Indicator type: Source of Stressors

Category: Landscape Conditions

Risk level: High

Urban Development

The source of many stressors in the Dry Creek watershed is the changing landscape: the conversion of open space to urban/suburban land uses. One way to measure these changes is by quantifying the amount of impervious cover. Impervious cover refers to hardscape of any type: roads, building, or parking lots. Impervious cover, especially in close proximity to the waterways, is the primary driver of the physical and chemical stressors in the watershed; it is a high risk source of stress.

In the analysis of the source of stressors in the Dry Creek watershed, impervious cover (IC) was measured at six different spatial scalesin order to provide better information to guide potential actions that could reduce the adverse impacts on aquatic life. In this summary, the two scales that were most important are discussed: a) within the 100 foot stream buffer and b) within the sub-watershed.

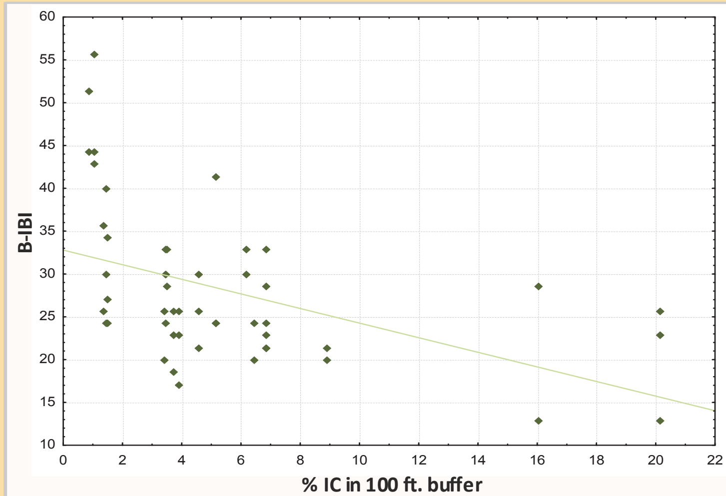


Figure 1. The % IC in the 100 foot buffer. Each data point represents the % IC in the 100 ft. buffer upstream of each of the 10 sampling sites over a 5 year period (2001-2006). It reflects the amount of hardscape within a buffer that extends 100 ft. on either side of the creek (200 feet total). The B-IBI is a multi-metric index that sums scores for 5 key metrics for benthic macroinvertebrates (BMI). Lower scores generally indicate sensitive BMI populations are impaired. Correlation coefficient = - 0.57, level of significance = .000013, sample size = 50. As imperviousness increased, the abundance and di-

I. Impervious cover in the 100 foot stream buffer

Impervious cover in the 100 foot stream buffer refers to all the hardscape contained within 100 feet of the banks on each side of the creek.

What is the graph showing?

Impervious cover was used as the metric for reporting on the impacts of urban development. Since the Dry Creek watershed has undergone significant urbanization during the past 25 years, impervious cover serves as a good measure of the landscape changes associated with this process. The data in Figure 1 suggests that disturbance near the waterways, measured by the percent IC, has had significant negative effects on aquatic life, measured as the benthic index of biotic integrity.

Why is the amount of impervious cover in the creek corridor important?

The creek corridor, or the riparian corridor or buffer, provides a unique environment that protects water quality as well as aquatic and terrestrial habitat. Dead vegetation is washed into the creek and provides food for bacteria, algae, and aquatic animals. Riparian grasses, shrubs, and trees provide shade around the creek and moderate water temperature. Branches of trees and shrubs that fall into the creek provide habitat for aquatic life. Vegetation surrounding the creek stabilizes the banks, preventing erosion, thereby reducing the delivery of fine sediment to creeks. Riparian corridors serve as floodplains, and if protected, allow for the natural meander of creeks as well as facilitate the cycling of nutrients and carbon, essential building blocks of all aquatic life. Taken together, the condition of riparian corridors provides many important services that maintain the health of creeks and the aquatic life they support. In numerous ways, discussed throughout this report, impervious cover and the human activity associated with it, interferes with these natural processes.

II. Impervious cover within the sub-watershed

The amount of impervious cover was not only important within the creek corridor, but also within the sub-watershed. In this analysis, sub-watershed refers to all the land that drains to one of 10 sampling points from which physical, chemical, and biological data was collected.

What is the graph showing?

As sub-watershed imperviousness increased, an important metric of BMI health, the abundance of EPT taxa, a group of pollution-sensitive insects, decreased (Figure 2). The EPT metric represents insects that are sensitive to stream disturbance. Although the relationship of EPT taxa to disturbances at the sub-watershed scale is not as strong as within the 100 foot buffer, the influence of impervious cover is still significant.

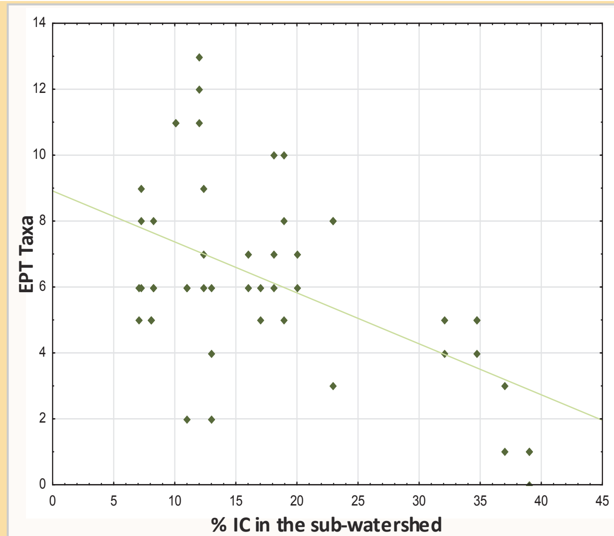


Figure 2. The relationship between % IC in the sub-watersheds and the number of EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa, another metric that reflects the health of benthic aquatic insects. Each data point represents the sub-watershed IC at one of 10 sampling sites. Insect data was collected each year for 5 years. Correlation coefficient = - 0.42, level of significance = 0.003, sample size = 46.

Why is the amount of impervious cover in the sub-watershed important?

As watersheds urbanize, multiple watershed processes are adversely affected, leading to the "urban stream syndrome" (Paul and Meyer, 2001). Impervious cover alters the hydrology within watersheds by preventing rain from percolating into the soil and groundwater as well as preventing coarse sediment from entering waterways. In undisturbed watersheds, rainfall soaks into the ground and helps to recharge the aquifer. In urbanized watersheds, however, the large volumes of stormwater produced by the IC are conveyed away from the land by the storm drain system and released into the closest waterway at a higher velocity and at a quicker rate than would occur naturally (Dunne and Leopold, 1978). This high velocity runoff

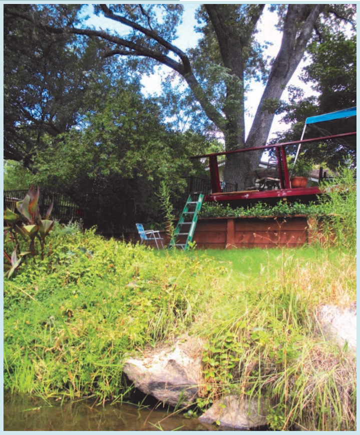


Figure 2. Structures within the stream corridor. Owners of property that backs onto the creeks have built patios, gazebos, and planted grass and invasive plants right up to the edge of the creek.

Figure 3. Removal of bank vegetation. Vegetation is often removed by residences to facilitate access. Similar denuding of the banks have been caused by off highway vehicles.

Figure 4. Impervious cover within the creek corridor. Bridges are one of the primary structures that disturb stream corridors. They physically alter the streambed and cause upstream and downstream erosion.

acts as a pressure washer on the beds and banks of creeks, causing the widening and deepening of the stream and the production of large volumes of fine sediment. The increased erosion causes habitat degradation resulting in harm to aquatic life. For example, both salmonids and benthic insects prefer habitat composed of large gravel and small rocks/cobble. This habitat can be buried by fine sediment eroded from the banks/bed of the stream, adversely affecting the viability of aquatic life. In addition to disturbing habitat, increased impervious cover can have negative impacts on water quality. Stormwater runoff washes nutrients, pesticides, and metals into the creeks. Because impervious cover is known to disrupt the hydrologic cycle, degrade stream habitat, and introduce contaminants, it is a key indicator of human disturbance.

In this watershed, the amount of IC within 100 feet of the edge of the creek was a more important predictor of the abundance and diversity of BMIs than at any other spatial scale examined. Although this may not be the case in other watersheds, it appears to be important in Dry Creek because approximately 45 percent of the watershed remains in semi-rural land uses that do not have a concrete storm drain infrastructure. As a consequence, in many areas of the watershed, precipitation remains where it falls; in fields, pastures, and ditches, and does not reach the streams. The result is that the influence of land use changes away from the creek is diminished while the influence of land use immediately adjacent to the creek takes on more importance. Additional discussion of the impact of IC at different spatial scales can be found in the Technical Considerations section.

What factors influence the amount of impervious cover in the Dry Creek stream corridor?

Within the stream corridor, the primary factor contributing to an increased amount of impervious cover is residential and commercial development. Patios, gazebos, driveways, and paved trails are examples of the types of hardscape seen within the stream corridor. There are additional examples of human disturbance in the riparian corridor that do not contribute to the quantitative measure of IC, but are linked to it. Use of off-highway vehicles

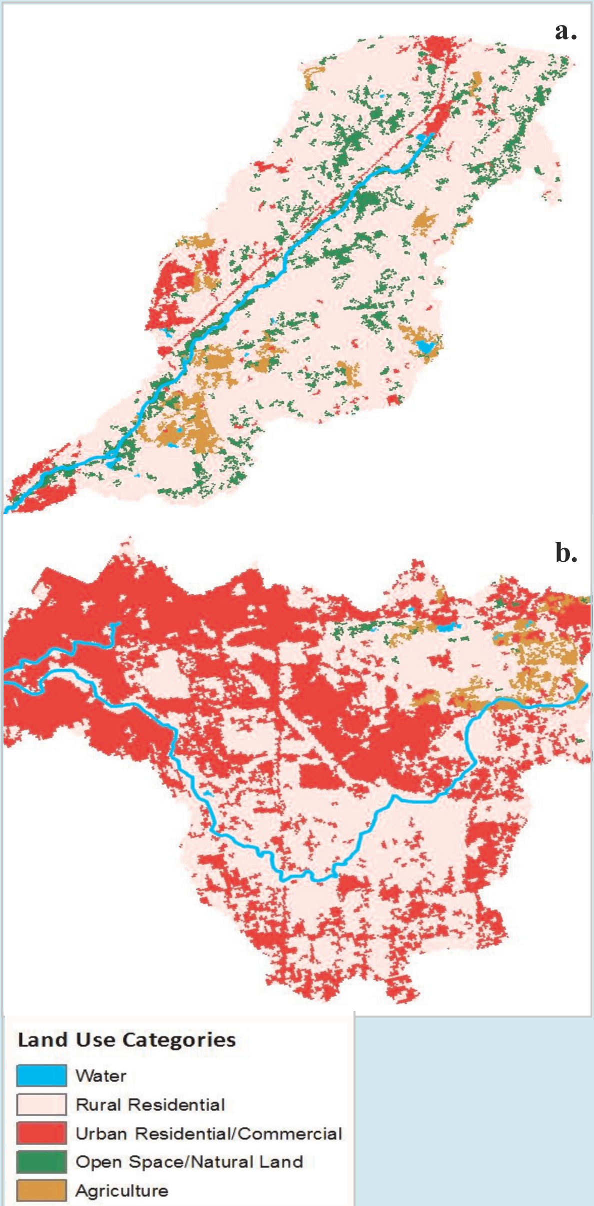
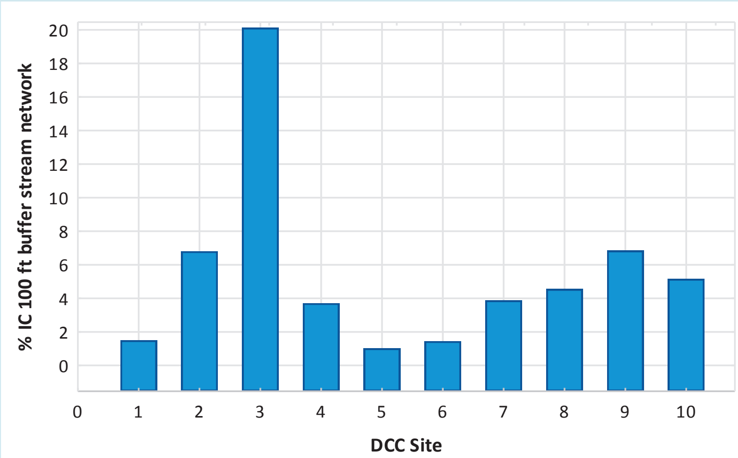


Figure 6. Land use maps of two sub-watersheds within the Dry Creek watershed. The degree of urbanization varies between different sub-watesheds. Upper Secret Ravine (a) is primarily a rural residential sub-watershed. This type of land use is most often characterized by open roadside ditches which do not convey water to the creeks. In contrast, the Linda/Cirby Creek sub-watersheds have a much greater percentage of residential and commercial development. In these areas, storm drains and pipes move water away from structures and into the closest creek. In sub-watershed like Linda/Cirby, the influences of impervious cover on aquatic life are more significant than in those areas such as Upper Secret Ravine.

(OHVs) is evident along the banks of the creeks, although recent efforts to curb their use have been successful in some areas. Backyard landscaping, including turf at the edge of the creek and removal of bankside vegetation to improve access to the water, were also found along Dry Creek streams. All of these alterations interfere with essential ecological functions of the aquatic ecosystem.

Within the sub-watershed**,** the nature of the built environment influences the amount of impervious cover and how it is connected. Development in the Dry Creek watershed is mainly characterized by a style of development that includes wide streets, large driveways and extensive areas of connected impervious cover. Many roof gutters have downspouts plumbed directly into storm drains. In addition, most development and landscaping practices involve grading, which compacts soil, further reducing stormwater infiltration in the remaining green space. All of this reflects historic engineering practices that emphasized stormwater conveyance through a system of channels and pipes designed to move water away from buildings as quickly and efficiently as possible.



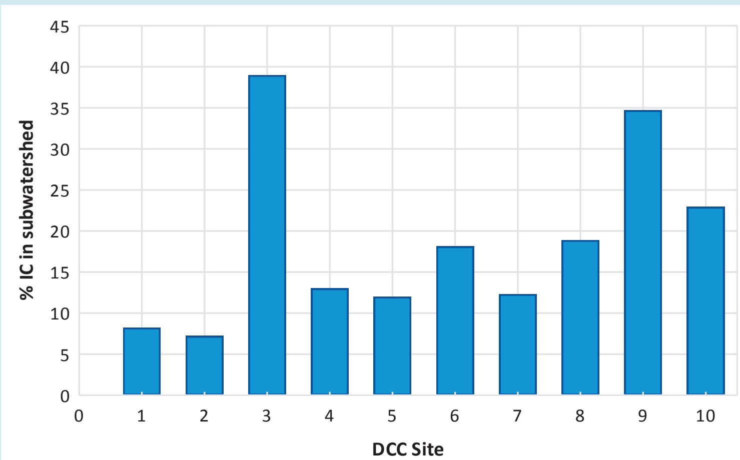


Figure 7. Spatial differences in impervious cover within the 100 foot buffer (upper panel) and within the sub-watershed (lower panel). Each bar represents the % IC, measured in 2006, using GIS analysis. The ten sampling sites that were used to define the sub-watersheds are identified on the x axis. Site 3, in the Cirby/Linda Creeks sub-watershed, had the highest percent of IC regardless of spatial scale. Site 5, Upper Secret Ravine and the comparator site, had the lowest % IC within the 100 foot stream buffer but not within the sub-watershed. The differences in % IC at Sites 5 and 3 is about 20 fold when measured within the 100 foot buffer but only about 3 fold when measured at the sub-watershed scale. These differences help to explain why impervious cover in the stream corridor is such an important source of stress. Details are discussed in the individual indicator chapters of this report.

TECHNICAL CONSIDERATIONS

1. Data Collection

The relationship between urbanization, impervious cover, and degradation of aquatic habitat and life has been well documented (NRC, 2009). The question of the relationship between the location of the hardscape and local waterways however is not as clear. Since this question could have significant implications for watershed management, the percent IC at a variety of spatial scales was evaluated in this assessment. Six different spatial scales were examined in this analysis; two of the most important are discussed in this indicator report.

Impervious area in the sub-watershed

Total impervious area within each sub-watershed was calculated using the impervious surface coefficients (ISC) for California (OEHHA, 2009). Each sub-watershed was delineated using ArcGIS Spatial Analyst. Data on land uses within the sub-watershed were obtained from the generalized land use categories data layer maintained by the Sacramento Area Council of Governments. Each area of the

20 different residential, commercial, and industrial land uses, as well as roads, was multiplied by the appropriate ISC. Some parcels did not conform to the land use identified on the SACOG data layer. Visual inspection was used to recode those parcels to the appropriate land use category and IC calculations were then performed.

Impervious area in 100 foot stream buffer

For each sub-watershed, impervious area within the 100 foot buffer (riparian corridor) throughout the entire stream network was determined by visual identification and digitizing in GIS since the ISCs were not designed to be used at this small of a spatial scale.

2. Summary of Stressor Identification process

The same Stressor Identification approach used to analyze stressors was also applied to the analysis of sources of stress or drivers. After an initial screening, IC in the sub-watershed and IC in the 100 foot buffer within the stream network (area encompassing the sampling site to the top of the stream) were analyzed using the SI methodology. The percent IC within the sampling reach (the drainage area 1.5 km upstream of the sampling site) was also identified as a relevant spatial scale because it was closely linked to BMI metrics; however, this data is not reviewed in this report.

a. Data from the case

Spatial Co-occurrence

The same general pattern of differences in imperviousness among the various sites was evident at the two spatial scales shown in Figure 7. Difference in percent IC between sites within the 100 foot buffer were clearly seen between Site 3 and all other sites. Site 3 had greater than 20% IC in the stream buffer, followed by Sites 2 and 9 at about 7% each. Site 5 had just 1 % IC in the buffer, which was very similar to Sites 1 and 6. At the sub-watershed scale, the differences were greater between Site 5 and Sites 3 and 9. Due to the fact that the differences between sites was not a clear cut at the sub-watershed scale, this data was assessed as neither strengthening nor weakening the case in the Stressor ID analysis. In the final analysis, the data on percent IC within the stream corridor strengthened the case for human activity/disturbance near the creek as a source of impairment of aquatic life.

Stressor response relationships

The stressor response relationships between percent IC in the 100 foot buffer and BMI metrics of diversity and abundance were among the strongest of any of the stressors analyzed. Of the 24 BMI metrics evaluated, 14 had significant relationships with IC at the 100 foot buffer ($p < 0.05$, 10 metrics were significant at the 0.01 level). BMI metrics, such as EPT taxa, B-IBI, and % clingers, which reflect intolerance to disturbance, were all negatively correlated with percent IC in the 100 foot buffer. The number and strength of these relationships strengthened the case for percent IC in the 100 foot buffer, the metric for strongly influencing aquatic life, at both the stream network and reach scales.

Stressor response relationships at the sub-watershed scale were less significant. Since large portions of the watershed are semi-rural with little connected impervious cover, it is likely that this condition is responsible for the relatively weak relationship.

Numerous reports and studies (NRC, 2009, Alberti et al., 2007; Roy et al., 2003) have described the adverse effect of urban land cover and its surrogate, impervious cover, on the health of aquatic life. Data from the Dry Creek watershed is consistent with these findings. About 55 percent of the watershed by area has drainage infrastructure associated with connected IC. In areas with less drainage infrastructure, such as rural residential areas with roadside ditches, the percent IC measured at small spatial scales were more highly correlated with BMI metrics than the entire percent IC at the sub-watershed scale. This condition helps to explain the weaker evidence for a stressor-response relationship at the sub-watershed scale.

An example of the type of relationships commonly seen at spatial scales more proximate to the creek is shown in Figure 8. The three BMI metrics chosen (percent scrapers, percent EPT, B-IBI) represent different measures of BMI health (a functional feeding group, a group of sensitive species, and a composite metric respectively). In all three cases, as the percent IC in the stream buffer increased, the condition of BMI health declined.

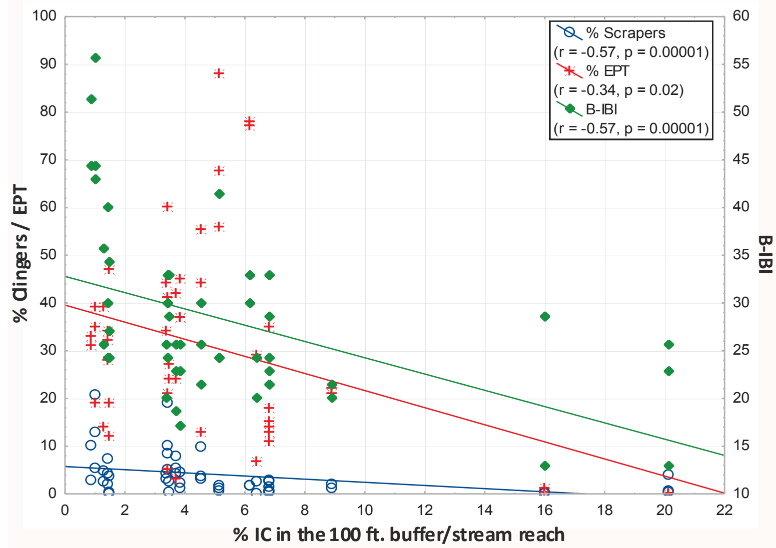


Figure 8. Relationships between BMI metrics and % IC in the 100 ft. buffer/stream network. The Y-axis on the left shows % scrapers and % EPT, while the Y-axis to the right shows the B-IBI score. Strength of correlation and level of significance are shown in the legend.

Casual Pathway

There were strong lines of evidence that supported a complete causal pathway linking impervious cover to changes in aquatic habitat and impairment of aquatic life (Figure 9). The strongest physical habitat relationship was found between percent IC in the 100 foot buffer and velocity/depth regime, a measure of flow diversity. The strongest water quality relationship was between percent IC in the 100 foot buffer and orthophosphate, a nutrient that contributes to eutrophication. Impervious cover was significantly correlated with multiple physical habitat metrics, including in-stream cover, bank stability, and percent of silt, sand and fine gravel. Other water quality metrics that showed highly significant relationships with impervious cover included temperature and specific conductance. This data provides strong evidence that impervious cover, a

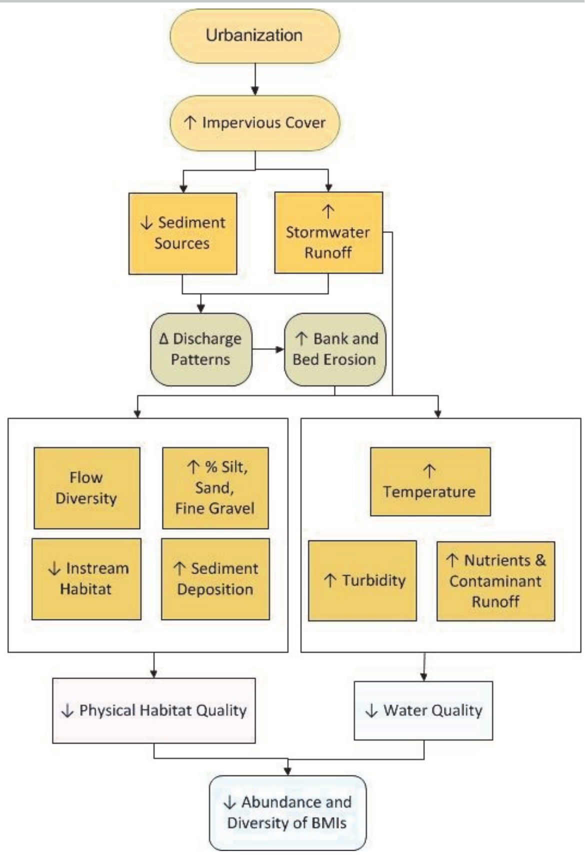


Figure 9. Causal pathway linking impervious cover to water quality and physical habitat, and ultimately, to the abundance and diversity of BMIs.

proxy for urban development, is the primary source of aquatic life impairment in this watershed.

b. Data from elsewhere

Research over the past 15 years has clearly established a relationship between land use and BMI metrics. However, studies vary regarding the importance imperviousness at various spatial scales has on the aquatic community. Morse et al. (2000) found that taxa richness declined as total impervious area within the subwatershed increased. Areas with the highest proportion of urban land cover were mainly populated with tolerant species such as *Diptera*. Further, habitat quality as measured by bank erosion and channel instability also decreased with increased total imperviousness. In a study of an urban watershed with 13% urban land use in Australia, Walsh et al. (2007) also found that total impervious area in the entire watershed was a better predictor of the health of aquatic life than canopy cover within a 300 foot stream buffer. In another study that included watersheds with up to 37% urban land uses, Walters et al. (2009) found that the ppercent IC at the watershed scale, not within the stream corridor, had the strongest relationship with BMI metrics. For comparison, the average percent IC in the sub-watershed in Dry Creek is 18 %. However, other studies found that IC in close proximity to the creek had a greater influence on aquatic life than IC found at greater distances from the waterway. In a study in Wisconsin, Wang et al. (2001) found that connected IC within 100 meters (328 feet) of the waterway had the greatest influence on fish community health. The relationships between IC and fish indices and BMI health were strongest up to 3.2 km (approximately 2 miles) upstream of the sampling site. Lastly, Roy et al. (2003) found that natural land cover within the 100 meter buffer were most strongly related to various metrics of BMI health, compared to conditions within the entire sub-watershed. These few studies reflect the findings of a large body of literature: urban land use or imperviousness adversely affect aquatic life, but the spatial scale which is most important is not consistent and clear.

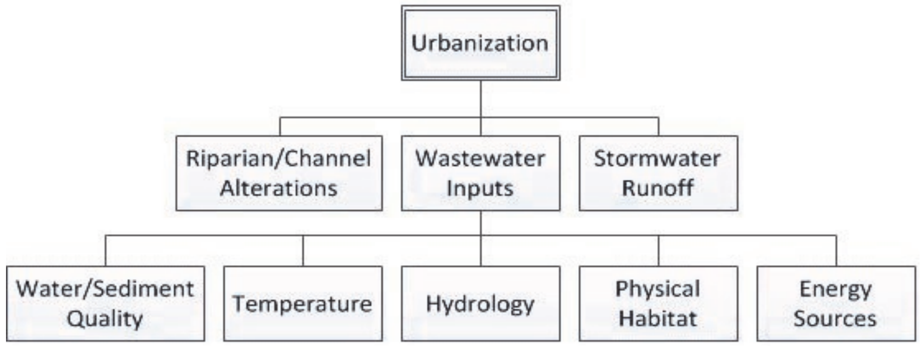
Numerous variables could influence the relationship between land use and disturbance and the abundance/diversity of BMIs. One such variable in the Dry Creek watershed is the mixture of suburban/urban areas in the lower portions and semi-rural areas in the upper portions of the watershed. In the urbanized areas, the storm drain system connects the landscape regardless of distance from the creeks. In contrast, in the upper areas of the watershed, the stormwater infrastructure consists of roadside ditches that do not convey runoff to the creeks. If connected storm drain systems ran throughout the Dry Creek watershed, it is possible that the IC in the watershed scale would be more closely linked to BMI metrics.

In summary, while urban land use significantly impairs BMI diversity and abundance, there was conflicting information in the scientific literature on the impacts of IC at different spatial scales in urban/urbanizing watersheds. As a result, data from other studies neither strongly supported nor refuted percent IC at any one spatial scale was the key source of the impaired aquatic life.

3. Strengths and Limitations of Data

Data on IC was among the most quantitative of all data used in the Dry Creek watershed assessment. Impervious cover was calculated either by identifying land uses in a geographic information system and applying impervious surface coefficients to calculate total impervious area or by digitizing hardscape for the calculation of IC in the 100 foot buffer. This method of measuring IC produced reliable data useful for a variety of analyses. By analyzing disturbance at various spatial scales, key relationships to conditions of the aquatic ecosystem were identified which could lead to focusing on preventative and restorative efforts.

Supplemental Information: *CADDIS urbanization conceptual model*



The US EPA has developed a module on the impacts of urbanization on the aquatic ecosystem. This module provides a wealth of information on the urban stressors and their effects (see conceptual model above). This module, as well as others, is posted at: http://www.epa.gov/caddis/ssr_home.html.

References

Alberti, M., Booth, D., Hill, K. , Coburn, B. , Avolio, C., Coe, S. and D. Spirandelli (2007). The Impact of Urban Patterns on Aquatic Ecosystems: An Empirical Analysis in Puget Lowland Sub-basins. Landscape Urban Plan 80(4): 345-361.

CADDIS. www.epa.gov/caddis.

Dunne T, Leopold LB. 1978. *Water in Environmental Planning.* New York: Freeman. 818 pp.

Harding, J. S., P. V. Bolstad, G.S. Helfman, E.B.D. Jones III (1998). Stream Biodiversity: Ghost of land use past. PNAS 95: 14843 - 14847.

Impervious Surface Coefficients for California, 2009. Posted at: http://oehha.ca.gov/ecotox/iscug123110.html.

McBride, M., Booth, Derek B. (2005). Urban Impacts on Physical Stream Condition: Effects of Spatial Scale, Connectivity, and Longitudinal Trends. JAWRA 41(3): 565-580.

Morse, C. C., A. D. Huryn, and C. Cronan (2003). Impervious Surface Area as a Predictor of the Effects of Urbanization on Stream Insect Communities in Maine, USA. Environ Monit Assmt 89: 95-127.

National Research Council. 2009. Urban Stormwater Management in the United States. Washington, DC: The National Academies Press.

Ode, P. R., A. C. Rehn, J.T. May (2005). A Quantitative Tool for Assessing the Integrity of Southern Coastal California Streams. Environmental Management 35(4): 493 - 504.

Paul, M. J. and J. L. Meyer (2001). Streams in the Urban Landscape. Annual Review of Ecology and Systematics **32**: 333 - 365.

Roy, A. H., A. D. Rosemond, et al. (2003). Stream macroinvertebrate response to catchment urbanisation (Georgia, U.S.A.). Freshwater Biology 48: 329 - 346.

S.V. Fend, J. L. C., and F.R. Kearns (2005). Relationships of field habitat measurements, visual habitat indices, and land cover to benthic macroinvertebrates in urbanized streams of the Santa Clara Valley, California. Am Fish Soc Symposium 47: 193-212.

Schiff, R. E. A. (2007). Effects of Impervious Cover at Multiple Spatial Scales on Coastal Watershed Streams. JAWRA 43(3): 18.

Shaw-Allen, P., Suter, G.W. II, Cormier, S.M., Yuan, L.L. Basic Analysis: Quantile Regression Causal Analysis Diagnosis Decision Information System. Volume 4: Data Analysis. Environmental Protection Agency. http://www.epa.gov/caddis/da_basic_3.html

Walsh, C. J., K. A. Waller, J. Gehling, and R. MacNally. (2007). Riverine invertebrate assemblages are degraded more by catchement urbanisation than by riparian deforestation. Fresh Biol. 52: 574-587.

Walters, D. M., A.H. Roy, & D.S. Leigh (2009). Environmental indicators of macroinvertebrate and fish assemblage integrity. Ecol Indic 9: 1222-1233.

Wang, L. E. (2001). Impacts of urbanization on stream habitat and fish across multiple spatial scales. Environ Managmt 28(2): 11.

Wright, I. A., P. J. Davies, et al. (2011). A new type of water pollution: concrete drainage infrastructure and geochemical contamination of urban waters Mar Fresh Res (62): 7.