Article 28

Chapter 1 from The Rapid Watershed Planning Handbook

Basic Concepts in Watershed Planning

This articleintroduces some of the basic watershed concepts that are at the heart of the rapid watershed planning approach. It is helpful to fully understand these concepts before embarking on a local watershed plan.

***Concept No. 1*. There are many different watershed management units.**

Watershed and subwatershed units are most practical for local plans. Each watershed is composed of many individual subwatersheds that can have their own unique water resource objectives. A watershed plan is a comprehensive framework for applying management tools within each subwatershed in a manner that also achieves the water resources goals for the watershed as a whole.

When developing a watershed plan, it is useful to consider how watersheds are configured. The term **management unit** is used to describe watersheds and their smaller segments. The two management units that will be focused upon in this handbook are the **watershed** and the **subwatershed**. A **watershed** can be defined as the land area that contributes runoff to a particular point along a waterway. A typical watershed can cover tens to hundreds of square miles and several jurisdictions.

Watersheds are broken down into smaller geographic units called **subwatersheds**. Subwatersheds typically have a drainage area of two to 15 square miles with boundaries that include the land area draining to a point at or below the confluence of two second order streams and almost always within the limits of a third order stream. While management unit size will vary among geographic regions and also as a function of slope, soils and degree of urbanization, this general definition provides a consistent and uniform basis for defining individual subwatershed boundaries within a larger watershed.

The terms "watershed" and "subwatershed" are *not* interchangeable. The term **watershed** is used when referring to broader management issues across an entire watershed, while the term **subwatershed** is used to refer assessment level studies and specific projects within the smaller subwatershed units.

There are other important management units to consider when developing a watershed plan. The largest watershed management unit is the basin. A **basin** drains to a major receiving water such as a large river, estuary or lake. Basin drainage areas typically exceed several thousand square miles and often include major portions of a single state or even a group of states. Within each basin are a group of **sub-basins** that extend over several hundred square miles. Sub-basins are a mosaic of many diverse land uses, including forest, agriculture, range, and urban areas. Sub-basins are composed of a group of watersheds, which, in turn, are composed of a group of subwatersheds. Within subwatersheds are **catchments**, which are the smallest units in a watershed. A **catchment** is defined as the area that drains an individual development site to its first intersection with a stream.

Table 1: Description of the Various Watershed Management Units

Watershed Management Unit	Typical Area (square miles)	Influence of Impervious Cover	Sample Management Measures
Catchment	0.05 to 0.50	very strong	practices and site design
Subwatershed	1 to 10	strong	stream classification and management
Watershed	10 to 100	moderate	watershed-based zoning
Subbasin	100 to 1,000	weak	basin planning
Basin	1,000 to 10,000	very weak	basin planning

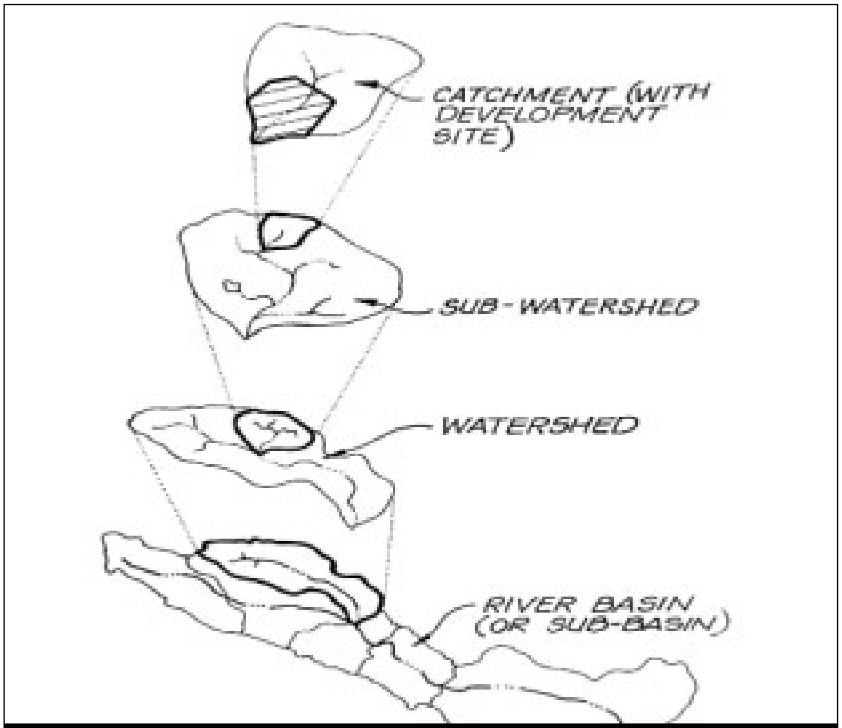

Figure 1: The Watershed Management Units (Clemens *et al.*, 1996)

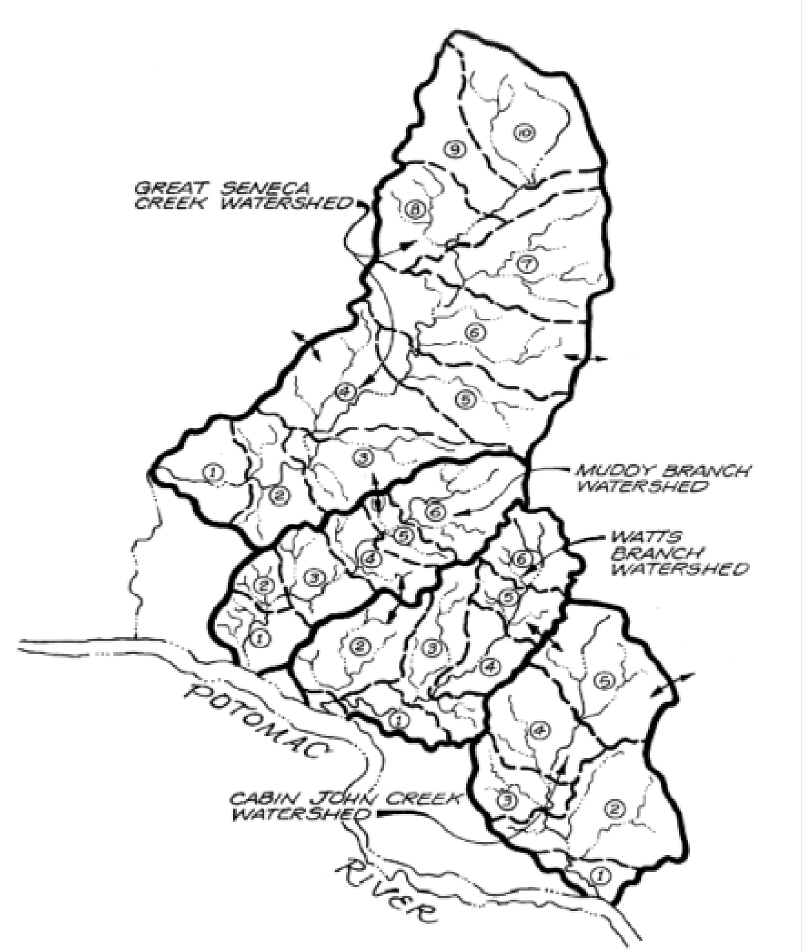

Figure 2: Four Watersheds Containing 27 Subwatersheds (MCDEP, 1998)

Table 1 describes the various management units and provides a comparison of impervious cover influences and possible management measures. Figure 1 illustrates how watershed management units nest together within the drainage system.

A local watershed may have dozens of individual subwatersheds within its boundaries. A watershed plan tracks the planning and management within individual subwatersheds. Figure 2 illustrates this concept of multiple subwatersheds within a larger watershed.

This article focuses on the subwatershed as the primary planning unit for several reasons:

- The influence of impervious cover on hydrology, water quality, and biodiversity is most evident at the subwatershed level where the influences of individual development projects are easily recognizable.
- Subwatersheds are small enough to be within just a few political jurisdictions where it is easier to establish a clear regulatory authority and incorporate the smaller number of stakeholders into the management process.
- Subwatersheds are limited so that few confounding pollutant sources (e.g., agricultural runoff, point sources, etc.) are present that confuse management decisions.
- A map of a subwatershed can usually fit on a standard 24 by 36 foot sheet with sufficient detail to provide useful management information.
- Locally, managers may prefer the subwatershed as a planning unit because it is small enough to perform monitoring, mapping, and other watershed assessment tasks in a rapid time frame. A subwatershed plan can generally be completed within a year's time and still allow ample time for goal development, agency coordination, and stakeholder involvement. This shorter time span enables planners to generate many subwatershed plans in a consistent and coordinated cycle.

***Concept No. 2*. Each subwatershed contains a network of small streams channels that are known as headwater streams.**

While each headwater stream is short and narrow, they collectively represent a majority of the drainage network of any watershed management unit. Consequently, it makes sense to focus on headwater streams in any watershed plan.

Stream classification is important in watershed management. It is also important to understand the spatial connections between the stream and its watershed. A network of streams drain each watershed.

Streams can be classified according to their order in that network. A stream that has no tributaries or branches is defined as a first-order stream. When two first-order streams combine, a second-order stream is created, and so on. **Headwater streams** are defined as first- and second-order streams. Figure 3 illustrates the stream order concept.

Headwater streams are the smallest streams but they are crucial in watershed management because they dominate the landscape through their shear number and cumulative length. Figure 4 illustrates the significance of a headwater stream network in a local landscape.

Headwater streams are typically short in length and drain relatively small areas, but are important because they comprise roughly 75% of the total stream and river mileage in the United States. Table 2 illustrates the proportion of smaller streams to larger streams in the United States.

What happens in the local landscape is directly translated to headwater streams and major receiving waters are affected in turn. As urbanization increases, streams handle increasing amounts of runoff which degrades headwater streams as well as major tributaries.

Focusing on the headwater stream level is important in watershed management for several reasons:

- Streams are exceptionally vulnerable to watershed changes
- Streams are on the same scale as development
- The public intuitively understands streams and strongly supports their protection
- Streams are the "narrowest door" for water resource protection
- Streams are good indicators of watershed quality

The watersheds and subwatersheds that drain to these streams are "readily identifiable landscape units that integrate terrestrial, aquatic, geologic, and atmospheric processes" (Clements *et al.*, 1996). They are the most appropriate geographic unit to protect water resources.

***Concept No. 3*. Recent research has shown that the amount of impervious cover in a subwatershed can be used to project the current and future quality of many headwater streams.**

There are also strong lines of evidence that suggest that impervious cover is linked to the quality of other subwatershed resources such as lakes, reservoirs, estuaries and aquifers.

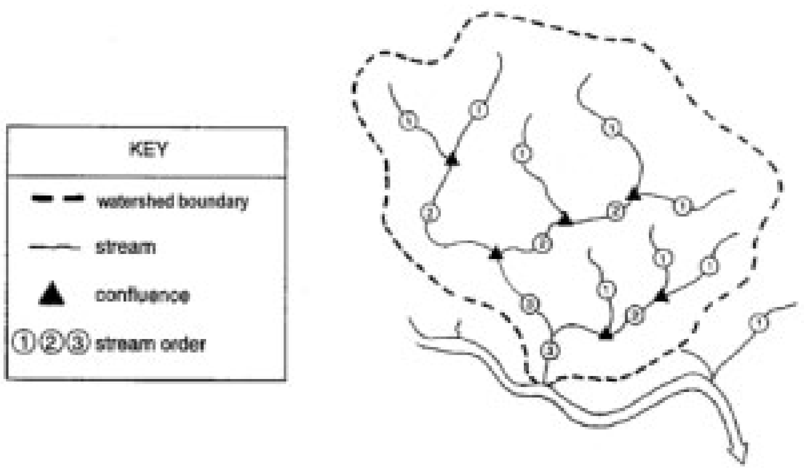

Figure 3: A Network of Headwater and Third-Order Streams

Figure 4: An Example of a Stream Network (MC DEP, 1998)

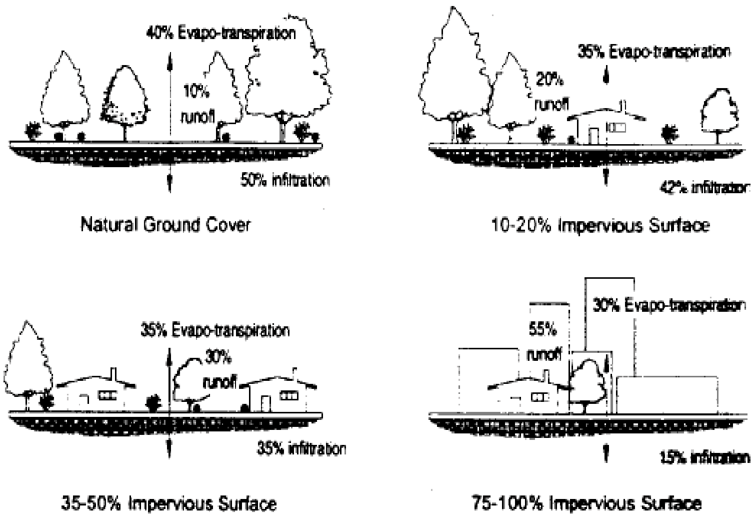

Figure 5: The Impact of Impervious Surface Changes on the Annual Water Balance (PGDER, no date)

The Influence of Impervious Cover on Stream Quality

The conversion of farmland, forests, wetlands, and meadows to rooftops, roads, and lawns creates a layer of impervious surface in the urban landscape. Impervious cover is a very useful indicator with which to measure the impacts of land development on aquatic systems. The process of urbanization has a profound influence on the hydrology, morphology, water quality, and ecology of surface waters (Horner *et al.*, 1996). Recent research has shown that streams in urban watersheds possess a fundamentally different character than streams in forested, rural, or even agricultural watersheds. The amount of impervious cover in the watershed can be used as an indicator to predict how severe these differences can be. In many regions of the country, as little as 10% watershed impervious cover has been linked to stream degradation, with the degradation becoming more severe as impervious cover increases (Schueler, 1994).

Impervious cover directly influences urban streams by dramatically increasing surface runoff during storm events. Depending on the degree of impervious cover, the annual volume of stormwater runoff can increase by two to 16 times its predevelopment rate, with proportional reductions in groundwater recharge (Schueler, 1994). Figure 5 illustrates the influence of impervious cover on the hydrologic cycle and the amount of infiltration which occurs. In natural settings, very little annual rainfall is converted to runoff and about half is infiltrated into the underlying soils and the water table. This water is filtered by the soils, supplies deep water aquifers, and helps support adjacent surface waters with clean water during dry periods. In urbanized areas, less and less annual rainfall is infiltrated and more and more volume is converted to runoff. Not only is this runoff volume greater, it also occurs more frequently and at higher magnitudes. As a result, less water is available to streams and waterways during dry periods and more flow occurs during storms.

Other key changes in urban streams due to increases in impervious cover levels are detailed below:

Bankfull and sub-bankfull floods increase in magnitude and frequency. The peak discharge associated with the bankfull flow (i.e., the 1.5 to two-year return storm) increases sharply in magnitude in urban streams. In addition, channels experience more bankfull and sub-bankfull flood events each year, and are exposed to critical erosive velocities for longer intervals (Hollis, 1975; Booth *et al.*, 1996; and MacRae, 1996).

Dimensions of the stream channel are no longer in equilibrium with its hydrologic regime. The hydrologic regime that had defined the geometry of the predevelopment stream channel irreversibly changes and the channel faces higher flow rates on a more frequent basis. The higher flow events of the urban stream are capable of performing more "effective work" in moving sediment than they had done before (Wolman, 1954).

Table 2: Proportion of National Stream and River Mileage in Headwater Streams (Leopold *et al.*, 1964)

Stream Order*	Number of Streams	Total Length of Stream (miles)	Mean Drainage Area (square miles)**
1	1,570,000	1,570,000	1.0
2	350,000	810,000	4.7
3	80,000	420,000	23
4	18,000	220,000	109
5	4,200	116,000	518
6	950	61,000	2,460
7	200	30,000	11,700
8	41	14,000	55,600
9	8	6,200	264,000
10	1	1,800	1,250,000
Total	2,023,400	3,250,000	N/A

* stream order based on Strahler (1957) method, analyzing maps at a scale of 1:24,000
** cumulative drainage area, including tributaries

Channels enlarge. The customary response by an urban stream is to increase its cross-sectional area to accommodate the higher flows. This is done by stream bed down-cutting, stream bank widening, or a combination of both. Urban stream channels often enlarge their cross-sectional area by a factor of two to five, depending on the degree of impervious cover and the age of development in the upland watershed (Arnold *et al.*, 1982; Gregory *et al.*, 1992; and MacRae, 1996).

Stream channels are highly modified by human activity. Urban stream channels are extensively modified in an effort to protect adjacent property from streambank erosion or flooding. Headwater streams are frequently enclosed within storm drains, while others are channelized, lined, and or "armored" by heavy stone. Another modification that is unique to urban streams is the installation of sanitary sewers underneath or parallel to the stream channel. According to May *et al.* (1997), 20 to 30% of natural stream channels are modified in typical urban watersheds.

Upstream channel erosion contributes greater sediment load to the stream. The prodigious rate of channel erosion in urban streams, coupled with sediment erosion from active construction sites, increases sediment discharge to urban streams. Researchers have documented that channel erosion constitutes as much as 75% of the total sediment budget of urban streams (Crawford and Lenat, 1989; Trimble, 1997). Urban streams also tend to have a higher sediment discharge than non-urban streams during the active channel enlargement stage.

Dry weather flow in the stream declines. Since impervious cover prevents rainfall from infiltrating into the soil, less flow is available to recharge groundwater. Consequently, during extended periods without rainfall, baseflow levels are often reduced in urban streams (Simmons and Reynolds, 1982).

Wetted perimeter of the stream during low flow declines. The wetted perimeter of a stream is the fraction of the total cross-sectional area of the channel that is covered by flowing water during dry-weather periods, and is an important indicator of habitat degradation in urban streams. Given that urban streams develop a larger channel cross-section while their baseflow rates decline, it follows that the wetted perimeter becomes smaller. Thus, for many urban streams, this results in a very shallow low flow channel that "wanders" across a very wide stream bed, often changing its lateral position in response to storms.

Instream habitat structure degrades. Urban streams are routinely scored as having poor instream habitat quality, regardless of the specific metric or method employed. Habitat degradation is often exemplified by a loss of pool and riffle structure, embedding of stream bed sediments, shallow depths of flow, eroding and unstable banks, and frequent stream bed turnover.

Large woody debris is reduced (LWD). Large woody debris is an important structural component of many low order streams systems, creating complex habitat structure and generally making the stream more retentive. In urban streams, the quantity of LWD found in stream channel declines sharply, due to the loss of riparian forest cover, storm washout, and channel maintenance practices (Booth *et al.*, 1996; May *et al.*, 1997).

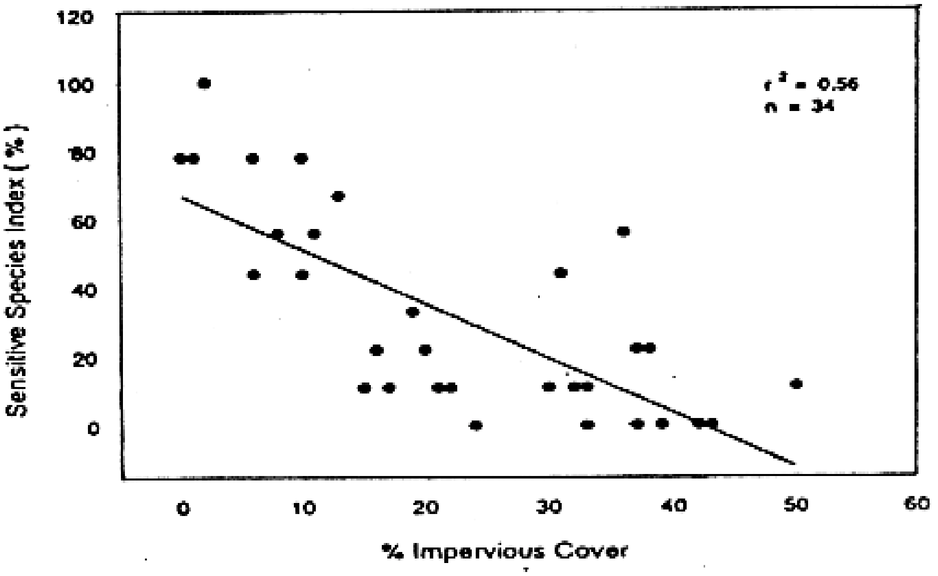

Figure 6: Relationship Between Impervious Cover and the Sensitive Aquatic Insect Index in Delaware's Northern Piedmont Streams (Maxted and Shaver, 1996)

Stream crossings and potential fish barriers increase. Many forms of urban development are linear in nature (e.g., roads, sewers, and pipelines) and cross stream channels. The number of stream crossings increases directly in proportion to impervious cover (May *et al.*, 1997), and many crossings can become partial or total barriers to upstream fish migration, particularly if the stream bed erodes below the fixed elevation of a culvert or a pipeline.

Riparian forests become fragmented, narrower and less diverse. The important role that riparian forests play in stream ecology is often diminished in urban watersheds, as tree cover is often partially or totally removed along the stream as a consequence of development (May *et al., 1997).* Even when stream buffers are reserved, encroachment often reduces their effective width, and native species are supplanted by exotic trees, vines and ground covers.

Water quality declines. The water quality of urban streams during storm events is consistently poor. Urban stormwater runoff contains moderate to high concentrations of sediment, carbon, nutrients, trace metals, hydrocarbons, chlorides and bacteria (Schueler, 1987). While considerable debate exists as to whether stormwater pollutant concentrations are actually toxic to aquatic organisms, researchers agree that pollutants deposited in the stream bed exert an undesirable impact on the stream community.

Summer stream temperatures increase. The impervious surfaces, ponds, and poor riparian cover found in urban watersheds can increase mean summer stream temperatures by two to 10 degrees Fahrenheit (Galli, 1991). Since temperature plays a central role in the rate and timing of biotic and abiotic reactions in streams, even moderate increases can have an adverse impact on streams. In some regions, summer stream warming can irreversibly shift a cold-water stream to a cool-water or even warm-water stream, with deleterious effects on salmonoids and other temperature sensitive organisms.

Reduced aquatic diversity. Urban streams are typified by fair to poor fish and macro invertebrate diversity, even at relatively low levels of watershed impervious cover or population density. The ability to restore pre-development fish assemblages or aquatic diversity is constrained by a host of factors: irreversible changes in carbon supply, temperature, hydrology, lack of instream habitat structure, and barriers that limit natural recolonization.

A typical relationship between impervious cover and the presence of sensitive aquatic insects from the Delaware Piedmont region is illustrated in Figure 6. As the level of impervious cover in the watershed increases, the amount of sensitive species declines. Beyond watershed imperviousness levels of 10 to 15%, about 90% of the sensitive organisms are lost from the stream (Maxted and Shaver, 1996).

In recent years, many studies have begun to quantify the relationship between development and the health of the receiving waters. In general, the studies point to a decrease in stream quality with increasing urbanization. Other measures may also have predictable relationships to stream quality, such as the quantity and quality of riparian cover, or the amount of compacted urban turf (Schueler, 1995).

The Influence of Impervious Cover on Other Aquatic Systems

The impact of impervious cover on the quality of lakes, water supply reservoirs, aquifers, or coastal

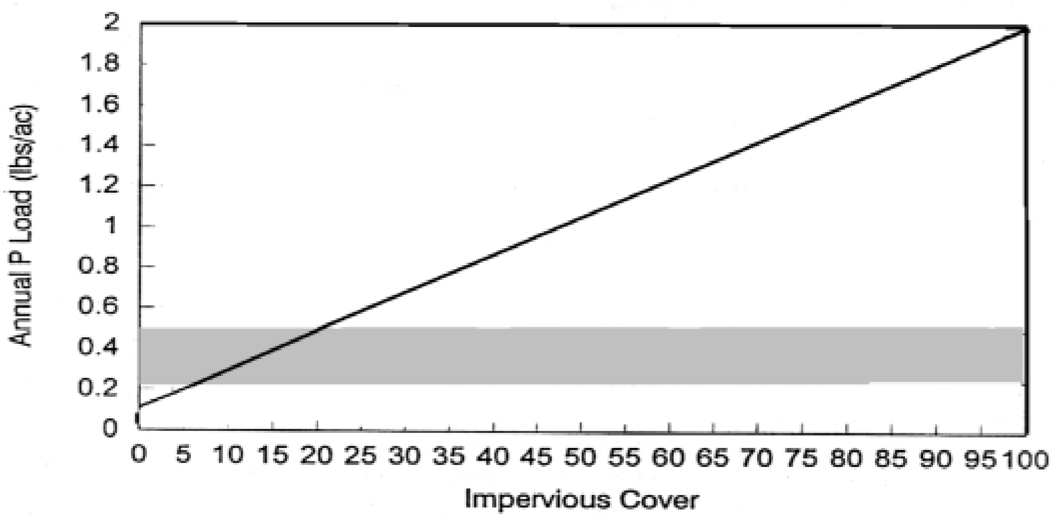

Figure 7: Relationship Between Phosphorus Load and Impervious Cover

The gray band indicates typical "background" Phosphorus loads from undeveloped watersheds.

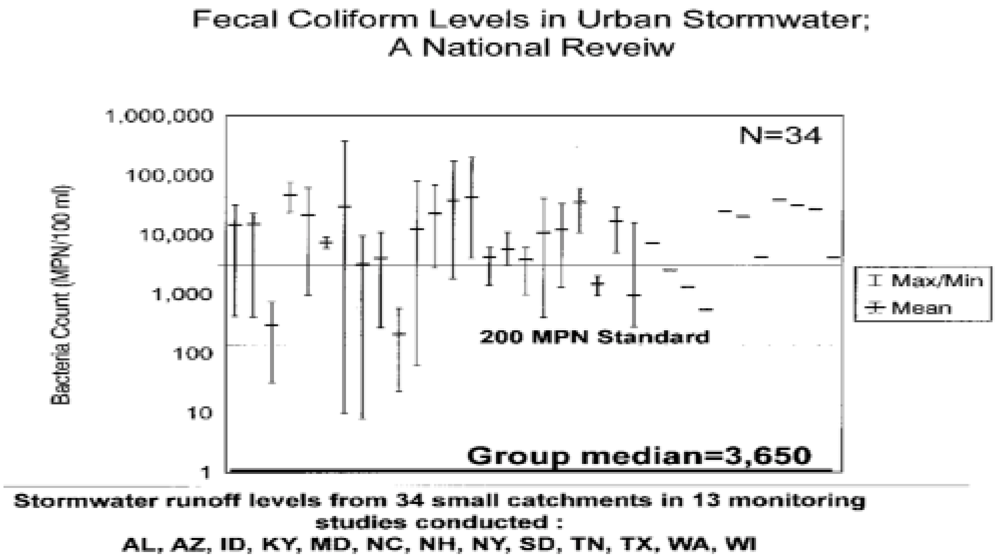

Figure 8: Fecal Coliform Levels in Urban Stormwater

areas has not been as well investigated as it has for urban streams. Although research is scarce, there is some evidence that impervious cover does have a similar impact on these aquatic systems. The impacts to these systems are manifested in different ways and may occur at different levels of impervious cover than are often seen for urban streams.

Even small increases in impervious cover change stream morphology and degradation of aquatic habitat. In contrast, aquatic systems such as lakes, water supply reservoirs, aquifers, and coastal areas tend to be impacted more by a decline in water quality due to nonpoint source pollutants. Research has shown that stormwater pollutant loads increase when the percentage of impervious cover in a watershed increases.

Urban Lakes

For urban lakes, the major water quality impacts are caused by higher stormwater pollutant loads. Elevations in total phosphorus and chlorophyll *a* are often associated with the impervious cover generated in developing areas. These factors can negatively affect the quality of the lake for activities such as fishing, swimming, or other water contact recreation. Sediment inputs may also be heightened with additional development in the watershed, which can often affect water clarity. In addition, the natural level of the lake may also be affected by the increased stormwater runoff which occurs with changes in impervious cover levels in the watershed.

Research has shown that impervious cover may be strongly related to water quality in small urban lakes, where eutrophication is considered the primary measure of degradation (i.e, in nutrient- sensitive lakes). Some indication of the possible relationship is illustrated in Figure 7, which shows the urban phosphorus load as a function of impervious cover.

In this general model, post-development phosphorus loads exceed background loads in many lakes once watershed imperviousness exceeds 20 to 25% impervious cover. The use of effective stormwater practices can raise the phosphorus threshold to higher levels, but eventually an impervious cover level will be reached where predevelopment phosphorus levels can no longer be maintained.

The water quality of urban lakes is a very important issue due to its economic and health impacts. Many of the states in the upper Midwest region, such as Michigan and Minnesota, have programs designed to protect their important inland lake resources from rapid urban growth. Similar programs are being developed in Maine where a phosphorus allocation model is used to limit phosphorus export from new development to lake resources (Monagle, 1996). Other examples include Deal Lake, New Jersey where a lake commission is working with five watershed municipalities to upgrade watershed plans to prevent eutrophication and sedimentation (US EPA, 1995).

Water Supply Reservoir

While water supply reservoirs also experience the same impacts as urban lakes, the issue of public health and water quality is often a major concern. Of greatest concern is the fact that stormwater runoff from watersheds with very little impervious cover routinely exceeds state and federal standards for fecal coliform. This means that urbanizing watersheds must carefully plan to ensure the safety of public drinking water supplies. Excessive algal blooms may also occur with greater

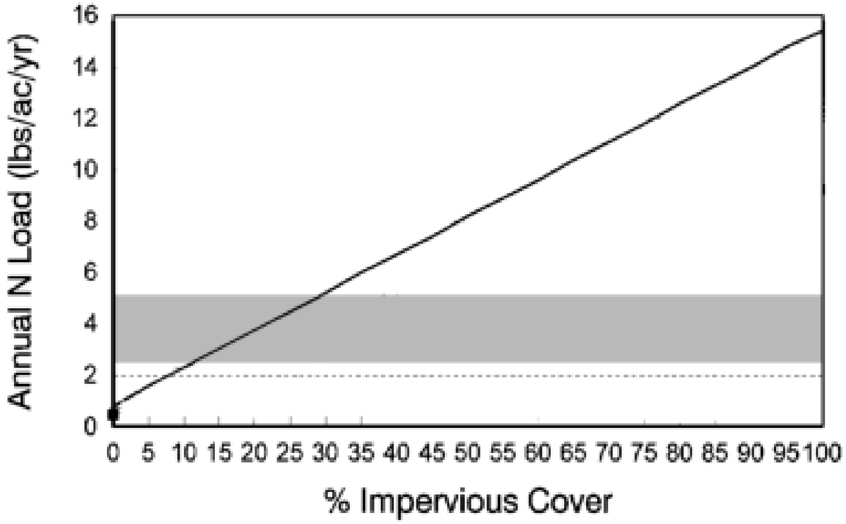

Figure 9: Relationship Between Nitrogen Load and Impervious Cover

stormwater inputs, causing taste and odor problems and formation of a cancer causing agent THM (Tri-Halo-Methanes). In addition, increased sediment inputs attributed to elevated levels of stormwater runoff have a twofold impact on water supply reservoirs; first, turbidity of the water is negatively affected; and second, sedimentation can result in a loss in reservoir capacity. The input of certain metals (barium, copper, zinc, etc.) may also be enhanced by stormwater runoff levels.

When evaluating possible impacts to water supply reservoirs, it is important at this point to distinguish between filtered and unfiltered water supplies. In a filtered water supply reservoir, the water from the reservoir travels to a water treatment facility where chemical and physical processes are used to remove pollutants, eliminate bacteria, and ensure that the water is fit for human consumption. In an unfiltered water supply, the treatment of the water supply is more limited, with chlorination or UV irradiation being the usual forms of treatment. Thus the potential risk from fecal coliform bacteria and other pathogens is often greater in unfiltered water supply reservoirs.

Bacterial levels in urban stormwater runoff can be a major concern for water supply reservoirs. A national review of fecal coliform levels in urban stormwater indicates that urban runoff has bacteria levels which routinely exceed established health standards. Figure 8 demonstrates the results of a review of 34 urban watershed monitoring studies from around the country. For these watersheds, the mean level of fecal coliform is 18 times the recreational water contact standard. Several examples from around the country illustrate the growing concern over water quality and water supply reservoirs. For example, in North Carolina concerns over adequate protection of water supplies have led to changes in zoning and land use in both the Cane Creek and University Lake watersheds. In the Kensico Reservoir in New York, watershed protection programs are being implemented to protect water supplies and retain a “filtration avoidance" status. In Wachusetts, MA efforts are being made to protect the local water supply reservoir through watershed planning and stormwater practice implementation.

Coastal/Estuarine

The impacts to coastal/estuarine areas from impervious cover are numerous. Nitrogen inputs from stormwater runoff and non-structural discharges can have serious consequences due to increases in algal bloom occurrences. Increased inputs of metals, toxins, and hydrocarbons from urban runoff can directly affect the health of these important aquatic areas. Decreases in water quality due to pollutant loading may also have an adverse impact on valuable spawning habitat and anadromous fish passages. Additionally, high bacterial levels may result in contamination of shellfish beds, causing closures and economic impacts on fishing industries located in the watershed. Stormwater runoff may also have a physical effect on important wetland resources.

Research points to the strong influence of impervious cover on coastal/estuarine systems such as shellfish beds and wetlands (Duda and Cromartie, 1982; Hicks, 1995; Taylor, 1993). Interestingly, each study found degradation thresholds when impervious cover exceeded 10%. Impervious cover also has a direct effect on the levels of nitrogen entering into coastal and estuarine areas. Figure 9 illustrates the nature of this relationship. Nitrogen levels are an important consideration, since they are related to eutrophication in coastal/estuarine areas in the same way phosphorus is an indicator of eutrophication for freshwater lakes.

Researchers from various parts of the country have sought to study the impact of urbanization on coastal areas and wetland resources. Reports from areas such as Tampa Bay, FL, Neuse River, NC, Puget Sound, WA and San Francisco Bay, CA all indicate that stormwater can be a significant source of pollutants to coastal areas and estuaries.

Aquifers

Aquifers can be impacted by impervious cover in terms of both the quantity and quality of groundwater. Impervious cover decreases infiltration rates and allows more stormwater to be converted to runoff. The loss of this infiltration affects the quantity of water available to recharge an aquifer, as well as the rate of recharge. This reduced recharge rate may result in wells using the aquifer going dry as groundwater levels fall. Water quality in wells connected to aquifers is also a concern, since urban stormwater tends to have more pollutants and pathogens associated with it and may mean that drinking water standards are not being met. The aquifers in karst areas, where porous underlying layers allow for rapid infiltration of stormwater, are a major concern.

To our knowledge, no systematic research has been conducted to determine whether groundwater recharge or quality are predictably influenced as a function of impervious cover. It is speculated that such relationships will be complex and hard to detect, since groundwater recharge and quality are also influenced by septic systems, wells, lawn irrigation, and sewer inflow and infiltration. However, the impacts of impervious cover and its effect on dry weather stream flows have been studied. Several studies (Evett, 1994; Ferguson and Suckling, 1990) have observed that there were decreases in stream flow during dry weather periods which have been attributed to increases in urbanization. This decrease is a result of diminished groundwater recharge which lowers the water table and causes streamflows in urbanizing areas to fall below a pre development sustainable base flow. Figure 10 illustrates the effect of reduced groundwater recharge on streamflow.

Groundwater quality has been linked to impervious cover in several watersheds. For example, the Edwards Aquifer in Texas is a prime example of an urbanizing watershed in which runoff from increased development has affected water quality. Contamination of the Barton Springs segment of the Edwards Aquifer has been well documented. Several studies have found contaminant levels for some heavy metals in excess of the EPA maximum for drinking water. In addition, water quality studies for six streams which recharge Barton Springs have found that water quality is degrading with increased development. In the more developed lower reaches of Barton Creek, stormflow concentrations of contaminants such as nitrogen, phosphorus, and fecal coliform have been found to exceed values found in the upper reaches by several hundred percent or more.

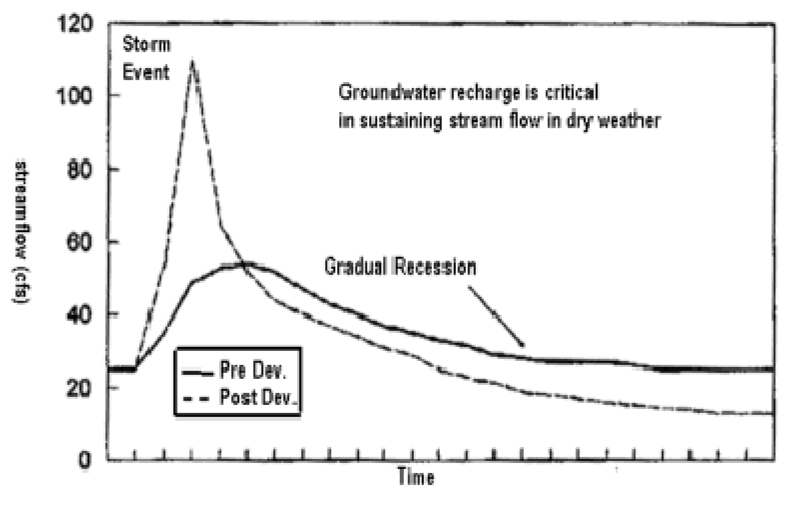

Figure 10: The Effect of Groundwater Recharge on Streamflow

This trend in decreasing groundwater quality has been found in a number of other areas of the country (Fulbright Springs, MO–WWE, 1995; Clarksville, TN–Hoos, 1990). This has led several local governments to implement watershed planning efforts to control stormwater runoff and associated contaminants. These efforts have often included controls on land use, and restrictions on development in order to cap the amount of impervious cover in the aquifer recharge area.

***Concept No. 4*. The relationship between impervious cover and subwatershed quality can be predicted by a simple model that projects the current and future quality of streams and other water resources at the subwatershed level.**

It is important to understand the assumptions and limitations of the simple model before using it to develop individual subwatershed plans within a watershed.

The Impervious Cover Model

Stream research generally indicates that certain zones of stream quality exist, most notably at about 10% impervious cover, where sensitive stream elements are lost from the system. A second threshold appears to exist at around 25 to 30% impervious cover, where most indicators of stream quality consistently shift to a poor condition (e.g., diminished aquatic diversity, water quality and habitat scores).

Taking all the research together, it is possible to construct a simple urban stream classification scheme based on impervious cover and stream quality. This simple classification system contains three stream categories, based on the percentage of impervious cover. Figure 11 illustrates this simple yet powerful model that predicts the existing and future quality of streams based on the measurable change in impervious cover.

The model classifies streams into one of three categories; sensitive, impacted, and non-supporting. Each stream category can be expected to have unique characteristics as follows:

Sensitive Streams. These streams typically have a watershed impervious cover of zero to 10%. Consequently, sensitive streams are of high quality, and are typified by stable channels, excellent habitat structure, good to excellent water quality, and diverse communities of both fish and aquatic insects. Since impervious cover is so low, they do not experience frequent flooding and other hydrological changes that accompany urbanization. It should be noted that some sensitive streams located in rural areas may have been impacted by prior poor grazing and cropping practices that may have severely altered the riparian zone, and consequently, may not have all the properties of a sensitive stream. Once riparian management improves, however, these streams are often expected to recover.

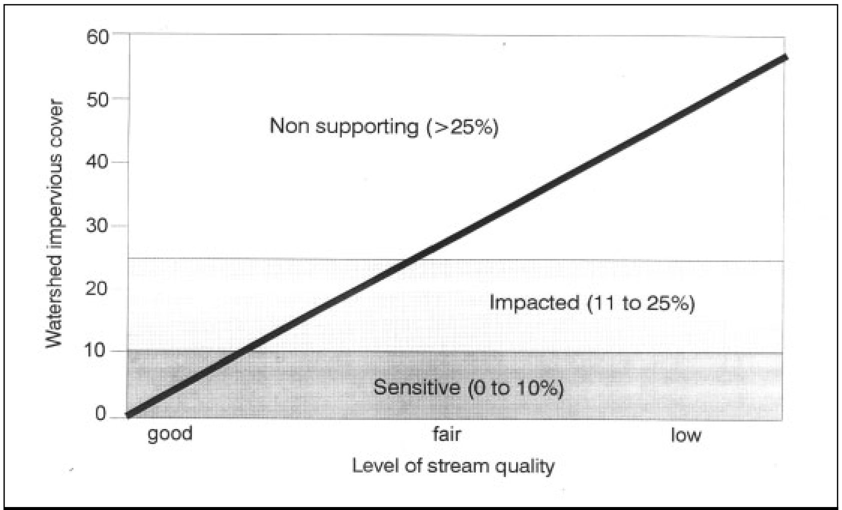

Figure 11: Impervious Cover vs. Stream Quality for Sensitive, Impacted, and Non-Supporting Streams

Impacted Streams. Streams in this category possess a watershed impervious cover ranging from 11 to 25%, and show clear signs of degradation due to watershed urbanization. Greater storm flows begins to alter the stream geometry. Both erosion and channel widening are clearly evident. Stream banks become unstable, and physical habitat in the stream declines noticeably. Stream water quality shifts into the fair/good category during both storms and dry weather periods. Stream biodiversity declines to fair levels, with the most sensitive fish and aquatic insects disappearing from the stream.

Non-Supporting Streams. Once watershed impervious cover exceeds 25%, stream quality crosses a second threshold. Streams in this category essentially become a conduit for conveying stormwater flows, and can no longer support a diverse stream community. The stream channel becomes highly unstable, and many stream reaches experience severe widening, down-cutting and streambank erosion. Pool and riffle structure needed to sustain fish is diminished or eliminated, and the stream substrate can no longer provide habitat for aquatic insects, or spawning areas for fish. Water quality is consistently rated as fair to poor, and water contact recreation is no longer possible due to the presence of high bacterial levels. Subwatersheds in the non-supporting category will generally display increases in nutrient loads to downstream receiving waters, even if effective urban stormwater practices are installed and maintained. The biological quality of non-supporting streams is generally considered poor, and is dominated by pollution tolerant insects and fish.

Figure 12 compares the three classes of urban streams and the corresponding degradation of stream quality with increases in impervious cover. These three stream reaches are located in the Mid-Atlantic Piedmont, each has about the same drainage area. As the figure shows, impervious cover can create a dramatic difference on channel stability, water quality, and aquatic biodiversity within the same physiographic region.

Limitations on Impervious Cover Model

Although the impervious cover model is supported by research, its assumptions and limitations need to be clearly understood. There are some technical issues involved in its development that are discussed below.

1. Scale effect. The impervious cover model should generally only be applied to smaller urban streams from first to third order. This limitation reflects the fact that most of the research has been conducted at the catchment or subwatershed level (0.2 to 10 square mile area), and that the influence of impervious cover is strongest at these spatial scales. In larger watersheds and basins, other land uses, pollution sources and disturbances often dominate the quality and dynamics of streams and rivers.

2. Reference condition. The simple model predicts **potential** rather than **actual** stream quality. Thus, the reference condition for a sensitive stream is a high quality, non-impacted stream within a given ecoregion or sub-ecoregion. It can and should be expected that some individual stream reaches or segments will depart from the predictions of the impervious cover model. For example, physical and biological monitoring may find poor quality in a stream classified as sensitive, or good diversity in a non-supporting one. Rather than being a shortcoming, these "outliers" may help watershed managers better understand local watershed and stream dynamics. For example, an "outlier" stream may be a result of past human disturbance, such as grazing, channelization, acid mine drainage, agricultural drainage, poor forestry practices, or irrigation return flows.

Sensitive Stream
(Impervious Cover ≤10%)
-Stable Channel
-Excellent Biodiversity
-Excellent Water Quality

Impacted Stream
(Impervious Cover 10-20%)
-Channel Becoming Unstable
-Fair to Good Biodiversity
-Fair to Good Water Quality

Non-Supporting Streams
(Impervious Cover 40-65%)
-Poor to No Biodiversity
-Poor Water Quality

Figure 12: Impacts of Increasing Imperviousness on Stream Quality

3. Statistical variability. Individual impervious cover/stream quality indicator relationships tend to exhibit a considerable amount of scatter, although they do show a general trend downward as impervious cover increases. Thus, the impervious cover model is not intended to predict the precise score of an individual stream quality indicator for a given level of impervious cover. Instead, the model attempts to predict the average behavior of a group of stream indicators over a range of impervious cover. In addition, the impervious cover thresholds defined by the model are not sharp breakpoints, but instead reflect the expected transition of a composite of individual stream indicators.

4. Measuring and projecting impervious cover. Given the central importance of impervious cover to the model, it is very important that it be accurately measured and projected. Yet comparatively relatively little attention has been paid to standardizing techniques for measuring existing impervious cover, or forecasting future impervious cover. Some investigators define effective impervious area (i.e., impervious area directly connected to a stream or drainage system which may be lower than total impervious cover under certain suburban or exurban development patterns (Sutherland, 1995).

5. Regional adaptability. To date, much research used to develop the model has been performed in the mid-Atlantic and Puget Sound eco-regions. In particular, very little research has been conducted in western, midwestern, or mountainous streams. Further research is needed to determine if the impervious cover model applies in these eco-regions and terrains.

6. Defining thresholds for non-supporting streams. Most research has focused on the transition from sensitive streams to impacted ones. Much less is known about the exact transition from impacted streams to non-supporting ones. The impervious cover model projects the transition occurs around 25% impervious cover for small urban streams, but more sampling is needed to firmly establish this threshold.

7. Influence of stormwater practices in extending thresholds. Urban stormwater practices may be able to shift the impervious cover thresholds higher. However, the ability of the current generation of urban stormwater practices to shift these thresholds appears to very modest according to several lines of evidence. First, a handful of the impervious cover/stream indicator research studies were conducted in localities that had some kind of requirements for urban best management practices; yet no significant improvement in stream quality was detected. Second, Maxted and Shaver (1996) and Jones *et al.* (1996) could not detect an improvement in bioassessment scores in streams served by stormwater ponds.

8. Influence of riparian cover in extending thresholds. Conserving or restoring an intact and forested riparian zone along urban streams appears to extend the impervious cover threshold to a modest degree. For example, Steedman (1988) found that forested riparian stream zones in Ontario had higher habitat and diversity scores for the same degree of urbanization than streams that lacked an intact riparian zone. Horner *et al*. (1996) also found evidence of a similar relationship. This is not surprising, given the integral role the riparian zone plays in the ecology and morphology of headwater streams. Indeed, the value of conserving and restoring riparian forests to protect stream ecosystems is increasingly being recognized as a critical management tool in rural and agricultural landscapes as well (CBP, 1995).

9. Potential for stream restoration. Streams classified by their potential for restoration (also known as restorable streams) offer opportunities for real improvement in water quality, stability, or biodiversity and hydrologic regimes through the use of stream restoration, urban retrofit and other restoration techniques.

10. Pervious areas. An implicit assumption of the impervious cover model is that pervious areas in the urban landscape do not matter much, and have little direct influence on stream quality. Yet urban pervious areas are highly disturbed, and possess few of the qualities associated with similar pervious cover types situated in non-urban areas. For example, it has recently been estimated that high input turf can comprise up to half the total pervious area in suburban areas (Schueler, 1995). These lawns receive high inputs of fertilizers, pesticides and irrigation, and their surface soils are highly compacted.

Although strong links between high input turf and stream quality have yet to be convincingly demonstrated, watershed planners should not neglect the management of pervious areas. Pervious areas also provide opportunities to capture and store runoff generated from impervious areas. Examples include directing rooftop runoff over yards, use of swales and filter strips, and grading impervious areas to pockets of pervious area. When pervious and impervious areas are integrated closely together, it is possible to sharply reduce the “effective” impervious area in the landscape (Southerland, 1995).

While there are some limitations to the application of the urban stream impervious cover model, impervious cover still provides us with one of the best tools for evaluating the health of a subwatershed. Impervious cover serves not only as an indicator of urban stream quality but also as a valuable management tool in reducing the cumulative impacts of development within subwatersheds.

Concept No. 5. **A watershed manager needs to implement eight different watershed management tools in order to comprehensively protect any subwatershed.**

The eight tools roughly correspond to the stages of the development cycle from land use planning, site design, construction and ownership. A subwatershed plan is used to define how and where the tools are specifically applied to meet unique water resource objectives.

Perhaps the most important concepts in this handbook are the tools of watershed protection, which are thoroughly presented in article 27. Together, these eight tools can comprehensively protect and manage urban subwatersheds in the face of growth.

The first tool, **Watershed Planning**, is perhaps the most important because it involves decisions on the amount and location of development and impervious cover, and choices about appropriate land use management techniques. The second tool, **Land Conservation,** involves choices about the types of land that should be conserved to protect a subwatershed. **Aquatic Buffers** are the third tool, and involve choices on how to maintain integrity of streams, shorelines, and wetlands, and provide protection from disturbance. The fourth tool is **Better Site Design**. This tool seeks to design individual development projects with less impervious cover which will reduce impacts to local streams. **Erosion and Sediment Control** deals with the clearing and grading stage in the development cycle when runoff can carry high quantities of sediment into nearby waterways.

The sixth tool, **Stormwater Treatment Practices**, involves choices about how, when, and where to provide stormwater management within a subwatershed, and which combination of best management practices can best meet subwatershed and watershed objectives. The seventh tool, **Non-stormwater Discharges**, involves choices on how to control discharges from wastewater disposal systems, illicit connections to stormwater systems, and reducing pollution from household and industrial products. The final tool, **Watershed Stewardship Programs**, involves careful choices about how to promote private and public stewardship to sustain watershed management.

It is important to note that the watershed protection tools are flexible and can, and should, be applied differently in each subwatershed. Their application can also depend on the subwatershed category. For example, if development is being planned in an area that falls into the "sensitive stream" category, the tools involving land conservation and site design may be emphasized.

Concept No. 6. **While each subwatershed is unique, each can generally be classified into one of eight possible management categories, depending on its impervious cover and receiving water resource.**

These management categories are very useful in simplifying and expediting the preparation of subwatershed plans, since similar analysis techniques and man-

Table 3: Eight Subwatershed Management Categories

Subwatershed Category	Description
Sensitive Stream	Less than 10 % impervious cover High habitat/water quality rating
Impacted Stream	10% to 25% impervious cover Some decline in habitat and water quality
Non-Supporting Stream	Watershed has greater than 25% impervious cover Not a candidate for stream restoration
Restorable Stream	Classified as Impacted or Non-Supporting High retrofit or stream restoration potential
Urban Lake	Subwatershed drains to a lake that is subject to degradation
Water Supply Reservoir	Reservoir managed to protect drinking water supply
Coastal/ Estuarine Waters	Subwatershed drains to an estuary or near-shore ocean
Aquifer Protection	Surface water has a strong interaction with groundwater Groundwater is a primary source of potable water

agement tools are often applied to subwatersheds in the same management category.

Since each type of water resource has unique management characteristics, it is beneficial to create a strategy to differentiate between them. This manual introduces a series of eight distinct **subwatershed management categories** based on the type of water resource (i.e., stream, lake, estuary, or aquifer) and the intensity of the land uses within the subwatershed. Table 3 introduces each of the subwatershed categories and their management characteristics.

Distinguishing between the different aquatic systems helps watershed managers define the appropriate uses for a water resource and set realistic goals for managing those uses and protecting existing resources.

Concept No. 7. **Watershed managers have to make hard choices about what mapping, modeling, monitoring, and management techniques are needed to support watershed and subwatershed plans.**

A basic subwatershed plan, which utilizes the least cost techniques, represents about $30,000 (although the actual cost can be reduced by volunteers or in-kind services). Much higher costs can be expected if watershed-wide analyses and subwatershed surveys are deemed necessary. An eight-step process is recommended todevelop cost-effective watershed and subwatershed plans that lead to rapid implementation.

This process guides the watershed manager through the hard choices needed for a successful watershed plan. Each step in the process answers commonly asked questions, such as "What goals are attainable in my watershed?" The eight-step process is shown in Figure 13.

In the first step, the watershed manager establishes a watershed baseline. Important information is gathered, such as watershed and subwatershed boundaries, possible stakeholders, and existing impervious cover. Step 2 presents a watershed management structure that assists the manager with focusing various stakeholders while preparing, implementing, and revising the watershed plan in a timely manner. Step 3 helps the watershed manager determine available funding resources and how they can best be allocated. Step 4 discusses forecasting future land uses and associated impervious cover. This information will help you decide how the aquatic resources in your watershed will be affected.

Step 5 covers watershed and subwatershed goal setting. In this step, the information gathered in steps 1 through 4 is used to determine appropriate and achievable watershed protection goals. In the sixth step, the development of subwatershed plans is discussed. This step guides the manager in the basic analyses needed to effectively apply the watershed protection tools. Step 7 discusses how the watershed plan can be administered in a watershed. This step provides guidance in the legalities of plan implementation. Step 8 takes the watershed manager through the process of revising and updating the watershed management plan as changes in monitoring data or development occur over time.

Concept No. 8. **A watershed plan stands little chance of ever being implemented unless broad consensus is reached among the many stakeholders that might be affected by the plan.**

A stakeholder is defined as any agency, organization, or individual that is involved in or affected by the decisions made in the subwatershed plan. Stakeholders should be given frequent and meaningful input in plan development: sharing data and maps, establishing goals and objectives, selecting watershed indicators, and customizing watershed management tools. Ultimately, a group of stakeholders can evolve into a more permanent watershed management structure that can provide the long-term commitment and resources needed to implement the plan.

In a real sense, every current and future resident of a watershed is a stakeholder, even though they may be unaware of this fact. Watershed stewardship programs can increase awareness and broaden community support to implement watershed plans. The ideal group of stakeholders for designing a subwatershed plan will be determined by the level of interest of local parties in water quality and resource protection issues. Typical non-agency and agency stakeholders are listed in Figure 14.

Concept No. 9. **Watershed planning is a continuous management process that leads to real implementation.**

To manage workloads and budgets, it is often useful to develop groups of subwatershed plans within a defined management cycle. Individual subwatersheds can be initiated on an alternating sequence so that a few subwatersheds are finished every year, and all are finished within five to seven years. Each subwatershed plan is revisited in the next watershed management cycle, and plans are refined for more effective implementation. The watershed management cycle helps integrate individual subwatershed management with watershed-wide management.

Effective watershed management requires periodic reevaluation of plans as land uses change over time. A recommended approach is to develop each subwatershed plan within a defined management cycle that may last from five to seven years. The preparation of individual subwatershed plans can be arranged in an

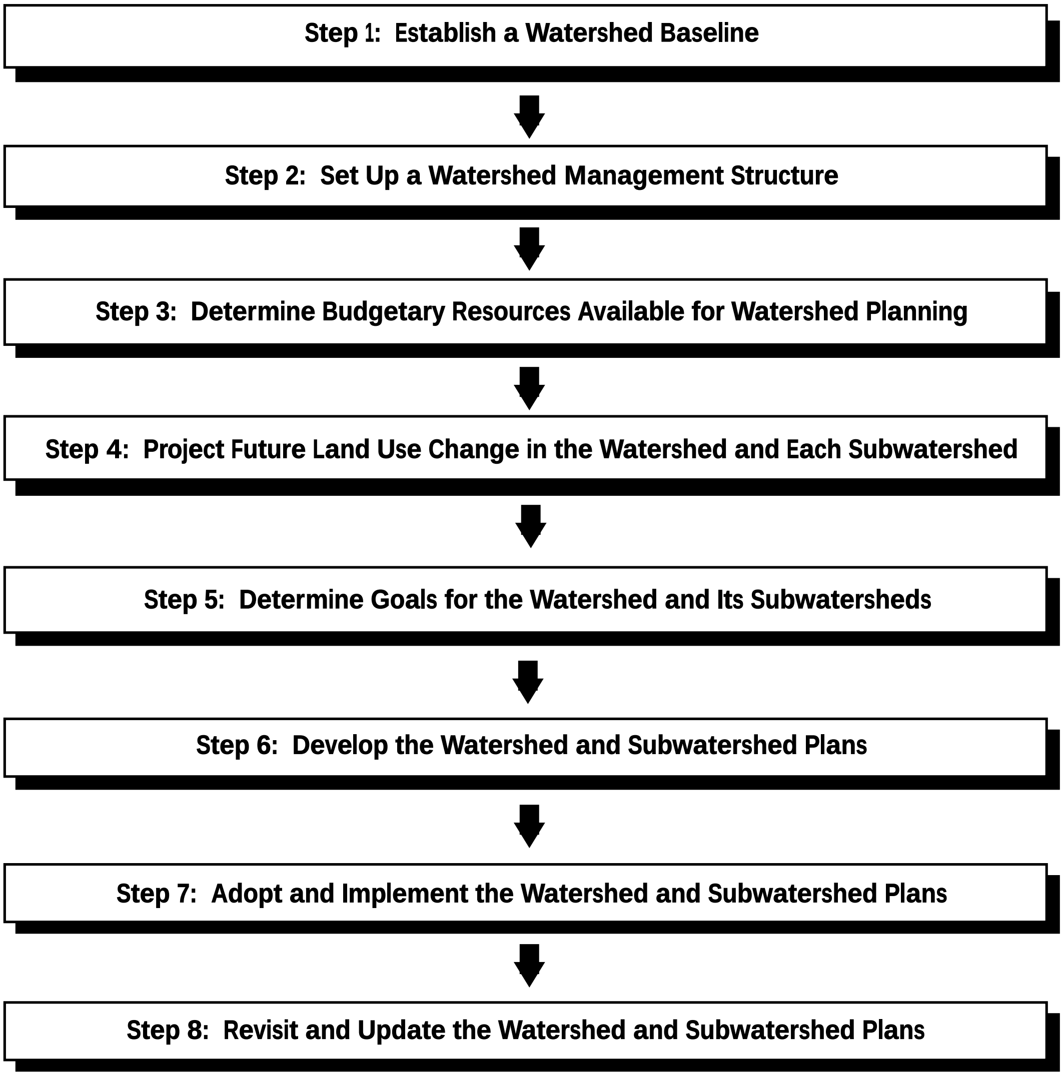

Figure 13: The Eight Rapid Steps of a Local Watershed Plan

Typical Non-Agency Stakeholders:

- Citizen Associations
- Water Resource Conservation Groups
- Developers
- Property Owners
- Outdoor Recreation Clubs
- Local Planner
- Individual Citizens
- Farmers
- Business Interests (industrial, commercial business owners)
- Utility Companies
- Environmental Advocates

Typical Agency Stakeholders:

- Regional Council of Government
- Planning Board
- Health Department

Figure 14: Typical Stakeholders in the Watershed Management Process

alternating series so that a few are started each year with all the plans being completed within a five to seven year time span. Larger jurisdictions with several watersheds may choose to identify watershed planning regions and have several planning cycles running concurrently.

Another benefit of the subwatershed management cycle is that workloads can be balanced against the schedule for conducting management and assessment. This allows managers to group subwatersheds into units so that each year a set of subwatersheds will begin a new phase in the process. This type of scheduling may also help conserve an organization's resources by simultaneously conducting stakeholder, monitoring, and implementation activities for whole sets of subwatersheds.

It may be practical to schedule some measurement or monitoring actions for all subwatersheds at the onset of the cycle. Early scheduling of activities, such as measuring impervious cover and conducting resource based monitoring, allows planners to designate subwatershed classification categories (i.e., sensitive, impacted, or non-supporting stream) and more easily prioritize subwatersheds according to their classification.

Communities may also consider phasing the management cycle. This entails identifying the different types of subwatershed management categories within the watershed as a first step. On an interim basis, specific subwatershed criteria can be applied to all the subwatersheds within the same management categories. This allows the most important and specific goals, like preventing stream degradation from one classification to the next, to be applied until the details of the watershed plan are complete.

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