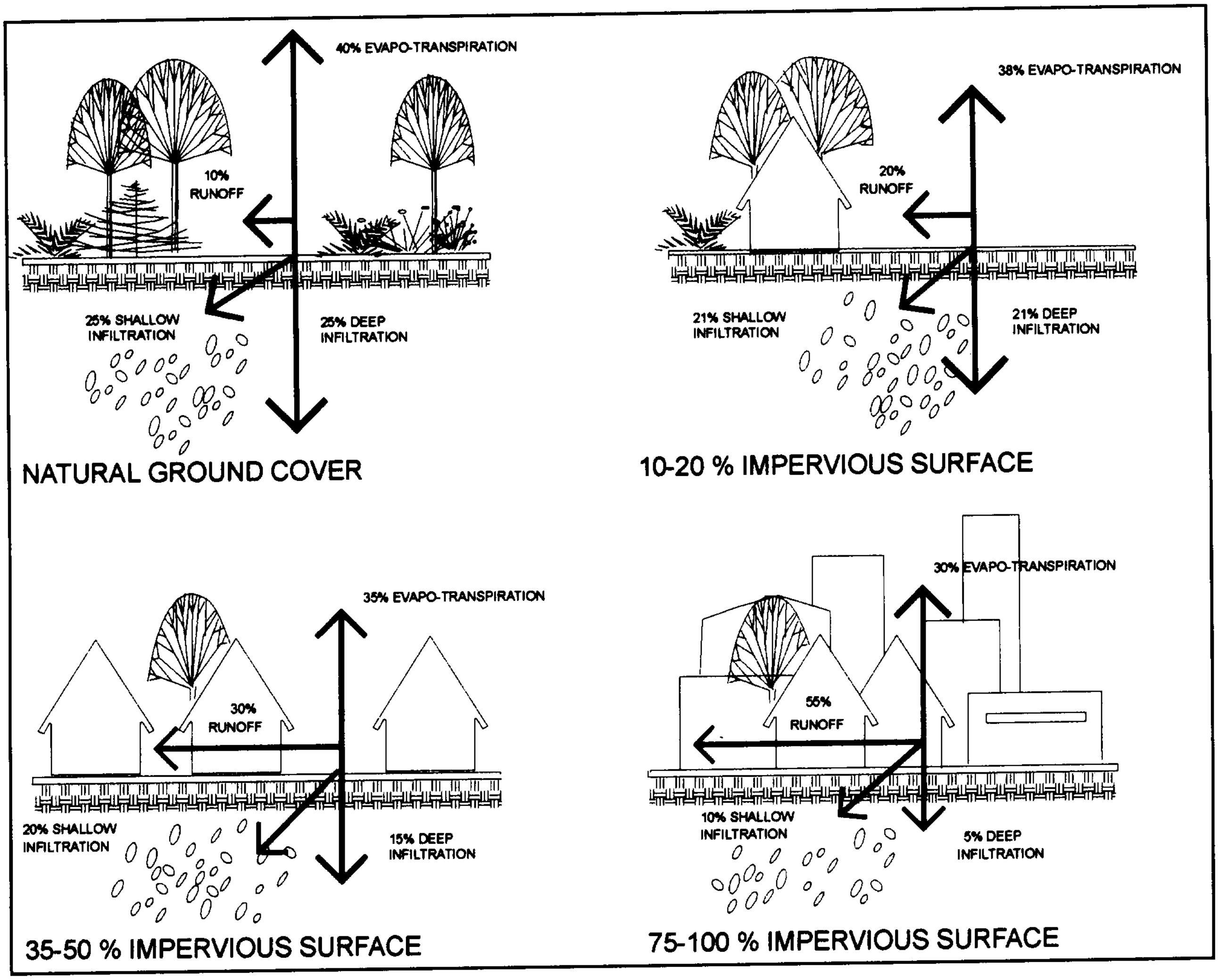


FIGURE 1. **Water cycle changes associated with urbanization**
Source: Environmental Protection Agency 1993a

impervious coverage increases, the velocity and volume of surface runoff increase, and there is a corresponding decrease in infiltration. The larger volume of runoff and the increased efficiency of water conveyance through pipes, gutters, and artificially straightened channels result in increased severity of flooding, with storm flows that are greater in volume and peak more rapidly than is the case in rural areas (Carter 1961; Anderson 1968; Leopold 1968; Tourbier and Westmacott 1981). The shift away from infiltration reduces groundwater recharge, lowering water tables. This both threatens water supplies and reduces the groundwater contribution to stream flow, which can result in intermittent or dry stream beds during low flow periods (Dunne and Leopold 1978; Harbor 1994).

Hydrologic disruption gives rise to physical and ecological impacts. Enhanced runoff causes increased erosion from construction sites, downstream areas and stream banks. The increased volume of water and sediment, combined with the "flashiness" of these peak discharges, result in wider and straighter stream channels (Arnold, Boison, and Patton 1982). Loss of tree cover leads to greater water temperature fluctuations, making the water warmer in the summer and colder in the winter (Galli 1991). There is substantial loss of both streamside (riparian) habitat through erosion, and in-stream habitat as the varied natural stream bed of pebbles, rock ledges, and deep pools is covered by a uniform blanket of eroded sand and silt (Schueler 1992). Engineered responses to flooding like stream diversion, channelization, damming, and piping further destroy stream beds and related habitats like ponds and wetlands. Finally, with more intensive land uses comes a corresponding increase in the generation of pollutants. Increased runoff serves to transport these pollutants directly into waterways, creating nonpoint source pollution, or polluted runoff.

Major categories of nonpoint source pollutants include pathogens (disease-causing microorganisms), nutrients, toxic contaminants, and debris. Pathogen contamination indicates possible health hazards, resulting in closed beaches and shellfish beds. Overabundance of nutrients such as nitrogen and phosphorous can threaten well water supplies, and in surface waters can lead to algal "blooms" that, upon decaying, rob the waters of life-sustaining oxygen. Toxic contaminants like heavy metals and pesticides pose threats to the health of aquatic organisms and their human consumers, and are often persistent in the environment. Debris, particularly plastic, can be hazardous to animal and human alike, and is an aesthetic concern. Sediment is also a major nonpoint source pollutant, both for its effects on aquatic ecology and because of the fact that many of the other pollutants tend to adhere to eroded soil particles (Environmental Protection Agency 1992, 1993a).

The results of polluted runoff are evident in every corner of the United States. According to the Environmental Protection Agency (1994), nonpoint source pollution is now the number one cause of water quality impairment in the United States, accounting for the pollution of about 40% of all waters surveyed across the nation. The effects of nonpoint source pollution on coastal waters and their living resources have been of particular concern (U.S. House of Representatives 1988; Environmental Protection Agency 1993a). Urban runoff alone ranks as the second most common source of water pollution for lakes and estuaries nationwide, and the third most common source for rivers (Environmental Protection Agency 1994).

As point source pollution is increasingly brought under control, the true impact of urban nonpoint source pollution is being recognized. For instance, even in an urbanized estuary like Long Island Sound, where the major environmental problems have been strongly linked to point source discharges from sewage treatment plants, an estimated 47% of the pathogen contamination is from urban runoff (Long Island Sound Study 1994).

Imperviousness as an Environmental Indicator

Planners wishing to protect their community's water resources against these threats may not know where to begin. The site-specific and diffuse nature of polluted runoff seems to demand extensive technical information on pollutant loadings, hydrologic modeling, and the effectiveness of various management practices. This information is difficult to acquire, not only because of the cost of such studies, but because nonpoint-source-related research and engineering are new and evolving fields.

Enter impervious surfaces. When doing community-level planning, or where detailed site information is unavailable, impervious coverage may often be the most feasible and cost-effective vehicle for addressing water pollution. Two major factors argue for its potential utility to the local planner.

First, imperviousness is integrative. As such, it can estimate or predict cumulative water resource impacts without regard to specific factors, helping to cut through much of the intimidating complexity surrounding nonpoint source pollution. Although impervious surfaces do not generate pollution, they: (1) are a critical contributor to the hydrologic changes that degrade waterways; (2) are a major component of the intensive land uses that do generate pollution; (3) prevent natural pollutant processing in the soil by preventing percolation; and (4) serve as an efficient conveyance system transporting pollutants into the waterways. It is not surprising, then, that research from the past 15 years consistently shows a strong correlation between the imperviousness of a drainage basin and the health of its receiving stream (Klein 1979; Griffin 1980; Schueler 1987; Todd 1989; Schueler 1992; Booth and Reinfelt 1993; Schueler 1994a).

Figure 2 is a stylized graph of this general relationship, showing stream health decreasing with increasing impervious coverage of the watershed, or drainage basin, of the stream. The horizontal lines mark average threshold values of imperviousness at which degradation first occurs (10%), and at which degradation becomes so severe as to become almost unavoidable (30%). These thresholds serve to create three broad categories of stream health, which can be roughly characterized as "protected" (less than 10%), "impacted" (10%-30%), and "degraded" (over 30%).

Thresholds are always controversial and subject to change, yet it is important to note that to date, the threshold of initial degradation in particular seems to be remarkably consistent. The scientific literature includes studies evaluating stream health using many different criteria—pollutant loads, habitat quality, aquatic species diversity and abundance, and other factors. In a recent review of these studies, Schueler (1994a) concludes that "this research, conducted in many geographic areas, concentrating on many different variables, and employing widely different methods, has yielded a surprisingly similar conclusion—stream degradation occurs at relatively low levels of imperviousness (10-20%)" (100). Recent studies also suggest that this threshold applies to wetlands health. Hicks (1995) found a well-defined inverse relationship between freshwater wetland habitat quality and impervious surface area, with wetlands suffering impairment once the imperviousness of their local drainage basin exceeded 10%. Impervious coverage, then, is both a reliable and integrative indicator of the impact of development on water resources.

The second factor in favor of the use of imperviousness is that it is measurable. This enhances its utility both in planning and regulatory applications. (Examples follow in a later section.) Depending on the size of the area being considered and the particular application being applied, a wide range of techniques—with a wide range of price tags—exists for the measurement of impervious coverage.

For site level applications, on-site measurement

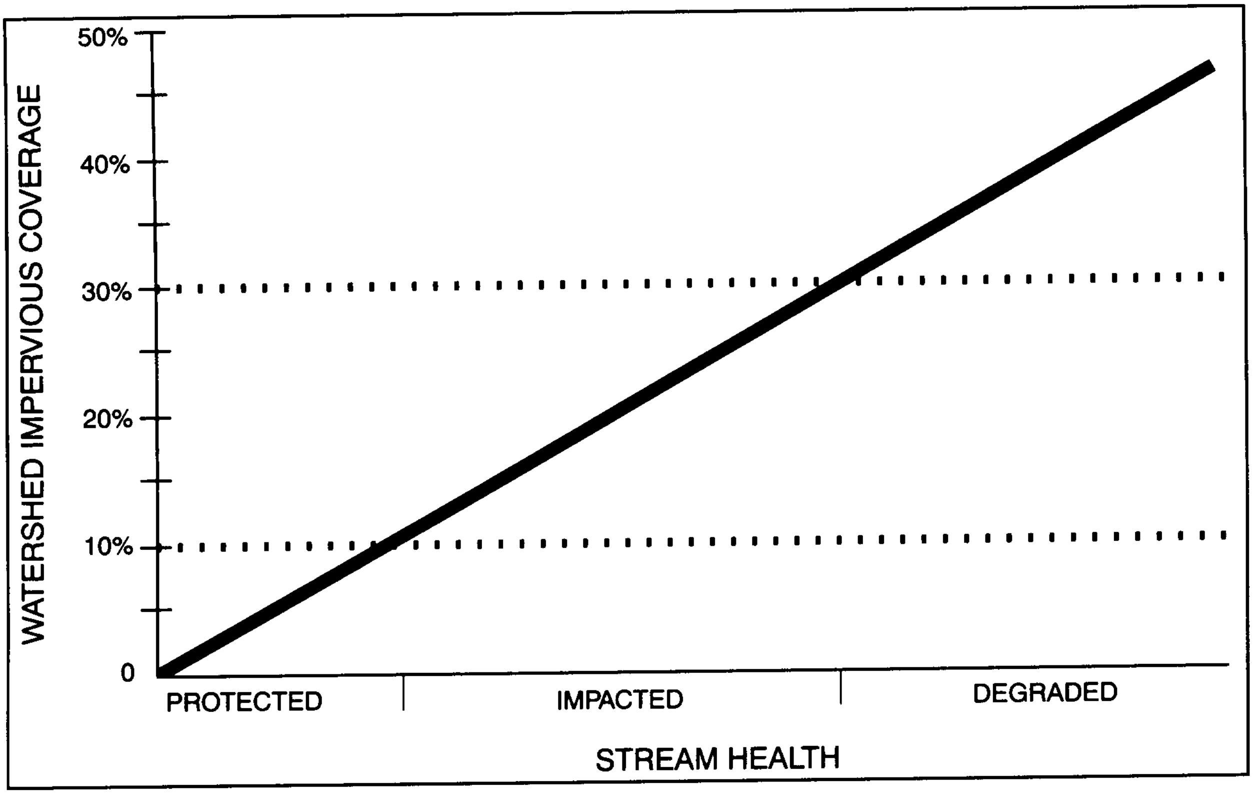


FIGURE 2. Stylized relationship of imperviousness to stream health
Modified from Schueler 1992

using surveying equipment (sometimes as basic as a tape measure) is the most accurate and appropriate method. On the neighborhood level, "windshield" surveys may be appropriate where it is less important to have exact numbers. For community- or regional-scale areas, land cover derived from aerial photographs provides perhaps the best compromise between accuracy and cost. Finally, for applications encompassing even larger areas, remotely-sensed satellite-based land cover can be a viable option. At present, impervious estimates based on satellite data must be calculated by applying literature values of imperviousness to satellite land cover categories. We are currently involved with a remote sensing research project at the University of Connecticut that is attempting to devise a method for directly estimating imperviousness from satellite images (Civco and Arnold 1994).

It is important to note that all of these methods of measurement are increasingly being digitized and presented in the form of computerized maps in a geographic information system, or GIS. This trend eventually will make the information easier to acquire, often at lower expense. Many communities have been unable to afford GIS, and others have been disillusioned at its cost and complexity once they invested in it. Evolution of the technology, however, is making GIS more accessible to local officials every day.

The Components of Imperviousness

To measure and use impervious coverage as a tool for protecting water resources, it is necessary to know how imperviousness is distributed about the landscape. On a scale of increasing refinement, impervious coverage can be broken down by land use, by function within each land use, and by its relative impact on runoff. Each of these pieces of the puzzle can help to target planning and/or regulatory approaches to reducing impervious coverage. As with measurement techniques, the extent to which planners need detailed information on these components depends on the particular application.

The percentage of land covered by impervious surfaces varies significantly with land use. The most frequently cited estimates come from a report by the Soil Conservation Service (1975) (figure 3). "Strip" type

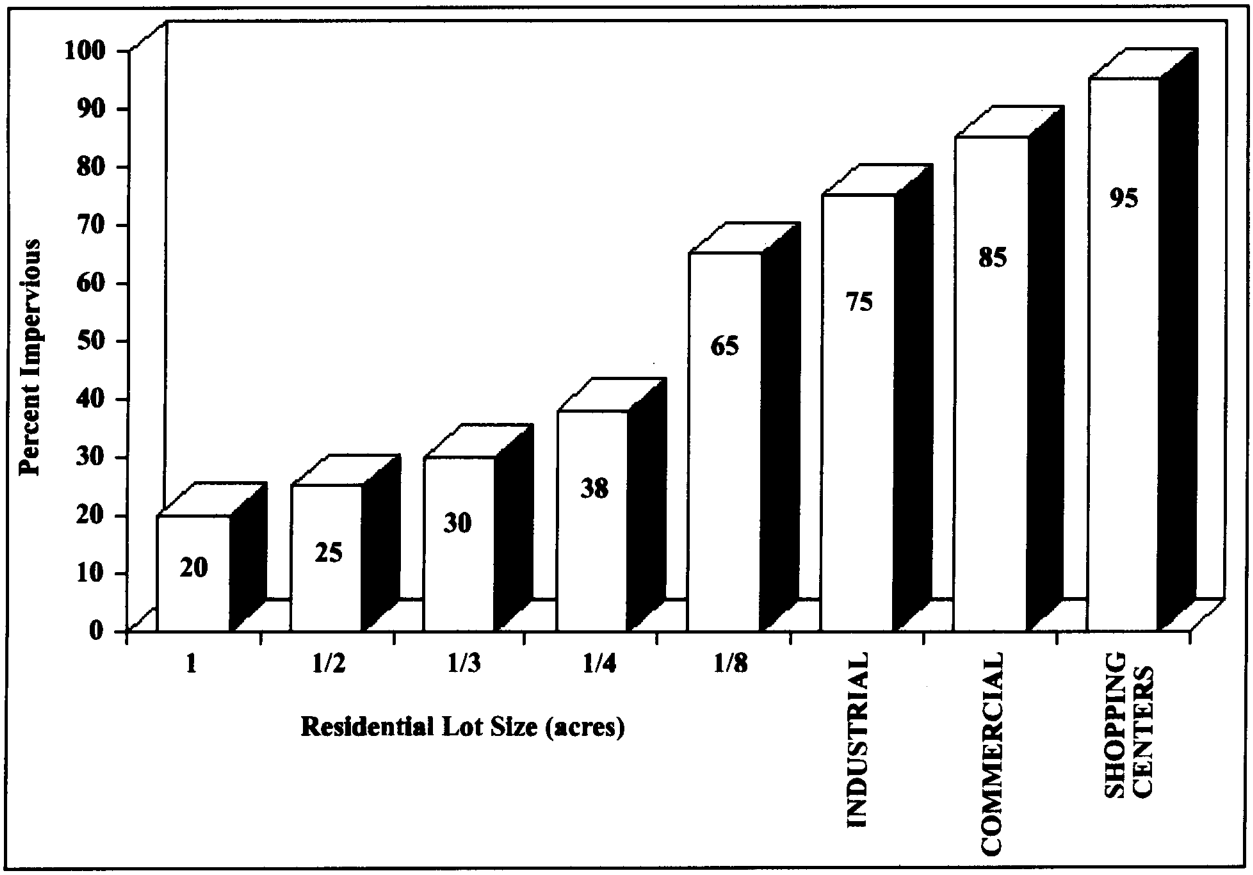


FIGURE 3. Average percentage of impervious coverage by land use
Source: Soil Conservation Service 1975

commercial development tops the chart at around 95% coverage, with other business areas and industrial development lagging slightly behind. In residential areas, there is a wide range of imperviousness that varies predictably with lot size, going from about 20% in one-acre zoning to as high as 65% in one-eighth-acre zoning.

The City of Olympia, Washington, recently conducted a thorough study of impervious coverage in their area. For 11 sites measured, they found coverage values similar to the SCS values, finding four high-density residential developments (3-7 units/acre) to average 40% impervious, four multifamily developments (7-30 units/acre) to average 48% impervious, and three commercial/industrial sites to average 86% impervious coverage (City of Olympia 1995) (table 1).

In addition to the relationship between land use and the total amount of impervious coverage, studies show that all land uses are not equal with regard to the levels of contaminants present in the runoff. As noted, pollutant or land-use-specific studies are relatively new to the scientific community, but existing information supports the common-sense assumption that some land uses are more contaminating than others; for instance, runoff from gasoline stations contains extremely high levels of hydrocarbons and heavy metals (Schueler 1994b).

Recent research from Wisconsin goes one major step further, actually determining the pollutant concentrations from specific categories of impervious surfaces. Using micro-monitoring samplers that collected the runoff from 12 different types of surfaces (e.g., roofs, streets, parking lots, lawns, driveways) in residential, commercial, and industrial areas, Bannerman et al. (1993) were able to show distinct differences in the types and amounts of certain pollutants, depending on the source of the runoff. The study clearly identified streets as the impervious surfaces having the highest pollutant loads for most land-use categories (table 2). Roofs, with the exception of the zinc from industrial roofs, were generally low in pollutant loads, while parking lots had surprisingly moderate

TABLE 1. Site coverage for three land uses in Olympia, Washington

Surface Coverage Type	Average Approximate Site Coverage, % High Density Residential (3-7 units/acre)	Multifamily (7-30 units/acre)	Commercial
1. Streets	16	11	03
2. Sidewalks	03	05	04
3. Parking/driveways	06	15	53
4. Roofs	15	17	26
5. Lawns/landscaping	54	19	13
6. Open space	n/a	34	n/a
Total impervious surface (1-4)	40	48	86
Road-related impervious surface (1-3)	25	31	60
(Road-related as a percentage of total impervious coverage)	(63%)	(65%)	(70%)

Adapted from City of Olympia 1995

TABLE 2. Surfaces exhibiting highest levels of runoff-borne pollutants, out of twelve surface types sampled in selected urban areas in Wisconsin

POLLUTANT	SURFACE Highest levels	Second highest levels	Third highest levels
e. coli (pathogens)	residential feeder streets	residential collector streets	residential lawns
solids (sediment)	industrial collector streets	industrial arterial streets	residential feeder streets
total phosphorous	residential lawns	industrial collector streets	residential feeder streets
zinc	industrial roofs	industrial arterial streets	commercial arterial streets
cadmium	industrial collector streets	industrial arterial streets	commercial arterial streets
copper	industrial collector streets	industrial arterial streets	residential collector streets

Adapted from Schueler 1994d

levels of pollutants. The one unpaved surface monitored, residential lawns, showed high levels of phosphorous, presumably from lawn and garden fertilizers. As this study is augmented by others over time, reliable relationships between pollutant loads and specific landscape components will undoubtedly emerge.

Impervious cover can be further broken down into its functional components. Schueler (1994a) and others point out the two major categories of impervious surface: rooftops, and the transport system (roads, parking lots, driveways, sidewalks). In general, the transport system is the dominant component, reinforcing the concept of an automobile-centric society. In the Olympia study, for instance, the transportation component ranged from 63% for single-family residential development to 70% for commercial development (City of Olympia 1995) (table 1).

One last refinement of the impervious component is its relationship in the landscape to surrounding areas, in the sense of how much of the rainfall onto a given surface is actually conveyed to a stream or stormwater collection system. In general, the rooftop component, which often drains to a lawn or other permeable areas, has less impact than roadways, which typically channel runoff directly to the stormwater system. The Olympia study (1994b) calls this factor the *effectiveness* at producing runoff, and estimates impervious areas in low-density residential developments to be about 40% effective, while those in commercial/industrial areas are close to 100% effective. In theory this concept could be applied to all surfaces—lawns themselves, for instance, can have a significant coefficient of runoff—but to our knowledge this level of refinement has not been researched, nor is it generally needed for most applications.

Imperviousness in Planning: A Framework, Some Examples

By considering the distribution of impervious cover by land use, function, and contribution to runoff, strategies begin to emerge for the reduction of both current and future levels of imperviousness. We suggest that these strategies can be grouped into three basic categories: community or regional planning; neighborhood and site planning, and regulation. Each category presents opportunities to revisit the *status quo* with an eye to water resource protection. Following are some general concepts and specific examples of such opportunities.

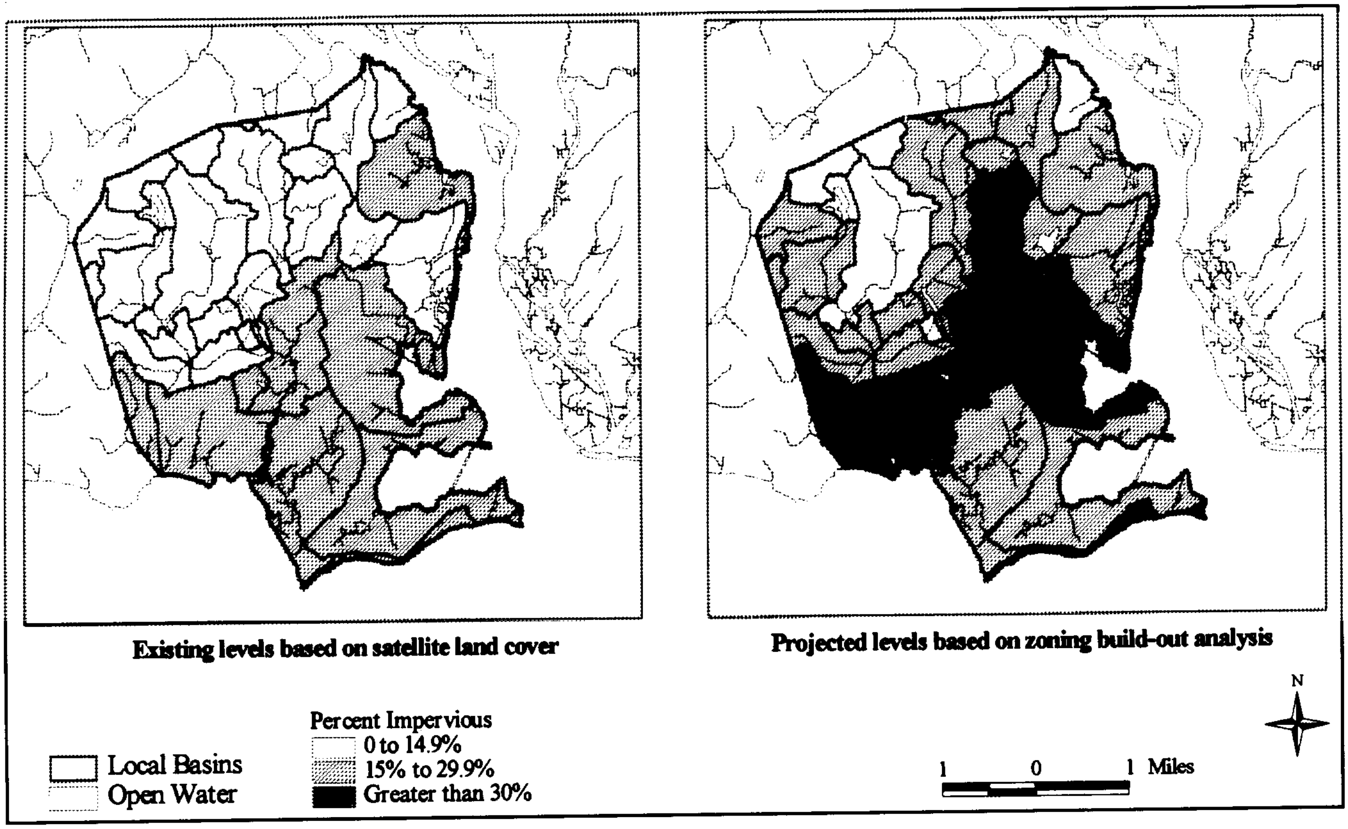
Planning at the Community or Regional Level

Land-use planning, even at the town level, need not be based on traditional political boundaries. Increasingly, environmental and natural resource professionals recommend planning based on the organization of natural systems (Environmental Protection Agency 1993c). Ecosystems as an organizational unit have been suggested, but the functional definition of an ecosystem remains elusive.

A more promising trend has been toward using watersheds as planning units (Environmental Protection Agency 1993b). A watershed, or drainage basin, is an area that drains to a common body of water, be it a lake, river, stream, aquifer, or bay. Watersheds have an advantage in that they can be clearly defined as geographic units. In addition, the watershed can be used as a system of organization at any number of scales, from a major basin encompassing several states, to a regional basin involving several municipalities, to a local sub-basin on the neighborhood level.

Thinking in terms of watersheds is particularly appropriate for stormwater management, which, after all, is all about drainage. At the University of Connecticut, we have developed a regional/community-level planning approach that provides an example of the use of both watersheds and impervious coverage. The Nonpoint Education for Municipal Officials (NEMO) project was initiated in 1991 to assist communities in dealing with the complexities of polluted runoff management (Arnold et al. 1993). The project, funded by the United States Department of Agriculture's Cooperative State Research, Education and Extension Service, is run by an interdisciplinary team that includes water quality, natural resource planning, and computer technology expertise. NEMO uses geographic information system (GIS) technology as a tool to educate local land-use decision-makers about the links between their town's land use and its water quality. Natural resource information on waterways and watersheds is combined with satellite-derived, land-cover information, and then displayed on colorful maps created with the GIS.

At the heart of NEMO is an analysis of impervious cover. Literature values for the percentage of impervious cover are applied to satellite land-cover categories to come up with rough estimates for the current level of imperviousness within a town or watershed. These values are averaged and displayed by local drainage basin (average area about one square mile) and categorized according to the protected/impacted/degraded scale of increasing impervious cover previously described and shown in figure 2. The current values are then contrasted with a zoning-based, build-out analysis of imperviousness, again displayed by local subbasin (figure 4). The build-out allows town officials a look into the possible future of their town, not in conventional terms of population or lot coverage, but in


Existing levels based on satellite land cover

Projected levels based on zoning build-out analysis

FIGURE 4. Impervious coverage analysis for Old Saybrook, CT

terms of impervious cover—and by inference, the health of their local water resources.

The results of the impervious surface analysis can be used to help guide planning emphasis within each local basin area. For areas in the lower impervious zone, emphasis should be placed on preventive measures that retain existing natural systems, using techniques like open space planning and stream buffers. For areas that are in, or will be in, the "impacted" (10–30%) zone, preventive planning should be accompanied by a focus on site design considerations that reduce runoff and imperviousness. Finally, for areas at (or climbing into) the "degraded" (over 30%) zone, the focus shifts to remediation through pollutant mitigation and resource restoration.

NEMO is one example of the use of imperviousness for broad-based community or regional water resource planning. Similar approaches are beginning to spring up around the country. Schueler (1994a) recommends watershed-based zoning that "is based on the premise that impervious cover is a superior measure to gauge the impacts of growth, compared to population density, dwelling units or other factors." In Alpine Township, Michigan, concern about the effects of urbanization on a formerly productive coldwater trout fishery has prompted researchers from Grand Valley State University to design a watershed-based GIS decision support system for local land-use authorities (Frye and Denning 1995). The system makes use of a number of hydrologic and land-use factors, including impervious surface estimates and zoning-based build-out analyses. In Montgomery County, Maryland, a detailed planning study was done to formulate a land-use strategy to protect the water resources of the Paint Branch stream (Montgomery County MD 1995). The study both measures and projects future impervious surface coverage by subwatershed basin, and uses this information to help guide its recommendations for protective actions.

Each of these efforts contains the elements of impervious cover, subbasin-level analysis, and build-out projections. An even more comprehensive treatment is that undertaken by the City of Olympia, Washington. During 1993 and 1994, Olympia conducted their Impervious Surface Reduction Study (ISRS), from which information is cited repeatedly in this paper. The ISRS Final Report (City of Olympia 1995) contains an impressive and comprehensive body of research, policy analysis, and build-out scenarios, culminating in 19 specific action recommendations. The study concludes that "a 20% reduction [in future impervious cover] is a feasible and practical goal for Olympia and will not require exceptional changes in the Olympia community." The recommended reduction is equal to approximately 600 fewer acres of impervious coverage by the year 2012. Planners wishing to see an example of a comprehensive approach to reducing imperviousness would do well to read the Olympia ISRS report.

As with other natural resource protection efforts, community and watershed-level planning approaches like these are often the most effective way of achieving results. Addressing the issue at this scale provides an overall perspective and rationale for the design and regulatory tools described in the following sections. Site-level considerations are then based not only on the immediate impacts of a given development on the local stream or pond, but also on the site's incremental contribution to the pollution (or protection) of a larger-scale water body or aquifer. Review of site design and stormwater management plans, for instance, can be checked for consistency with goals for the appropriate watershed.

Providing this broad context has the added benefit of allowing for greater flexibility at the site level. Planners can evaluate individual factors like a site's location within the watershed, its land use, and the relative priority of the receiving stream as they relate to the overall plan, rather than applying a rigid and uniform set of requirements to all parcels.

Site-Level Planning

Site planning is perhaps the least-explored approach to reducing water pollution. Kendig (1980) states that "good design begins with an analysis of the natural and environmental assets and liabilities of a site," and that these factors should be the determinants of development patterns. Applying this principle to water resource protection translates to maintaining the natural hydrologic function of a site, through retaining natural contours and vegetation to the maximum extent possible. Consideration of impervious surface is a key element of this overall strategy, extending to all site-level considerations. These include construction practices, design that reduces imperviousness, and design that includes measures to mitigate the effects of the runoff from impervious areas.

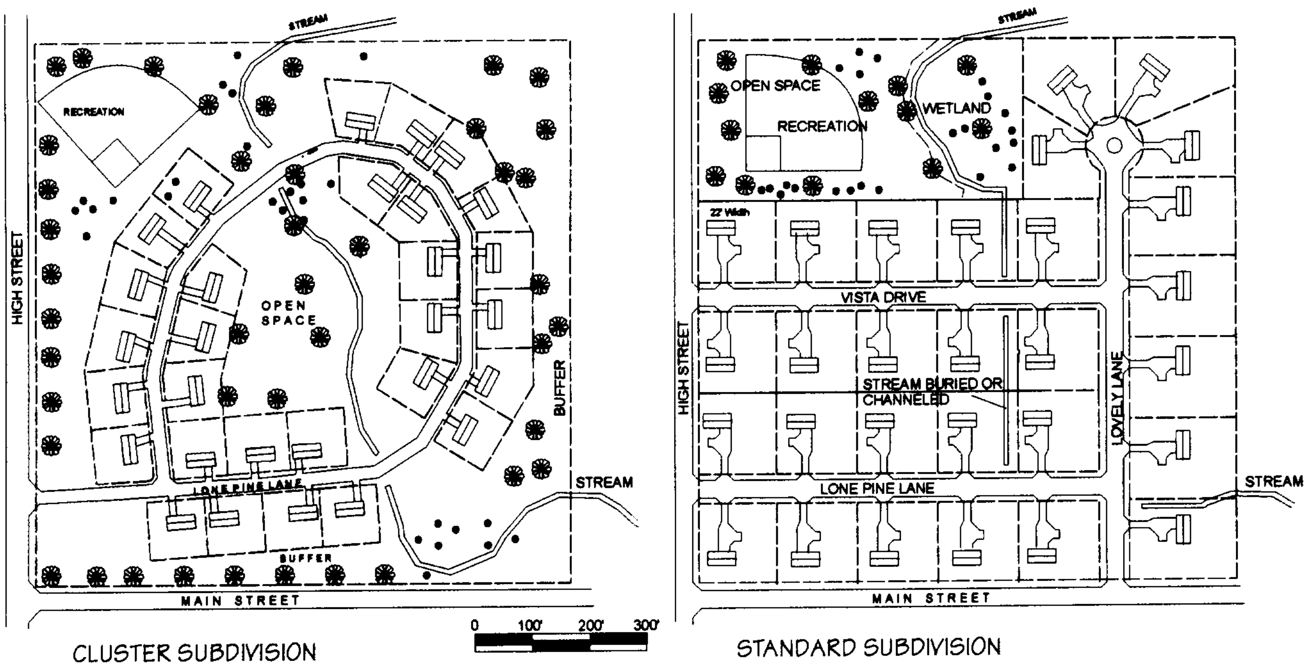
Construction activity itself usually creates impervious surface, severely compacting earth with heavy machinery. Although erosion control practices may require procedures for limiting the area of exposed soil and how long it remains exposed, that requirement does not necessarily minimize the amount of compacted soil. Construction should be sequenced with this goal in mind, and it may be necessary later to loosen compacted areas and/or cover them with additional pervious materials (Craul 1995).

From construction, we move to reduction. For virtually all land uses, one of the best design-related opportunities for reducing imperviousness is through the reduction of road widths. As has been seen, roads both constitute a major fraction of a community's impervious coverage, and tend to produce the most pollutant-laden runoff.

The long-established concept of road hierarchies, which relates road size to the intensity of use, has many positive aspects beyond water quality, among them cost reductions and aesthetic benefits. Yet Southworth and Ben-Joseph (1995), in a recent article on the history of residential street design, found that, for a variety of historical and institutional reasons, road hierarchies are often overlooked by local planners and commissions. The authors conclude that an overemphasis on traffic control has resulted in a "rigid, over-engineered approach ... deeply embedded in engineering and design practice." Simple math dictates that for a given length of subdivision road, reduction from a typical 32-foot to a 20-foot width results in a 37.5% reduction in pavement, or over 63,000 square feet (about one and one-half acres) per linear mile. The Olympia study estimated that changing the width of local access roads from 32 to 20 feet would result in an overall 6% reduction in imperviousness for a given development site in their region, that is, six acres less street pavement for a typical 100-acre subdivision (City of Olympia 1994b).

Road surface reduction is a primary reason why clustering is the most pavement-stingy residential design. Large-lot subdivisions, which have long been recognized as being antithetical to most conservation goals (Arendt 1994a, 1994b) generally create more impervious surface and greater water resource impacts than cluster-style housing does. This is true even though the large lots may have less impervious coverage per lot, because the attenuated design requires longer roads, driveways, and sidewalks, which make the overall subdivision parcel more impervious (figure 5). Schueler (1994c) states that cluster development can reduce site imperviousness by 10–50%, depending on lot size and the road network.

In commercial and industrial zones, the focus of design-related reductions in imperviousness shifts to parking areas, the largest component of impervious cover (table 1). Research has shown oversupply of parking to be the rule. Willson (1995), citing his research and that of many others, found that the "golden rule" of 4.0 parking spaces per 1,000 square



CLUSTER SUBDIVISION
Site area = 20 acres
1/4 acre lots
Density = 1.45 DU/Acre

Total impervious surface = 10.7% (2.14 acres)
Lot impervious surface = 14%

Designated open space = 10 acres
Road length = 2,127 feet (22' width)

STANDARD SUBDIVISION
Site area = 20 acres
1/2 acre lots
Density = 1.45 DU/Acre

Total impervious surface = 17.5% (3.5 acres)
Lot impervious surface = 13.7%

Designated open space = 2.6 acres
Road length = 2,390 feet (30' width)

FIGURE 5. Clustering reduces overall site imperviousness.
Source: John Alexopoulos, University of Connecticut

feet of office floor space is often almost twice what is actually needed. Using a generic, medium-sized office building as a hypothetical example, he shows that a typical parking supply ratio of 3.8 results in an extra 55,000 square feet of parking lot, compared to using a more factually-based ratio of 2.5.

The City of Olympia found not only parking oversupply, with vacancy rates of 60–70%, but also developers consistently building parking above minimum ratios, with 51% more parking spaces at their 15 survey sites than were required by zoning (City of Olympia 1994c). This agrees with our observation that, at least in Connecticut, overbuilding of parking appears to be a recent trend with "big box" retail store developers, who typically require at least 5 spaces per 1,000 square feet, principally to meet peak demands on weekends and during the busy period from Thanksgiving to Christmas.

Reductions in parking-related impervious coverage can be attained in ways other than adjusting parking supply ratios. Shoup (1995) suggests that parking can be reduced through economic incentives that effectively end the subsidy provided by employer-paid parking. Employee commuter option programs, mandated by the Clean Air Act Amendments of 1990 in areas of "severe nonattainment" for ozone standards, hold some promise for reducing parking demand. The Olympia study (City of Olympia 1994d) concluded that sharing, joining, or coordinating parking facilities can reduce parking significantly. Finally, vertical garages (above or below ground) can be encouraged, although this alternative can be expensive. Many of these strategies were recently combined in an innovative office park design in Lacey, Washington, where the new 360,000-square-foot headquarters of the state Department of Ecology was designed around a "parking diet" that slashed parking spaces from 1500 to 730 (Untermann 1995).

Imperviousness also has a role in design related to mitigation of polluted runoff. "Best management practices" (BMPs) is the most commonly-used term to describe the wide range of on-site options available to manage stormwater runoff. BMPs are often divided into two major types: those involving structures such as stormwater detention ponds or infiltration trenches, and "nonstructural" practices that usually involve use of vegetated areas to buffer, direct, and otherwise break up the sea of asphalt. Maintenance measures like road sand sweeping and storm drain cleaning are also included.

It is not within the scope of this article to give a thorough discussion of these practices; choosing the correct assemblage is a combination of art and science, and involves many considerations. From the standpoint of imperviousness, however, BMPs can be viewed in terms of how well they replicate the natural hydrological functioning of the site. This perspective puts a premium on restoring infiltration, which has been suggested by Ferguson (1994) and others to be highly preferable to surface detention.

Emphasizing infiltration and nonstructural solutions often comes into conflict with established development practices. Curbing is a good example. Just as Southworth and Ben-Joseph (1995) found the over-engineering of road widths to be ingrained in local practice, our experience has been that to many town engineers, the necessity of curbing is a given. Safety and structural integrity of the road are often given as reasons for curbing, above and beyond its drainage function. Highway engineers in our state, however, have told us that the sole purpose of curbing is to direct stormwater, and even then, it is only truly needed during the unstable construction phase (Connecticut Department of Transportation 1995). In many cases, more pervious alternatives to directing runoff should be investigated. Grassy swales, for instance, might be constructed in the margin created when existing right-of-way widths are retained while road widths are reduced.

Mitigating the impacts of polluted runoff in the "ultra-urban" inner city environment is a particularly thorny issue. Regional approaches like the Olympia ISRS may target these areas for increased impervious cover (City of Olympia 1994a). Growth policies that encourage urban "infilling" may result in higher inner-city imperviousness in order to reduce sprawl and overall imperviousness, region-wide. In effect, this is "clustering" on a regional scale.

Nonetheless, even for these seemingly intractable areas, using imperviousness as a planning framework can be useful. Usually, this involves linking the reduction of impervious surfaces to complementary urban initiatives. Parking is one example. Excess parking can be attacked from many angles other than water quality, including air quality, traffic congestion, promotion of sprawl, and inefficient use of building lots. A parking reduction initiative could be combined with a plan to use the recouped paved area either for active stormwater treatment (infiltration basins, detention ponds) or for more modest stormwater management (vegetated strips). Such a strategy could be combined with the creation of "vest pocket" parks and other green spaces, shown by urban forestry research as having positive sociological and psychological effects on city dwellers (Gobster 1992; Schroeder and Lewis 1992).

Research on the pollutant-processing capability of various types of vegetation suggests a slight twist on parking lot design that may reap large benefits in water quality for urban areas. Parking lots often incorporate landscaped areas, usually in raised beds surrounded by asphalt curbing. However, these vegetated areas can be planted *below* the level of the parking surface, serving as infiltration and treatment areas for runoff (Bitter and Bowers 1994) (figure 6). This idea can be extended to other areas where vegetated "islands" are traditionally used, such as in the middle of cul-de-sac circles.

Another consideration for urbanized areas is pervious alternatives to pavement. This includes various mixes of asphalt with larger pore spaces (e.g., "popcorn" mix), and alternative systems such as open-framework concrete pavers filled with sand or gravel, or turf reinforced with plastic rings. These systems can become clogged with sediment, particularly during construction, but are often a suitable alternative in low traffic areas like emergency roads, driveways, and overflow parking areas. Cahill (1994) asserts that, contrary to common belief, pervious pavement can be used successfully in many places if certain siting, construction, and maintenance practices are followed; for instance, he recommends vacuum cleaning at least twice per year. Granular surfacings are being promoted by some landscape architects as attractive, inexpensive, and more aesthetically-pleasing alternatives to paved pathways and trails (Sorvig 1995).

One last important note about reducing imperviousness through planning and design—it can save money. Savings to both the private and public sectors in reduced construction and infrastructure costs can be considerable. For instance, a recent study done for the Delaware Estuary Program compared the impacts on twelve communities in the watershed, over a 25-year horizon, of a continuation of current "sprawl" development patterns versus the Program-recommended pattern of promoting mixed uses, open space, and

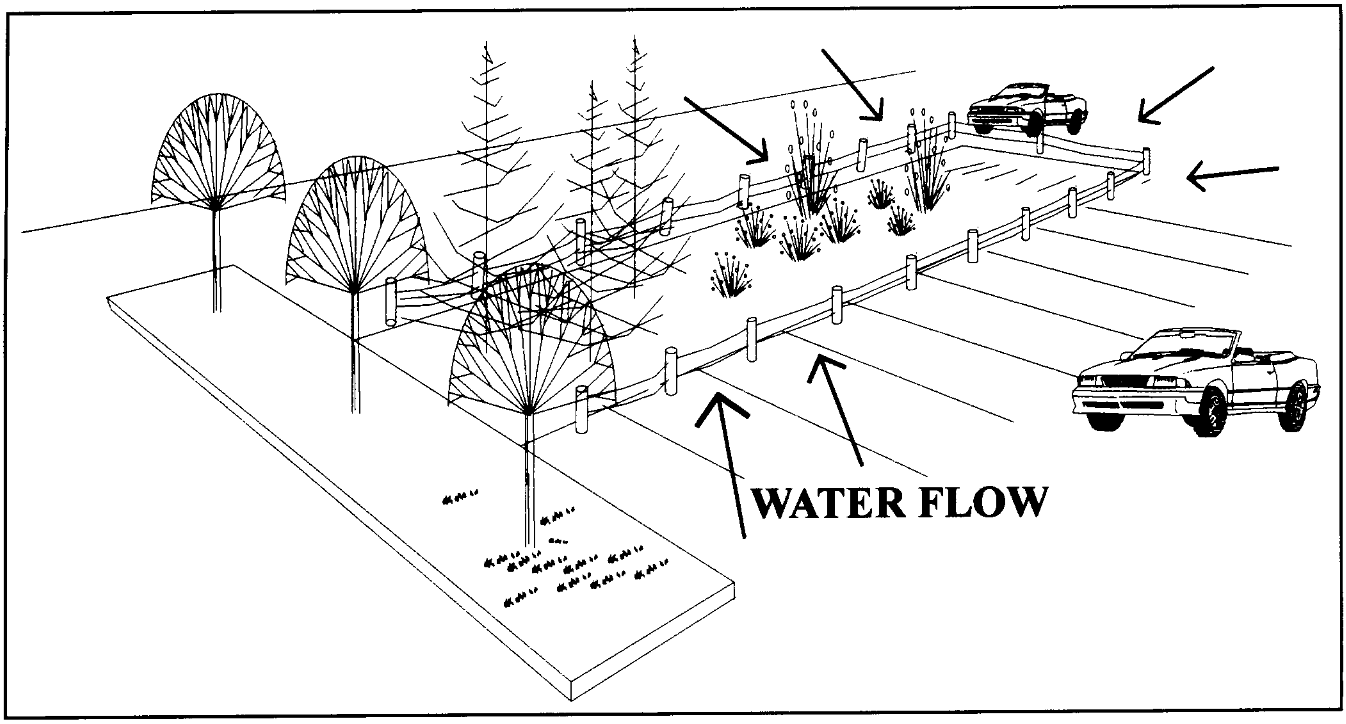


FIGURE 6. Sunken vegetated parking lot "islands" intercept and treat runoff.
Source: John Alexopoulos, University of Connecticut

growth around existing centers. They concluded that for these communities, the less consumptive pattern resulted in savings of $28.8 million in local road costs, $9.1 million in annual water treatment costs, $8.3 million in annual sewer treatment costs, as well as an 8.4% reduction in overall housing costs, and a 6.9% savings in annual costs of local public-sector services (Burchell, Dolphin, and Moskowitz 1995).

The Use of Imperviousness for Regulation

Planning approaches at the community and site level can be complemented with specific applications that give regulatory teeth to planning objectives. To begin with, planners can revisit their current zoning and subdivision requirements with an eye to imperviousness. For instance, many lot coverage limits, particularly for residential uses, refer to rooftops but do not include parking space, sidewalks, and driveway coverage.

Impervious cover lends itself well to zoning that uses performance standards. In fact, Kendig (1980) defines performance zoning as that which regulates development on the basis of four fundamental measures of land-use intensity, one of which is the impervious surface ratio. Jaffe (1993), in a critical assessment of performance-based zoning, concludes that "Kendig's recreational and impervious surface ratios are especially effective in achieving local environmental objectives for stormwater management and groundwater recharge." Performance zoning has the added effect of encouraging mixed uses, which generally result in less impervious coverage and less pollution, by reducing roads and vehicle traffic.

Community-wide applications encompassing large areas with varied land use will require sliding scales of impervious coverage limits that depend on the location, size, and type of use. Such standards have been in place in some Florida communities for almost a decade (American Planning Association Zoning News 1989). More recently, ordinances limiting impervious cover have been enacted in Austin and San Antonio, Texas, driven by concern about pollution of the area's major drinking water aquifer (City of Austin 1992; City of San Antonio 1995).

In instances where protection of a particularly important resource is desired, strict limits on impervious coverage may be imposed. Such is the case in Brunswick, Maine, where a "coastal protection" zone was created for areas draining to Maquoit Bay, site of shellfish beds critically important to the town. The special zone has certain stringent performance standards, among them a maximum impervious-surface lot coverage of 5%. This coverage includes ". . . buildings, roads, driveways, parking areas, patios, and other similar surfaces" (Town of Brunswick 1991). In this case, the very low impervious limit was feasible because the total area affected was fairly small, the use was largely residential, and the specific pollutant of concern was nitrogen emanating from septic systems, resulting in zoning that called for a minimum lot size of one unit per five acres. This "down-zoning" approach, which has also been used in the Buttermilk Bay area in Massachusetts (Horsley and Witten 1991), is practicable for small areas with septic-related concerns, but if applied over large areas, can lead in the long run to promotion of sprawl.

Strict limits may be appropriate, yet in practice they can result in the need for complicated exemption provisions, or even raise the specter of private property rights takings (Land Use Law and Zoning Digest 1995; Ross 1995; Settle,Washburn, and Wolfe 1995). One method for "softening" the concept of limits is to allow for flexibility on the site level. In this scenario, an ordinance setting a limit (or goal) for a site's impervious coverage would require more stringent on-site stormwater treatment when the limit is exceeded. This type of approach will undoubtedly become more common as the information base on removal efficiencies of various treatment measures expands. Another type of flexibility comes from applying performance standards to specific elements of imperviousness within the landscape. In their discussion of next steps, the Olympia study (City Of Olympia 1995) cites the development of performance-based standards for sidewalks, parking, and landscaping "to encourage innovation and provide flexibility in meeting impervious surface reduction goals."

One practical regulatory application of impervious coverage is for stormwater utility assessment, an "impact fee" that is growing in use in urban areas of the country as a way of paying for the treatment and control of polluted runoff. Impervious surface has long been a key determinant in mathematical models that predict the volume of runoff from a given piece of land. Stormwater utility assessments have taken the lead from these models in using imperviousness as a basis for a utility rate structure that fairly distributes the cost of treatment according to a property's contribution to runoff.

Such systems are now in place in many areas, including Kansas City, Missouri; Kitsap County, Washington; and throughout the state of Florida. This type of application requires a community-wide assessment of impervious coverage, and a wide range of techniques is being used. In Kansas City, rate structures are based on digitized high-resolution orthorectified aerial photos (Murphy 1995), while in Florida they are based on statistical surveys of area lots (Livingston 1995). The Kitsap County, Washington, Comprehensive Surface and Stormwater Management Program, established in 1994, creates a rate structure based on an "equivalent service unit" equal to the average estimated amount of impervious surface area on a single-family residential parcel (Kitsap County 1994).

Such programs not only raise funds for mitigation of adverse impacts, but also, by attaching a cost to imperviousness, provide an economic incentive to reduce it. Apparently, this effect is beginning to be seen in Florida, where the cost savings associated with lower stormwater utility fees have provided the impetus for reduction of impervious cover during site redevelopment (Livingston 1995).

Integrating Stormwater Control into Community Planning

The strategies described above demonstrate that for the planner, imperviousness can provide a useful framework for addressing the impacts of urbanization on water resources. But the advantage of this approach goes beyond any specific application. We have found that working with a town on water resource protection often leads to related natural resource issues like open space preservation and forest management. Our recent experience with NEMO has taught us that framing water issues largely in terms of imperviousness serves to expand the range of these connections.

Once water pollution is linked to impervious coverage and its various components, it has a way of insinuating itself into issues currently "on the table" in town. Road widths and curbing may be subjects of town debate about cost or neighborhood character. Parking and landscaping requirements for commercial zones may be undergoing reexamination for aesthetic reasons. The appropriateness of "big box" retailers may be a hot topic, with arguments centered around traffic congestion and the impact on local merchants. An open space plan may be in the formative stages, or the use of stream buffers being questioned. Citizens may be interested in naturalistic landscaping, water conservation, or volunteer monitoring of local waterways. These typical local debates, drawn from towns working with the NEMO Project, now have elements of water quality and impervious surface reduction as part of the mix. And through these debates, the subject of water quality in the community is extended beyond land-use-related staff and boards to include engineering and public works departments, land trusts and other nonprofits, and citizens.

Cross connections of this type are an important key to ensuring the implementation of any planning initiative. For the professional planner, they create opportunities to reinforce complementary planning concepts from several different angles. Beyond the well-established concept of planning and designing with nature (McHarg 1969), there are many relatively recent themes in transportation, subdivision design, and landscape architecture that go hand-in-glove with the reduction of impervious surfaces. Performance zoning is one example. Another is neotraditional residential design, which champions styles of development patterned after the traditional New England village in order to foster a sense of community (Duany and Plater-Zyberk 1991). The open space subdivision designs promoted by Arendt (1994b) for land conservation are also a good fit. On another front, residential street layouts promoting "traffic calming" for a variety of safety, aesthetic, and sociological benefits (Hoyle 1995; Ben-Joseph 1995) could easily incorporate pavement reduction. Landscape architects are calling for more naturalistic schemes that follow the natural contours and make use of low-maintenance, drought-resistant plants (Ash 1995). Planners should seize the opportunity to "piggy-back" water quality with these complementary initiatives, making sure to explicitly incorporate the reduction of paved surfaces and their impacts into official policy, plans, and procedures.

The other advantage of the cross-cutting nature of water resource protection in general, and imperviousness specifically, is that it seems to make sense to the average citizen. Reduction of paved areas is one of relatively few planning initiatives that "plays" at all levels, from the suburban driveway to the big box parking lot, and even to the Chief Justice of the Supreme Court, who recognized the link between the growth of paved surfaces and increased runoff (in *Dolan v. City of Tigard*) (Merriam 1995).

From our standpoint as educators, this feature is critical to the success of any local planning initiative. Education of citizens and local officials on the issues is a necessary and integral part of the process of changing land-use procedures. Volunteer commissioners on local land-use boards are particularly important. In our experience, almost any narrowly-framed issue or problem (environmental or otherwise) brought before busy city, town, or county boards is already operating with two strikes against it. Few issues are isolated, yet they are frequently presented to communities as such, reflecting not the nature of community planning but that of regulatory agencies. A regional planner we work with has called this the "environmental flavor of the month" syndrome.

The result is that even legally mandated initiatives may be doomed to failure by the sheer inertia involved in integrating new and complex information into the busy world of local land-use decision-making. Framing the issue of nonpoint source pollution in terms of imperviousness, although it may be a bit simplistic, appears to be an effective way of enabling local decision-makers to grasp the issue sufficiently to take action.

Conclusion

Water pollution is getting more complex, while at the same time the responsibility for water resource protection is shifting toward local authorities. The use of impervious surface coverage as an environmental indicator can assist planners to construct a game plan to protect their community's natural resources.

Imperviousness integrates the impacts of development on water resources, so it can help to cut through much of the complexity. It is measurable, and so appropriate for a wide range of planning and regulatory applications. It is a cross-cutting feature that is a frequently hidden, but nonetheless substantial, component of many current trends in road, neighborhood, and landscape design, so it can be used as a reinforcing connection between seemingly unrelated planning initiatives. Finally, the basic tenets of reducing imperviousness—retaining the natural landscape, minimizing pavement, promoting infiltration to the soil—are simple concepts that can be understood by a community and its residents.

Impervious cover is rarely specifically identified or addressed in community goals, policies, or regulations. It should be. In this article, we have tried to facilitate the use of this indicator by (1) reviewing the scientific literature to provide a comfort level with its appropriateness; (2) creating a framework for its use in overall planning, site-level planning, and regulation; and (3) providing real-world examples of such applications. With imperviousness as a foundation, planning that begins with water resources often leads to character, design, and aesthetic issues that, taken together, define much of the overall quality of life in a community.

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