Recovery Potential Metrics Summary Form

Indicator Name: WATERSHED PERCENT IMPERVIOUS COVER

Type: Stressor Exposure

Rationale/Relevance to Recovery Potential: Impervious cover is an indicator of the impacts of urbanization and development on water resources. Impervious cover results in multiple stressors to a watershed, such as increased pollutant loads from stormwater runoff, altered stream flow, decreased bank stability, and increased water temperatures. The significance of this metric in reducing recovery potential is based on the multiple impacts to the watershed as well as the nearly irreversible nature of imperviousness at high levels.

How Measured: Multiply the watershed area classified as "urban" (i.e. low, medium, and high density residential; commercial; industrial; etc) by the appropriate impervious surface coefficient for each land use type. The percent impervious surface indicator is calculated by averaging the impervious surface areas across the total land area of the watershed. If possible, differentiating between impervious cover contiguous with or isolated from drainage should be done to estimate 'effective' impervious cover.

Data Source: The 2001 and 2006 National Land Cover Data contains information on impervious surfaces as well as urban land cover (See: http://www.epa.gov/mrlc/nlcd-2001.html and http://www.mrlc.gov/nlcd06_data.php). Approximate watershed boundaries can be constructed by aggregating small-scale catchments from the NHDplus datasets (See: http://www.horizon-systems.com/nhdplus/).

Indicator Status (check one or more)

______ Developmental concept.
___x__ Plausible relationship to recovery.
______ Single documentation in literature or practice.
___x__ Multiple documentation in literature or practice.
___x__ Quantification.

Examples from Supporting Literature (abbrev. citations and points made):

- (ourso and frenzel 2002) Eighteen of the 86 variables examined, including riparian and instream habitat, macroinvertebrate communities, and water/sediment chemistry, were significantly correlated with percent impervious area. A sliding regression analysis of variables significantly correlated with percent impervious area revealed 8 variables exhibiting threshold responses that correspond to a mean of 4.4 – 5.8% impervious area, much lower than mean values reported in other, similar investigations. The percentage of impervious area at which degradation of water quality begins is varied, ranging from 4–5% (May et al., 1997) to 10–12% (Klein, 1979; Booth & Jackson, 1997; Wang et al., 2000). Effective impervious area relates to the 'connectedness' of impervious area to a watercourse and intuitively has a greater effect on water quality than does impervious area separated from the watercourse. In other words, buffer areas and open space near water bodies are important in controlling runoff from impervious areas. In addition to buffer areas, the reduction of impervious area also must be considered. Although the thresholds reported here appear low compared with values reported elsewhere (Schueler, 1994), the differences in this study may be related to the more advanced technology used to quantify PIA.

- (Moore and Palmer 2005) There was a highly significant difference in impervious surface cover between land use groups (*P* , 0.0001). Urban sites had higher imperviousness than all other land use groups, while agriculture and mixed agriculture sites had significantly lower imperviousness than either of the urban groups. We also found a subsequently strong negative linear relationship between impervious surface cover and richness in these headwater streams (Fig. 4; *r*2 5 0.70, *P* , 0.0001). It has been previously suggested that thresholds may exist in this relationship at ;10–15% imperviousness (Schueler 1994, Stepenuck et al. 2002); however, we found that a quadratic model was no better at explaining the relationship between richness and impervious surface cover (*r*2 5 0.68) than a simple linear model (1173).
- (Moore and Palmer 2005) Impervious surface cover is specifically known to lead to extreme disturbances instream ecosystems, including increased flood flows (Booth and Jackson 1997, Paul and Meyer 2001). Our urban subwatersheds have more impervious surface cover than the agricultural subwatersheds, and there was a strong negative relationship between invertebrate richness and imperviousness (Fig. 4). Wang et al. (2000) and Stepenuck et al. (2002) examined stream communities across a similar land use gradient in Wisconsin, and likewise found that macroinvertebrate and fish diversity, respectively, decreased with the amount of impervious surface cover (1175).
- (Gergel et al. 2002) Finally, the amount of the catchment in impervious surface, or urbanized areas, is a valuable landscape indicator of biotic, hydrologic and geomorphic changes in rivers (see Paul and Meyer, 2001 for a thorough review). Impervious surface cover can influence a variety of hydrologic aspects of streams by shortening the time to flood peaks, causing increases in bankfull discharges and higher surface runoff (Arnold and Gibbons, 1996; Leopold, 1968). Geomorphic changes such as changes in channel width have been associated with percent impervious areas as low as 2 –10% (Booth and Jackson, 1997; Morisawa and LaFlure, 1979; Dunne and Leopold, 1978). Initial degradation of fish communities and lower larval densities have been associated with percent impervious areas as low as 10% (Steedman, 1988; Limburg and Schmidt, 1990). It is noteworthy that several thresholds of degradation in streams occur at approximately 10–20% of the catchment in impervious area (Paul and Meyer, 2001) (122).
- (Novotny at al. 2005) Percent of imperviousness is a surrogate for many adverse stresses caused by urbanization and development (Field et al., 2000). The relationship of this parameter to benthic macroinvertebrate indices was published by Schueler (1994) for Washington, DC metropolitan area and May et al. (1997) for Puget Sound (Washington) lowland streams. Similar plots have been developed using percent urbanization or population density (Dreher, 1997). Wang et al. (2000, 2001) evaluated the effect of changes from agriculture to urban use and analyzed and published negative effects of % impervious area on the fish IBI that were even more profound than the effects on the benthic IBI mentioned above. Wang et al. (2001) then found that the ‘‘connected impervious area’’ directly draining into a concentrated flow surface drainage conduit (e.g., storm sewer) yields the best correlation to the fish IBI of urban and urbanizing watersheds. Wang et al. (2001) concluded that most of the studies listed above have noted a sharp decline in fish community integrity attributes at 8–12% imperviousness (188).
- (Novotny et al. 2005) Unfortunately, the percent imperviousness parameter is irreversible in most cases and, typically, can only increase with time. It would not be logical to argue that every watershed with more than 8–12% imperviousness was degraded and urban development should consist of low-density scattered subdivisions. Major stressors due to imperviousness include changes in hydrology that impact bank stability and habitat, increased frequency of overflows fromsewer systems and frequency of washoff of pollutants. Watershed managers and urban planners can counteract these effects, e.g., by retrofitting fast conveyance urban drainage with storage. Knowing these thresholds of impairment related to impervious surface is important in avoiding impacts before those thresholds are exceeded in suburban (developing) setting by introducing best management practices that would reduce the hydrological and pollution impacts of imperviousness (188-189).

- (Walsh et al. 2005) Changes to hydrographs are perhaps the most obvious and consistent changes to stream ecosystems influenced by urban land use, with urban streams tending to be more ''flashy'', i.e., they have more frequent, larger flow events with faster ascending and descending limbs of the hydrograph. The primary driver of these changes occurs from a combined effect of increased areas of impervious surfaces and more efficient transport of runoff from impervious surfaces by piped stormwater drainage systems (Dunne and Leopold 1978, Fig. 1). Total catchment imperviousness (TI) has commonly been used as an indicator of this class of hydrologic change, although the influence of TI on stream hydrographs varies substantially with permeability of pervious parts of the catchment (Booth et al. 2004) and with how much of the impervious area drains directly to streams through pipes rather than draining to the surrounding pervious land (Walsh et al. 2005) (707-708).
- (Paul and Meyer 2001) A dominant feature of urbanization is a decrease in the perviousness of the catchment to precipitation, leading to a decrease in infiltration and an increase in surface runoff (Dunne&Leopold 1978). As the percent catchment impervious surface cover (ISC) increases to 10–20%, runoff increases twofold; 35–50% ISC increases runoff threefold; and 75–100% ISC increases surface runoff more than fivefold over forested catchments (Figure 1) (Arnold & Gibbons 1996). Imperviousness has become an accurate predictor of urbanization and urban impacts on streams (McMahon & Cuffney 2000), and many thresholds of degradation in streams are associated with an ISC of 10–20% (Table 1) [hydrologic and geomorphic (Booth & Jackson 1997), biological (Klein 1979, Yoder et al. 1999)].

  Various characteristics of stream hydrography are altered by a change in ISC. Lag time, the time difference between the center of precipitation volume to the center of runoff volume, is shortened in urban catchments, resulting in floods that peak more rapidly (Espey et al. 1965, Hirsch et al. 1990). Decreases in flood peak widths from 28–38% over forested catchments are also observed, meaning floods are of shorter duration (Seaburn 1969). However, peak discharges are higher in urban catchments (Leopold 1968). Flood discharges increase in proportion to ISC and were at least 250% higher in urban catchments than forested catchments in Texas and NewYork after similar storms (Espey et al. 1965, Seaburn 1969) (335).
- (Paul and Meyer 2001) As discussed above, all find decreases in diversity and overall invertebrate abundance with increased urbanization. This response is correlated with impervious surface cover, housing density, human population density, and total effluent discharge (Klein 1979, Benke et al. 1981, Jones & Clark 1987, Tate & Heiny 1995, Kennen 1999). Klein (1979) studied 27 small catchments on the Maryland Piedmont and was among the first to identify impervious surface cover (ISC) as an important indicator of degradation. Invertebrate measures declined significantly with increasing ISC until they indicated maximum degradation at 17% ISC (Table 1). Degradation thresholds at ISC between 10 and 20% have been supported by numerous other studies for many different response variables (see Schueler 1994a) (349).
- (Paul and Meyer 2001) Large multi-site studies of fish responses to urban gradients also find dramatic decreases in diversity or fish multimetric indices [index of biotic integrity (IBI)] with increasing ISC or other urban land use indicators (Table 1) (Klein 1979, Steedman 1988,Wang et al. 1997, Frick et al. 1998, Yoder et al. 1999). Similar to effects observed for invertebrates, these studies also find precipitous declines in fish metrics between 0 and 15% ISC or urban land use, beyond which fish communities remain degraded (Klein 1979, Yoder et al. 1999) (352).
- (Morgan and Cushman 2005) For example, it will be logistically difficult, if not politically impossible, to reverse road density and catchment imperviousness within urban Maryland and throughout the USA (Brabec at al. 2002). Wang et al. (2001) and Wang and Kanehl (2003) both suggested that minimizing effective catchment imperviousness (Walsh et al. 2005a), or restricting total imperviousness (especially to ,10–15%), may be critical to maintaining species assemblages (Gergel et al. 2002, Groffman et al. 2003); we believe this recommendation also may be useful in protecting Maryland stream fishes (653).

- (Bernhardt and Palmer 2007) The most obvious and immediate consequences are an increase in impervious surface area with resultant increased runoff to receiving streams, higher peak discharges, greater water export and higher sediment loads during the construction phase (Dunne & Leopold, 1978; Arnold & Gibbons, 1986; McMahon & Cuffney, 2000; Rose & Peters, 2001; Nelson & Booth, 2002; Walsh, Fletcher & Ladson, 2005a). Over time as the catchment is built out (new construction slows or ceases), the hydrologic alterations remain but sediment delivery to streams decreases dramatically (Trimble, 1997; Wheeler, Angermeier & Rosenberger, 2005), leading to channel erosion and sometimes dramatic increases in channel width and depth (incision) (Booth, 2005; Leopold, Huppman & Miller, 2005). These changes in channel morphology disconnect the stream from its floodplain, decrease sinuosity, and homogenise stream profiles (Hammer, 1972; Douglas, 1974; Roberts, 1989; Booth, 1990). Leopold, Huppman & Miller (2005) described these hydrogeomorphic changes as part of the 'urbanization cycle' in small river basins. These impacts have historically been exacerbated by sealed and piped drainage systems, as well as channelisation, which is often used for reducing lateral channel migration and managing flow to protect urban infrastructure (Dunne & Leopold, 1978) (739).
- (Bernhardt and Palmer 2007) Spending large amounts of money on a restoration project along one kilometre of stream while the downstream kilometre remains under pavement, will not restore the ecological conditions of the stream network (Palmer et al., 2005) (746).
- (Bernhardt and Palmer 2007) Several studies have documented lower fish diversity and abundance in catchments with high degrees of imperviousness (Wang et al., 2000; Morgan & Cushman, 2005) (742).
- (Moore and Palmer 2005) Two factors, the amount of impervious surface and of riparian forest cover, are often the focal point of discussions on the link between land use change and stream ecosystem health (e.g., Schueler 1994, Weigel et al. 1999, Stewart et al. 2001). These two variables influence stream hydrology and water quality (Brabec et al. 2002). Furthermore, impervious cover has been shown to be correlated with the diversity of macroinvertebrates (Schueler 1994), and the removal or clearcutting of riparian trees in forested watersheds has been shown to have a strong influence on entire stream invertebrate communities (Wallace et al. 1997) (1170).
- (Allmendinger et al., 2007) Urbanization causes profound changes in patterns of erosion and sedimentation in watersheds. Impervious surfaces and compacted soils increase runoff (Leopold and Skibitzke, 1967; Hollis, 1975; Sauer et al., 1983), leading to bank erosion, channel enlargement, and channel incision (Hammer, 1972; Morisawa and LaFlure, 1979; Arnold et al., 1982; Peck, 1986; Neller, 1988). Upland sediment production may dramatically increase during construction, but after construction has ceased, buildings, lawns, and roadways are widely believed to produce relatively little sediment (Dawdy, 1967; Wolman, 1967; Wolman and Schick, 1967) (1483).
- (Allmendinger et al., 2007) Changes in flow regime associated with urban development can have dramatic effects on the structure of ecological communities and the rates of biological processes (Poff and Nelson-Baker, 1997; Palmer et al., 2002; Nilsson et al., 2003). Higher percentages of impervious surfaces in a watershed, for example, may be associated with decreases in invertebrate species richness (Moore and Palmer, 2005), and increased suspended sediment concentrations can have numerous important ecological effects (Waters, 1995). In downstream areas, changes in nutrient and sediment loading can adversely affect receiving waterways; this is a significant concern in the watersheds that drain to the Chesapeake Bay (Brush, 1989; Cronin and Vann, 2003; Kemp et al., 2005) (1484).
- (Allmendinger et al., 2007) In a study of Watts Branch, an urbanized watershed in Montgomery County, Maryland, Beighley and Moglen (2002) presented hydrological modeling results suggesting that the two-year peak discharge increased by factors from 1.3 to 3.0 from 1951-2007 for second-order subwatersheds similar in size to the Good Hope Tributary. A similar analysis was presented by Palmer et al. (2002) for the NW

Branch watershed from 1951 to 1997. The NW Branch watershed is immediately adjacent to the Good Hope tributary. Palmer et al. (2002) reported that peak discharge in second-order subwatersheds of the NW Branch increased by factors from 1.3 to 7.7. The variability in these predictions is largely controlled by the extent of impervious cover associated with urbanization in each subwatershed (1486).

- (Groffman et al., 2003) Stream incision, in combination with reduced infiltration in impervious urban uplands, can reduce riparian groundwater levels (Figures 3 and 4), which can have dramatic effects on soil, plants, and microbial processes. As discussed below, water table level is critical in the control of riparian ecosystem structure and function. It influences soil type, for example the presence of wetland or hydric soils (ie wet, with high levels of organic matter), plant communities (wetland and upland/wetland transition plants) (Gold *et al*. 2001), and the unique fauna (eg salamanders) that depend on the presence of specific soils and plants (Bodie 2001; Groom and Grubb 2002) (317).
- (Gergel et al., 2002) Landscape indicators that quantify the amount of and distance to land converted to human uses often explain variability in water chemistry parameters among catchments. For example, the amount of urban land cover and its distance from the stream were the most important variables in predicting N and P concentrations in stream water (Osborne and Wiley, 1988) (120).
- (Ekness and Randhir 2007) Species richness has been shown to increase as vegetative density increases and with distance from developed areas (1470).
- (Paul and Meyer 2001) High ISC associated with urbanization increases the frequency of bankfull floods, frequently by an order of magnitude or, conversely, increases the volume of the bankfull flood (Leopold 1973, Dunne & Leopold 1978, Arnold et al. 1982, Booth & Jackson 1997). As a result, increased flows begin eroding the channel and a general deepening and widening of the channel (channel incision) occurs to accommodate the increased bankfull discharge (Hammer 1972, Douglas 1974, Roberts 1989, Booth 1990) (339-340).
- (Paul and Meyer 2001) Changes in sediment supply may also alter channel pattern. Increased sediment supply during construction has converted some meandering streams to braided patterns or to straighter, more channelized patterns (Arnold et al. 1982). In the latter case, channelizing leads to increased slope and therefore higher in-stream velocities, especially where artificial channel alteration is carried out to increase the efficiency of the channel in transporting flows (Pizzuto et al. 2000).

  Urbanization can also alter sediment texture. Less fine sediment, increased coarse sand fractions, and decreased gravel classes have been observed in urban channels as a result of alteration of sediment supply and altered velocities (Finkenbine et al. 2000, Pizzuto et al. 2000). In addition to sediment changes, large woody debris is also reduced in urban channels. Catchments in Vancouver, British Columbia with greater than 20% ISC generally have very little large woody debris, a structural element important in both the geomorphology and ecology of Pacific Northwest stream ecosystems (Finkenbine et al. 2000).

  Other geomorphic changes of note in urban channels include erosion around bridges, which are generally more abundant as a result of increased road densities in urban channels (Douglas 1974). Bridges have both upstream and downstream effects, including plunge pools created belowbridge culverts that may serve as barriers to fish movement. Knickpoints are another common feature of urban channels. These readily erodeable points of sudden change in depth are created by channel erosion, dredging, or bridge construction and are transmitted throughout the catchment, causing channel destabilization (Neller 1988). Other features include increased tree collapse, hanging tributary junctions as a result of variable incision rates, and erosion around artificial structures (e.g., utility support pilings) (Roberts 1989).

  Changes in the hydrology and geomorphology of streams likely affect the hydraulic environment of streams, altering, among other things, the velocity profiles and hyporheic/parafluvial dynamics of channels. Such changes would affect many ecological processes, from filter-feeding organisms (Hart&Finelli 1999) to carbon processing and nutrient cycling (Jones & Mulholland 2000) (340-341).

- (Brett et al., 2005) The coefficients obtained for the multiple regression models suggest that paved urban areas generated two to three times more phosphorus than did forested urban areas (336).
- (Novotny et al., 2005) Instead of or in addition to an irreversible dominant surrogate stressor expressed, e.g., by percent imperviousness or percent urbanization, other stressors may be significant and more manageable. Obviously, for nonurban streams landscape features such as percent forested or agricultural area of the watershed (Wang et al., 2000; Van Sickle, 2003), riparian zone conditions and buffers, geology of the watershed and morphology of the stream, ecoregional attributes (Omernik, 1987; Omernik and Gallant, 1989) or hydrologic stressors such as flow variability (Poff and Ward, 1989) are important. The other surrogates of stresses such as agricultural or forest land become important as the dominating effect of urbanization diminishes at low percentages of imperviousness but may have the same drawbacks as using percent imperviousness (189).
- (Palmer et al., 2005) A major problem in urban streams is an increase in peak flows because of runoff from impervious surfaces in the watershed (212).
- (Xian et al. 2007) Impervious surfaces can alter the natural hydrological condition by increasing the volume and rate of surface runoff and decreasing ground water recharge and base flow (Moscrip and Montgomery, 1997). This eventually leads to larger and more frequent local flooding and reduced water supplies for urban and suburban areas (Harbor, 1994). Other direct environmental impacts of increasing impervious surface area (ISA) in watersheds include the degradation of water resources and water quality when surface runoff transports non-point source pollutants from their source areas to receiving lakes and streams (Gove et al., 2001; USEPA, 2001). Pollutants either dissolved or suspended in water or associated with sediment, including nutrients, heavy metals, and oil and grease, can accumulate and wash away from ISAs. Impervious surface also has been considered a key environmental indicator of the health of urban watersheds (Schueler, 1994) and as an indicator of non-point source pollution or polluted runoff (Arnold and Gibbons, 1996; Slonecker et al., 2001) (965).
- (Thurston et al. 2003) Excess storm-water runoff is a serious problem in most urban areas, resulting in negative ecological effects on receiving bodies of water and an increased risk of flooding frequency and magnitude. In fact one source, Schueler (1995), states that runoff from impervious areas can be as much as 16 times as high as that from natural areas. Proliferation of impervious surface allows storm water from rain events to reach a stream faster and in greater volumes than in the absence of such surfaces, causing higher peak flows that can lead to stream degradation (scouring and bank erosion) and habitat alteration. An impervious surface prevents rainfall from infiltrating the soil, causing less water to be available for groundwater recharge and reducing stream base flow, further degrading the aquatic habitat during drier periods. Also, depending on the land use in the watershed, nutrients and toxics can be scrubbed from roadways and parking lots and transported overland and through storm drains into waterways, causing toxic loading of streams (409).
- (Mallin et al. 2000) Percentage impervious surface area has been shown to be important in determining stream water quality as defined by ecological indicators such as benthic macroinvertebrate community composition and fish density and abundance (Klein 1979, May et al. 1997). These indices generally indicated impairment at ~10% impervious surface coverage (Schueler 1994, Arnold and Gibbons 1996) (1053).
- (Wissmar et al. 2004) A major issue facing management agencies is the conversion of vegetative land covers to impervious areas and subsequent impacts on watershed hydrology, aquatic, and riparian ecosystems (National Research Council 1999, Wissmar and Bisson 2003). Watersheds where forests are replaced by impervious surfaces (e.g., roads, parking lots, roof tops) experience changes in hydrologic balances between surface and subsurface waters (King County 1993, May and Horner 2000). Impervious

surfaces can affect the hydrology by increasing surface runoff during storms, altering water retention times in wetlands and lakes, decreasing water infiltration in soils and recharge of groundwaters (Dunne and Leopold 1978, Arnold and Gibbons 1996) (91).

- (Hou et al. 2008) Impervious surfaces have long been implicated in the decline of watershed integrity in urban and urbanizing areas as cites are being covered by more buildings and airproof concrete road surfaces (Klein 1979; Pratt 1999, 2002) (181).
- (Hou et al. 2008) The creation of any large impervious surface commonly leads to multiple impacts on stream systems. These impacts include higher peak stream flows, which cause channel incision, bank erosion and increased sediment transport (Trimble 1997; Konrad et al. 2002; Nelson & Booth 2002). Another impact mentioned above, a reduction of infiltration, lessens groundwater recharge and potentially lowers stream base flows (Klein 1979) (181).
- (Moglen 2009) Schueler (1994) was among the first to identify imperviousness as a simple, easily measured quantity to be used as an index of environmental disturbance. His paper has been broadly cited. His paper identifies threshold ranges of total imperviousness within a watershed associated with different degrees of stream quality: sensitive (1–10% impervious cover), impacted (11–25% impervious cover), and nonsupporting (26% impervious cover) (303)
- (Moglen 2009) Understanding the range and magnitudes of hydrologic impacts of impervious cover continues to be an important focus of researchers and practitioners in the urban storm water community. Glick (this issue) uses 20 years of data to demonstrate statistically significant relationships for runoff quantity with impervious cover, and runoff quality with impervious cover and land use. Homsey et al. (this issue) use data from 19 study watersheds to correlate increased watershed impervious cover with decreased stream baseflows (303).
- (Brabec et al. 2002) Increasing urbanization has resulted in increased amounts of impervious surfaces—roads, parking lots, roof tops, and so on— and a decrease in the amount of forested lands, wetlands, and other forms of open space that absorb and clean stormwater in the natural system (Leopold 1968; Carter 1961). This change in the impervious-pervious surface balance has caused significant changes to both the quality and quantity of the stormwater runoff, leading to degraded stream and watershed systems: an increased quantity of stormwater for stream systems to absorb, sedimentation, and an increased pollutant load carried by the stormwater (Morisawa and LaFlure 1979; Arnold et al. 1982; Bannerman et al. 1993) (499-500).
- (Brabec et al. 2002) Arnold and Gibbons (1996) defined four basic qualities of imperviousness that make it an important indicator of environmental quality: (1) although the impervious surface does not directly generate pollution, a clear link has been made between impervious surface and the hydrologic changes that degrade water quality; (2) an impervious surface is a characteristic of urbanization; (3) an impervious surface prevents natural pollutant processing in the soil by preventing percolation; and (4) impervious surfaces convey pollutants into the waterways, typically through the direct piping of stormwater (501).
- (Brabec et al. 2002) From a planning perspective, the most important numerical quantification of the impact of imperviousness on stream quality is the threshold level at which water quality impacts occur. However, May et al. (1997) state that the "physical, chemical and biological characteristics of streams change with increasing urbanization in a continuous rather than threshold fashion" (p. 491). Booth and Jackson (1997) concur, stating that degradation begins at very low levels of urban development. However, after a certain level of degradation, there may not be much aquatic life that remains to be harmed, even if the increments of measurable destruction become larger in relation to the amount of additional impervious surface (Wang et al. forthcoming) (501).
- (Brabec et al. 2002) Many studies of urban hydrology (Cherkaver 1975; Beard and Chang 1979; Alley et al. 1980; Driver and Troutman 1989) show that total impervious area (TIA), although correlating with changes in runoff, does not affect runoff as much as effective impervious area (EIA), the proportion of imperviousness that is directly

connected to the stream network. The difference between the two lies in the direct connection to the stream system: total imperviousness includes roofs, roads, parking lots, and other noninfiltrating surfaces, whereas effective imperviousness includes only those impervious areas that drain into a piped storm sewer and discharge into a surface-water body. The reason for this distinction in urban runoff is the fact that for EIA, virtually 100 percent of the stormwater will reach the surface-water body. TIA, on the other hand, includes both EIA and "noneffective impervious area" or those impervious surfaces that drain to pervious ground (such as a driveway into a lawn) (Alley and Veenhuis 1983). The noneffective impervious areas will infiltrate all or a portion of the stormwater, depending on soil, slope, and ground cover characteristics (Alley and Veenhuis 1983) (505).

- (Brabec et al. 2002) After watershed imperviousness reached 45 percent in Seattle area watersheds, riparian buffers ceased to effectively protect biological integrity (Horner et al. 1997). Steedman (1988) also found that the amount of riparian cover that can be removed while sustaining biological integrity is inversely proportional to the amount of impervious surface: with 0 percent urbanization, 75 percent of the riparian forest could be removed, and with 55 percent urbanization, 0 percent could be removed. Even complete retention of streamside buffers could not prevent "measurable degradation" after approximately 7 to 10 percent impervious area (Booth and Reinelt 1993). (509-510).