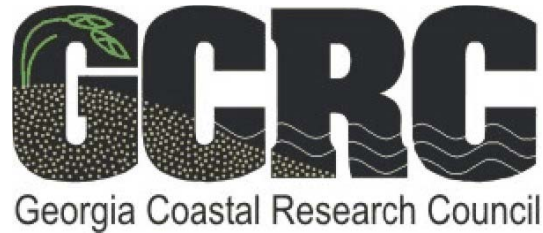


Impervious Surfaces: Review of Recent Literature

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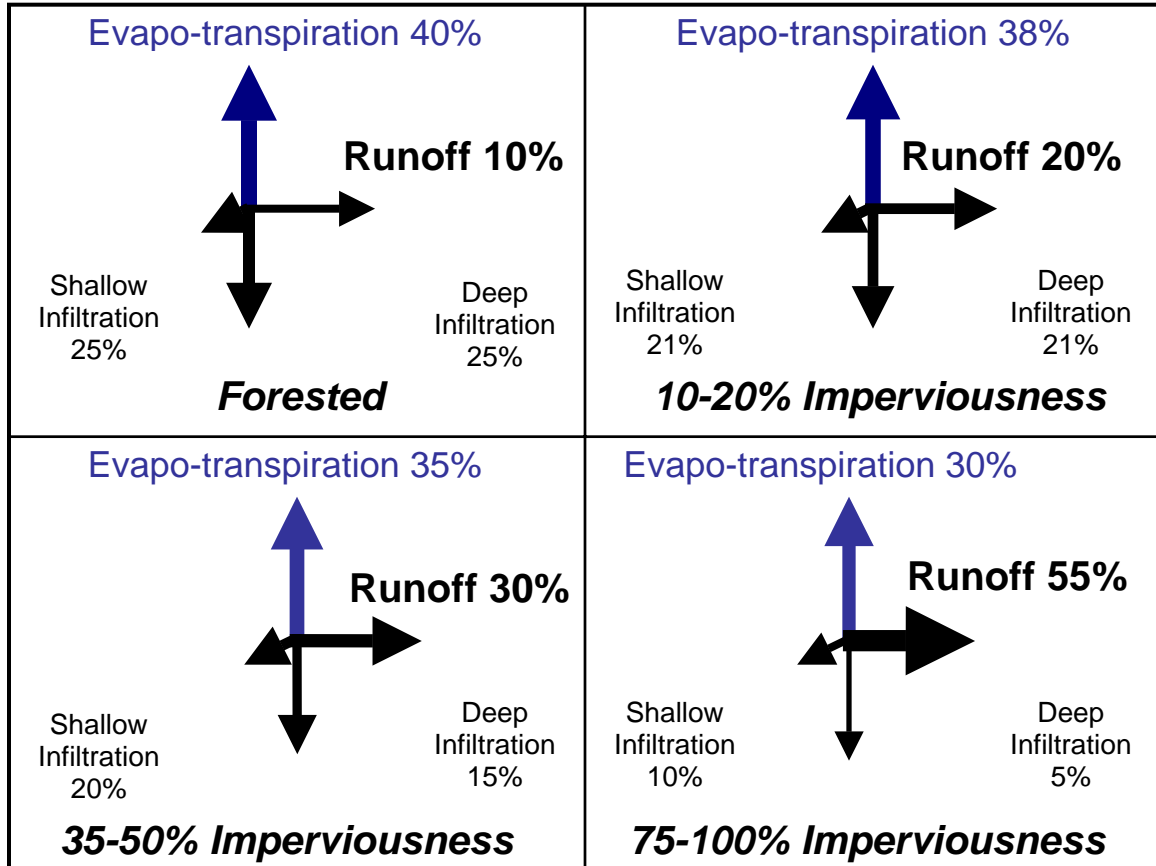


Introduction

Urbanization and the introduction of impervious surface cover are becoming an increasingly important issue for Georgia coastal communities. The South Atlantic region has exhibited the largest rate of population growth in the country with a 58% increase between 1980 and 2003 (NOAA 2004). The U.S. Census Bureau (2000) projects that by 2025, 11 million additional people will live in the Carolinas and Georgia. Between 1992 and 1997 Georgia had the largest increase from undeveloped land to developed land in the Southeast with a 27.4% change towards urbanization (USDA, 2000). As more people move to the coast, areas that were undeveloped are quickly being altered into urbanized land. Urban growth, both inland and at the coastal zone, puts many stresses on the physical, chemical, and biological resources of the environment. One of the most obvious results of development is the introduction of impervious surface.

Impervious surface consists of manmade coverings of the natural landscape where water cannot soak through, and includes any hard surface like roof tops, asphalt, or concrete. Any increase in impervious surface has a direct effect on water storage and movement in the system. Figure 1 details the changes in the hydrologic system that occur as the amount of impervious surface increases. In an undeveloped or forested system, runoff composes only 10% of the hydrologic flow with the rest of the water either lost to evaporation or infiltrating into the ground. However, as the amount of impervious surface increases to 35-50%, runoff increases to 30% and far less water is stored via infiltration. Runoff presents a particularly important problem to sensitive tidal creeks and estuarine systems: it frequently contains high concentrations of nutrients such as nitrogen and phosphorus, as well as pollutants such as polycyclic aromatic hydrocarbons (PAHs) and fecal coliform, which can cause harm to freshwater and marine organisms (Schiff, 2002; Lee, 2005, Mallin, 2006).

Figure 1: Effect of impervious surface cover on hydrologic flows (Paul and Meyer, 2001). Evapo-transpiration is water that evaporates back into the atmosphere; infiltration (whether shallow or deep) is water that percolates through the soil and becomes groundwater; runoff is water that flows over land, directly into surface water.



Current Research

Since the late 1970's, scientists have been attempting to quantify the biological and chemical effects of increases in impervious surfaces on the natural environment. Initial research focused on the impact of urbanization on freshwater streams: Klein (1979), for example, found a decline in species diversity when impervious surface covered more than 12% of the system. Similar studies have followed. Table 1 provides a summary of the most recent papers and the percentages of impervious area that accompanied changes in stream conditions.

One study of particular interest focused on the Etowah River basin in Georgia. Roy et al. (2003) researched the relationship between stream organisms and the amount of urbanization in the stream catchment area. The researchers also recorded water quality parameters such as total suspended solids, nutrients (nitrogen and phosphorus), dissolved oxygen, and total chlorophyll. Greater species diversity was found when stream water quality was good and reduced water quality was observed when the amount of urban land cover was >15%.

Table 1: Ecosystem Health and the Relationship to Impervious Surface

Location	Stream Condition Marker	% Impervious Area where marked change occurred	Reference
Delaware	Decline in species diversity	8-15%	Paul and Meyer, 2001
Georgia	Decline in species diversity	15%	Roy et al., 2003
North Carolina	Water quality (fecal coliform)	>10%	Mallin et al., 2000
South Carolina	Physical, chemical, and biological indicators	10-20%	Holland et al., 2004
Washington	Loss of aquatic system function	10%	Booth and Jackson, 1997
Wisconsin	Decline in species diversity	8-12%	Stepenuck et al., 2002 Wang et al., 2000

There has been less research on the effect of impervious surface in coastal areas as compared to inland sites. However, there have been several recent studies of this type for the Carolina coasts (which share physical and biological attributes with the Georgia coast). Mallin et al. (2000) studied five watersheds in North Carolina with varying amounts of urbanization. The project focused on fecal coliform as an indicator of water quality since high fecal coliform concentrations are frequently cited when beaches and shellfish areas are closed. The study found that fecal coliform abundance was significantly correlated with watershed population (i.e. as population increased, fecal coliform abundance increased), particularly when impervious cover was greater than 10% (Mallin et al., 2000). The relationship between impervious surface and fecal coliform concentration was even more striking, and suggests that impervious surface is a very good predictor of fecal coliform (Mallin, 2006).

Holland et al. (2004) also sought to study the relationship of watershed urbanization and tidal creek health. This work focused on twenty-three tidal creeks in South Carolina that represented different levels of urbanization. They found that creeks with higher levels of impervious cover had measurable physical, chemical, and biological impairments compared with undeveloped areas. High impervious surface correlated with high sediment contamination, coarser sediments, high fecal coliform levels, and different organisms. Changes occurred in both the physical and chemical characteristics of the creeks when impervious cover exceeded 10-20%. Detrimental biological changes occurred when impervious cover exceeded 20-30%.

There is also a small body of research on the effects of stormwater runoff on marine systems. Schiff et al. (2002) exposed sea urchins to stormwater diluted with various concentrations of seawater. At concentrations of 6-12% stormwater, sea urchins exhibited a reduction in egg fertilization. The stormwater was analyzed for several chemical constituents, including nutrients and trace metals. The researchers suggested that trace metals were responsible for the reproduction changes observed.

In two separate studies (one in SC and one in GA), Lee (2005; Lee et al., 2004) tested the effect that PAHs originating from stormwater runoff might have on grass shrimp. In both cases, he found that exposure to PAHs increased breakage in DNA and

reduced embryonic development. For the Georgia study, Lee studied PAHs and other chemical pollutants originating from runoff and retention ponds located in Chatham, Glynn and McIntosh counties near several Georgia estuaries. Along with PAHs, Lee also reported elevated concentrations in the retention ponds of metals and pesticides while estuarine sediments had higher concentrations of copper, chromium, lead, zinc and nickel.

Conclusions

The studies described here demonstrate that increases in impervious surface and concomitant surface runoff routinely lead to impairments in water quality and biological communities in both freshwater and estuarine systems (see also Paul and Meyer, 2001). Although the results vary from study to study, most studies find that detrimental effects are observable when the amount of impervious surface increases past 10-15%, with biological changes frequently observed above 15% (Mallin et al., 2000; Roy et al., 2003; Holland et al., 2004). Booth and Jackson (1997) and Booth et al. (2002) suggest that changes that occur due to increases in impervious surface through watersheds are irreversible. Paul and Meyer (2001) argue that if stream restoration is possible, it will require scientists and planners to reintroduce or stabilize the physical, chemical, and biological systems of the impaired systems.

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- Booth, D.B. and C.R. Jackson (1997) Urbanization of aquatic systems – degradation thresholds, stormwater detention, and the limits of mitigation. *Journal of the American Water Resources Association* 22 (5): 1-20.
- Booth, D.B., D. Hartley, and R. Jackson (2002) Forest Cover, Impervious-Surface Area, and the Mitigation of Stormwater Impacts. *Journal of the American Water Resources Association* 38: 835-845.
- Holland, A.F., D.M. Sanger, C.P. Gawle, S.B. Lerberg, M.S. Santiago, G.H.M. Riekerk, L.E. Zimmerman, and G.I. Scott (2004) Linkages between tidal creek ecosystems and the landscape and demographic attributes of their watersheds. *Journal of Experimental Marine Biology and Ecology* 298: 151-178.
- Klein, R.D. (1979) Urbanization and stream water quality impairment. *Water Resources Bulletin* 15: 948-963.
- Lee, R.F., K.A. Maruya, and K. Bulski (2004) Exposure of grass shrimp to sediments receiving highway runoff: Effects on reproduction and DNA. *Marine Environmental Research* 58: 713-717.

Lee, R.F. (2005) Final Report for Cycle V Coastal Incentive Grant “Genotoxicants in Retention Ponds and Adjacent Estuaries in Urban/Suburban Sites in Coastal Georgia”. Skidaway Institute of Oceanography, 10 pages.

Mallin, M.A., K.E. Williams, E.C. Esham, and R.P. Lowe (2000) Effect of Human Development on Bacteriological Water Quality in Coastal Watersheds. *Ecological Applications* 10(4): 1047-1056.

Mallin, M.A. (2006) Wading in Waste. *Scientific American* June 2006 issue: 50-59.

National Oceanic and Atmospheric Administration (NOAA) (2004) Population Trends along the Coastal United States, 1980-2008, by Crossett, K.N., T.J. Culliton, P.C. Wiley and T.R. Goodspeed. NOAA National Ocean Service Special Projects Office. Silver Spring, MD, 47pages.

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, M.J. Paul, D.S. Leigh, and J.B. Wallace (2003) Stream macroinvertebrate response to catchment urbanisation (Georgia, U.S.A.). *Freshwater Biology* 48: 329-346.

Schiff, K., S. Bay, and C. Stransky (2002) Characterization of stormwater toxicants from an urban watershed to freshwater and marine organisms. *Urban Water* 4: 215-227.

Stepenuck, K.F., R.L. Crunkilton, L.Z. Wang (2002) Impacts of urban land use on macroinvertebrate communities in southeastern Wisconsin streams. *Journal of the American Water Resources Association* 37: 1475-1487.

U.S. Department of Agriculture (2000) Summary Report: 1997 National Resources Inventory (revised December 2000), Natural Resources Conservation Service, Washington, D.C. and Statistical Laboratory, Iowa State University, Ames, Iowa, 89 pages.

U.S. Department of Commerce – Census Bureau (2005) Cumulative Estimates of Population Change for the United States and States, and for Puerto Rico and State Rankings: April 1, 2000 to July 1, 2005 (NST-EST2005-02) data provided by the Census Bureau webpage (<http://www.census.gov/popest/states/NST-pop-chg.html>) and accessed 2/17/05.

Wang, L., J. Lyons, P. Kanehl, R. Bannerman, E. Emmons (2000) Watershed urbanization and changes in fish communities in southeastern Wisconsin streams. *Journal of the American Water Resources Association* 26: 1173-1189.

Annotated Bibliography

Booth, D.B. and C.R. Jackson (1997) Urbanization of Aquatic Systems – Degradation Thresholds, Stormwater Detention, and the Limits of Mitigation. *Journal of the American Water Resources Association* 22(5): 1-20.

Abstract: Urbanization of a watershed degrades both the form and the function of the downstream aquatic system, causing changes that can occur rapidly and are very difficult to avoid or correct. A variety of physical data from lowland streams in western Washington display the onset of readily observable aquatic-system degradation at a remarkably consistent level of development, typically about ten percent effective impervious area in a watershed. Even lower levels of urban development cause significant degradation in sensitive water bodies and a reduced, but less well quantified, level of function throughout the system as a whole. Unfortunately, established methods of mitigating the downstream impacts of urban development may have only limited effectiveness. Using continuous hydrologic modeling we have evaluated detention ponds designed by conventional event methodologies, and our findings demonstrate serious deficiencies in actual pond performance when compared to their design goals. Even with best efforts at mitigation, the sheer magnitude of development activities falling below a level of regulatory concern suggest that increased resource loss will invariably accompany development of a watershed. Without a better understanding of the critical processes that lead to degradation, some downstream aquatic-system damage is probably inevitable without limiting the extent of watershed development itself.

Booth, D.B., D. Hartley, and R. Jackson (2002) Forest Cover, Impervious-Surface Area, and the Mitigation of Stormwater Impacts. *Journal of the American Water Resources Association* 38: 835-845.

Abstract: For twenty years, King County, Washington, has implemented progressively more demanding structural and non-structural strategies in an attempt to protect aquatic resources and declining salmon populations from the cumulative effects of urbanization. This history holds lessons for planners, engineers, and resource managers throughout other urbanizing regions. Detention ponds, even with increasingly restrictive designs, have still proven inadequate to prevent channel erosion. Costly structural retrofits of urbanized watersheds can mitigate certain problems, such as flooding or erosion, but cannot restore the predevelopment flow regime or habitat conditions. Widespread conversion of forest to pasture or grass in rural areas, generally unregulated by most jurisdictions, degrades aquatic systems even when watershed imperviousness remains low. Preservation of aquatic resources in developing areas will require integrated mitigation, which must include impervious-surface limits, forest-retention policies, stormwater detention, riparian-buffer maintenance, and protection of wetlands and unstable slopes. New management goals are needed for those watersheds whose existing development precludes significant ecosystem recovery; the same goals cannot be achieved in both developed and undeveloped watersheds.

Holland, A.F., D.M. Sanger, C.P. Gawle, S.B. Lerberg, M.S. Santiago, G.H.M. Riekerk, L.E. Zimmerman, and G.I. Scott (2004) Linkages Between Tidal Creek Ecosystems and the Landscape and Demographic Attributes of their Watersheds. *Journal of Experimental Marine Biology and Ecology* 298: 151-178.

Abstract: Twenty-three headwater tidal creeks draining watersheds representative of forested, suburban, urban, and industrial land cover were sampled along the South Carolina coast from 1994 to 2002 to: (1) evaluate the degree to which impervious land cover is an integrative watershed-scale indicator of stress; (2) synthesize and integrate the available data on linkages between land cover and tidal creek environmental quality into a conceptual model of the responses of tidal creeks to human development; and (3) use the model to develop recommendations for conserving and restoring tidal creek ecosystems. The following parameters were evaluated: human population density, land use, impervious cover, creek physical characteristics, water quality, sediment chemical contamination and grain size characteristics, benthic chlorophyll a levels, porewater ammonia concentration, fecal coliform concentration, and macrobenthic and nekton population and community characteristics. The conceptual model was developed and used to identify the linkages among watershed-scale stressors, physical and chemical exposures, and biological responses of tidal creeks to human development at the watershed scale. This model provides a visual representation of the manner in which human population growth is linked to changes in the physiochemical environment and ultimately the nursery habitat function of tidal creeks and the safety of seafood harvested from headwater tidal creeks. The ultimate stressor on the tidal creek ecosystem is the human population density in the watershed and associated increases in the amount of impervious land cover. Measurable adverse changes in the physical and chemical environment were observed when the impervious cover exceeded 10-20% including altered hydrography, changes in salinity variance, altered sediment characteristics, increased chemical contaminants, and increased fecal coliform loadings. Living resources responded when impervious cover exceeded 20-30%. The impacts on the living resources included reduced abundance of stress-sensitive macrobenthic taxa, reduced abundance of commercially and

recreationally important shrimp, and altered food webs. Headwater tidal creeks appear to provide early warning of ensuing harm to larger tidal creeks, tidal rivers and estuaries, and the amount of impervious cover in a watershed appears to be an integrative measure of the adverse human alterations of the landscape. Through education and community involvement, a conservation ethic may be fostered that encourages the permanent protection of lands for the services they provide.

Klein, R.D. (1979) Urbanization and Stream Water Quality Impairment. *Water Resources Bulletin* 15: 948-963.

Abstract: A study was conducted in the Piedmont province of Maryland to determine if a relationship exists between stream quality and the extent of watershed urbanization. During the first phase of the study, 27 small watersheds, having similar characteristics but varied according to land use, were investigated. Using these controlled conditions and eliminating as many interferences as possible, this first phase was intended to determine if a definite relationship did exist between the two factors. Finding that the first phase was successful, the second was initiated which consisted of a comparison of biological sampling data, from other studies, with degree of watershed urbanization. The purpose of this second phase was to ascertain if the relationship between degrees of urbanization and decline in stream quality was linear as watershed area increased and in streams spread throughout the Maryland Piedmont. The principal finding of this study was that stream quality impairment is first evidenced when watershed imperviousness reaches 12%, but impairment does not become severe until imperviousness reaches 30%.

Lee, R.F., K.A. Maruya, and K. Bulski (2004) Exposure of Grass Shrimp to Sediments Receiving Highway Runoff: Effects on Reproduction and DNA. *Marine Environmental Research* 58: 713-717.

Abstract: A grass shrimp bioassay was carried out on sediments from three estuarine stations which were different distances from a highway storm drain. Total polycyclic aromatic hydrocarbon (PAH) concentrations were 29, 1.5 and 0.1 microg/g sediment at stations A (next to drain), B (100 m from drain) and C (500 m from drain), respectively. Lower embryo production and embryo hatching rates and a higher level of DNA strand breaks (comet assay) were observed in grass shrimp exposed to stations A and B sediments. There appeared to be an association between reproduction abnormalities and increased DNA strand breaks as a result of grass shrimp exposure to estuarine sediments receiving highway runoff.

Lee, R.F. (2005) Final Report for Cycle V Coastal Incentive Grant "Genotoxicants in Retention Ponds and Adjacent Estuaries in Urban/Suburban Sites in Coastal Georgia". Skidaway Institute of Oceanography, 10 pages.

Summary: The focus of our Coastal Incentive Grant project has been on pollutants, including pesticides, polycyclic aromatic hydrocarbons (PAHs) and metals entering Georgia estuaries via runoff from gardens, golf courses and roads. It is often assumed that retention ponds/basins can prevent the entrance of such pollutant release into the environment. The use of retention ponds/basins is one of the Best Management Practices (BMPs) suggested by EPA to control runoff from new residential and commercial developments. The present study reports the results of studies on retention ponds and adjacent estuaries in several coastal Georgia counties. Analytical studies (pesticides, PAHs, and metals) and toxicity of sediments using a grass shrimp bioassay were carried out.

Mallin, M.A., K.E. Williams, E.C. Esham, and R.P. Lowe (2000) Effect of Human Development on Bacteriological Water Quality in Coastal Watersheds. *Ecological Applications* 10(4): 1047-1056

Abstract: Human development along the land-seawater interface is considered to have significant environmental consequences. Development can also pose an increased human health risk. In a rapidly developing coastal region we investigated this phenomenon throughout a series of five estuarine watersheds, each of which differed in both the amount and type of anthropogenic development. Over a four-year period we analyzed the abundance and distribution of the enteric pathogen indicator microbes, fecal coliform bacteria and *Escherichia coli*. We also examined how these indicator microbes were related to physical and chemical water quality parameters and to demographic and land use factors throughout this system of coastal creeks. Within all creeks, there was a spatial pattern of decreasing enteric bacteria away from upstream areas, and both fecal coliform and *E. coli* abundance were inversely correlated with salinity. Turbidity was positively correlated with enteric bacterial abundance. Enteric bacterial abundance was strongly correlated with nitrate and weakly correlated with orthophosphate concentrations. Neither fecal coliforms nor *E. coli* displayed consistent temporal abundance patterns. Regardless of salinity, average estuarine fecal coliform abundance differed greatly among the five systems. An analysis of demographic and land use factors demonstrated that fecal coliform abundance was significantly correlated with watershed population, and even more strongly correlated with the percentage of developed land within the watershed. However, the most important anthropogenic factor associated with fecal coliform abundance was percentage watershed-impervious surface coverage, which consists of roofs, roads, driveways, sidewalks, and parking lots. These surfaces serve to

concentrate and convey storm-water-borne pollutants to downstream receiving waters. Linear regression analysis indicated that percentage watershed-impervious surface area alone could explain 95% of the variability in average estuarine fecal coliform abundance. Thus, in urbanizing coastal areas waterborne health risks can likely be reduced by environmentally sound land use planning and development that minimizes the use of impervious surface area, while maximizing the passive water treatment function of natural and constructed wetlands, grassy swales, and other "green" areas. The watershed approach used in our study demonstrates that the land-water interface is not restricted to obvious shoreline areas, but is influenced by and connected with landscape factors throughout the watershed.

Mallin, M.A. (2006) Wading in Waste. *Scientific American* June 2006 issue: 50-59.

Summary: America's stunning, sinuous coastlines have long exerted an almost mystical pull on the imaginations of the country's citizens. The irresistible attraction is perhaps best described by Herman Melville in the opening pages of *Moby Dick*: "Nothing will content them but the extremest limit of the land.... They must get just as nigh the water as they possibly can without falling in." In recent years, millions of Americans have moved to coastal areas, particularly in the Southeast, to take advantage of their balmy climate, recreational opportunities and natural beauty. Unfortunately, rapid and poorly planned development is spoiling this beauty in a shocking way: a growing number of beaches and shellfish beds along the coast have been contaminated by disease-causing microorganisms coming from animal and human wastes. According to a recent report by the Natural Resources Defense Council, in 2004 coastal states ordered 19,950 days of closures and pollution advisories affecting 1,234 ocean and freshwater beaches, or about one third of all the beaches regularly monitored by health officials. The total number of beach days covered by the regulatory actions was 9 percent higher than the total for 2003 (which, in turn, was 50 percent higher than the 2002 total, although that jump was partly caused by changes in federal monitoring rules). The reason for 85 percent of the closures and advisories was the detection of excessive counts of fecal bacteria in the beach waters.

National Oceanic and Atmospheric Administration (NOAA) (2004) Population Trends along the Coastal United States, 1980-2008, by Crossett, K.N., T.J. Culliton, P.C. Wiley and T.R. Goodspeed. NOAA National Ocean Service Special Projects Office. Silver Spring, MD, 47pages.

Summary: Although population increase and coastal development give rise to numerous economic benefits, they also may result in the loss of critical habitat, green space, and biodiversity. Public policymakers and coastal managers are confronted with the daily task of finding a balance between benefiting from economic growth while mitigating the effects of this growth on coastal environments. This task is becoming ever more challenging as the coastal population continues to grow in a limited space. Population estimates and projections should be used cautiously as uncertainty and limitations are inherent to the data. However, these data provide critical information for coastal decision makers about recent and projected demographic trends along the coast. Characteristics such as age and income data provide information about who is living on the coast and why. Planning for and managing increased demands on infrastructure and resources are becoming increasingly complex and require analyses of demographic data. As the coastal population continues to grow (at the same rate as the rest of the nation), attention is brought to the methods by which the coastal environment is managed and studied. A change in paradigm is taking place, moving away from management based on political boundaries and toward an ecosystem-based management approach to population growth, urban sprawl, and their interactions with the sensitive coastal environment. Recently, the U.S. Commission on Ocean Policy (2004) highlighted the need to manage coastal resources in the framework of the watersheds that affect them, ultimately recognizing the crucial connection between coastal and upland areas and the effects of a growing population.

Paul, M.J. and J.L. Meyer (2001) Streams in the Urban Landscape. *Annual Review of Ecology and Systematics* 32: 333-65.

Abstract: The world's population is concentrated in urban areas. This change in demography has brought landscape transformations that have a number of documented effects on stream ecosystems. The most consistent and pervasive effect is an increase in impervious surface cover within urban catchments, which alters the hydrology and geomorphology of streams. This results in predictable changes in stream habitat. In addition to imperviousness, runoff from urbanized surfaces as well as municipal and industrial discharges result in increased loading of nutrients, metals, pesticides, and other contaminants to streams. These changes result in consistent declines in the richness of algal, invertebrate, and fish communities in urban streams. Although understudied in urban streams, ecosystem processes are also affected by urbanization. Urban streams represent opportunities for ecologists interested in studying disturbance and contributing to more effective landscape management.

Roy, A.H., A.D. Rosemond, M.J. Paul, D.S. Leigh, and J.B. Wallace (2003) Stream Macroinvertebrate Response to Catchment Urbanisation (Georgia, U.S.A.) *Freshwater Biology* 48: 329-346.

Summary: 1. The effects of catchment urbanisation on water quality were examined for 30 streams (stratified into 15, 50 and 100 km² ± 25% catchments) in the Etowah River basin, Georgia, U.S.A. We examined relationships between land cover (implying cover and use) in these catchments (e.g. urban, forest and agriculture) and macroinvertebrate assemblage attributes using several previously published indices to summarise macroinvertebrate response. Based on a priori predictions as to mechanisms of biotic impairment under changing land cover, additional measurements were made to assess geomorphology, hydrology and chemistry in each stream. 2. We found strong relationships between catchment land cover and stream biota. Taxon richness and other biotic indices that reflected good water quality were negatively related to urban land cover and positively related to forest land cover. Urban land cover alone explained 29–38% of the variation in some macroinvertebrate indices. Reduced water quality was detectable at c. >15% urban land cover. 3. Urban land cover correlated with a number of geomorphic variables such as stream bed sediment size (–) and total suspended solids (+) as well as a number of water chemistry variables including nitrogen and phosphorus concentrations (+), specific conductance (+) and turbidity (+). Biotic indices were better predicted by these reach scale variables than single, catchment scale land cover variables. Multiple regression models explained 69% of variation in total taxon richness and 78% of the variation in the Invertebrate Community Index (ICI) using phi variability, specific conductance and depth, and riffle phi, specific conductance and phi variability, respectively. 4. Indirect ordination analysis was used to describe assemblage and functional group changes among sites and corroborate which environmental variables were most important in driving differences in macroinvertebrate assemblages. The first axis in a non-metric multidimensional scaling ordination was highly related to environmental variables (slope, specific conductance, phi variability; adj. R² ¼ 0.83) that were also important in our multiple regression models. 5. Catchment urbanisation resulted in less diverse and more tolerant stream macroinvertebrate assemblages via increased sediment transport, reduced stream bed sediment size and increased solutes. The biotic indices that were most sensitive to environmental variation were taxon richness, EPT richness and the ICI. Our results were largely consistent over the range in basin size we tested.

Schiff, K., S. Bay, and C. Stransky (2002) Characterization of Stormwater Toxicants from an Urban Watershed to Freshwater and Marine Organisms. *Urban Water* 4: 215-227.

Abstract: Stormwater samples were collected from Chollas Creek, a highly urbanized watershed in San Diego, California, that discharges directly to San Diego Bay and tested using one freshwater species (*Ceriodaphnia*, water flea) and two marine species (*Strongylocentrotus purpuratus*, purple sea urchin; and *Mysidopsis bahia*, mysid shrimp). No two species responded similarly after exposure to urban wet weather discharges. *Strongylocentrotus* was extremely sensitive to stormwater, exhibiting responses during every storm at concentrations as low as 6-12% stormwater. In contrast, *Mysidopsis* exhibited no response to stormwater for any of the storms sampled. *Ceriodaphnia* exhibited intermediate toxic responses; two of three samples were toxic at relatively high concentrations of 50-100% stormwater. Toxicity identification evaluations (TIEs) were conducted on each species to determine the toxic constituent(s). Organophosphate pesticides, most likely diazinon and chlorpyrifos, were responsible for the toxicity observed in *Ceriodaphnia*. Trace metals, most likely zinc and copper, were responsible for the toxicity observed to the sea urchin.

Stepenuck, K.F., R.L. Crunkilton, L.Z. Wang (2002) Impacts of Urban Land Use on Macroinvertebrate Communities in Southeastern Wisconsin Streams. *Journal of the American Water Resources Association* 37: 1475-1487.

Abstract: Macroinvertebrates were used to assess the impact of urbanization on stream quality across a gradient of watershed imperviousness in 43 southeastern Wisconsin streams. The percentage of watershed connected imperviousness was chosen as the urbanization indicator to examine impact of urban land uses on macroinvertebrate communities. Most urban land uses were negatively correlated with the Shannon diversity index, percent of pollution intolerant Ephemeroptera, Plecoptera, and Trichoptera individuals, and generic richness. Nonurban land uses were positively correlated with these same metrics. The Hilsenhoff biotic index indicated that stream quality declined with increased urbanization. Functional feeding group metrics varied across a gradient of urbanization, suggesting changes in stream quality. Proportions of collectors and gatherers increased, while proportions of filterers, scrapers, and shredders decreased with increased watershed imperviousness. This study demonstrated that urbanization severely degraded stream macroinvertebrate communities, hence stream quality. Good stream quality existed where imperviousness was less than 8 percent, but less favorable assessments were inevitable where imperviousness exceeded 12 to 20 percent. Levels of imperviousness between 8 and 12 percent represented a threshold where minor increases in urbanization were associated with sharp declines in stream quality.

U.S. Department of Agriculture (2000) Summary Report: 1997 National Resources Inventory (revised December 2000), Natural Resources Conservation Service, Washington, D.C. and Statistical Laboratory, Iowa State University, Ames, Iowa, 89 pages.

Summary: This bulletin includes state and national level estimates for changes in broad land cover/use, cropland use by irrigated and nonirrigated acres, broad land cover/use by land capability class and subclass, prime farmland, erosion and erodibility, wildlife habitat diversity, and wetlands and deepwater habitats. These basic summary statistics are presented via the Internet and in hard copy to provide base-line natural resource information to a variety of groups and individuals interested in obtaining insight into the condition of our Nation's nonfederal rural lands. Subsequent sections of this bulletin discuss the broader suite of information available from the 1997 NRI and methods for obtaining access to other results. The NRI is a scientifically based, longitudinal panel survey of the Nation's soil, water, and related resources, designed to assess conditions and trends every five years. The 1997 NRI provides results that are nationally consistent for all nonfederal lands for four points in time 1982, 1987, 1992, and 1997.

U.S. Department of Commerce – Census Bureau (2005) Cumulative Estimates of Population Change for the United States and States, and for Puerto Rico and State Rankings: April 1, 2000 to July 1, 2005 (NST-EST2005-02) data provided by the Census Bureau webpage (<http://www.census.gov/popest/states/NST-pop-chg.html>) and accessed 2/17/05.

Summary: Web page provides links to data (in Excel or CSV format) for each State in the United States plus Puerto Rico. Data show populations in each state and the change from 2000 to 2005.

Wang, L., J. Lyons, P. Kanehl, R. Bannerman, E. Emmons (2000) Watershed urbanization and changes in fish communities in southeastern Wisconsin streams. *Journal of the American Water Resources Association* 26: 1173-1189.

Abstract: We compared watershed land-use and fish community data between the 1970s and 1990s in 47 small streams in southeastern Wisconsin. Our goal was to quantify effects of increasing urbanization on stream fishes in what had been a predominantly agricultural region. In the 43 test watersheds, mean surface coverage by agricultural lands decreased from 54 percent to 43 percent and urban lands increased from 24 percent to 31 percent between 1970 and 1990. Agriculture dominated the four reference watersheds, but neither agriculture (65-59 percent) nor urban (4.4-4.8 percent) land-uses changed significantly in those watersheds during the study period. From the 1970s to the 1990s the mean number of fish species for the test stream sites decreased 15 percent, fish density decreased 41 percent, and the index of biotic integrity (IBI) score dropped 32 percent. Fish community attributes at the four reference sites did not change significantly during the same period, although density was substantially lower in the 1990s. For both the 1970s and 1990s test sites, numbers of fish species and IBI scores were positively correlated with watershed percent agricultural land coverage and negatively correlated with watershed urban land uses, as indexed by percent effective connected imperviousness. Numbers of fish species per site and IBI scores were highly variable below 10 percent imperviousness, but consistently low above 10 percent. Sites that had less than 10 percent imperviousness and fewer than 10 fish species in the 1970s suffered the greatest relative increase in imperviousness and decline in species number over the study period. Our findings are consistent with previous studies that have found strong negative effects of urban land uses on stream ecosystems and a threshold of environmental damage at about 10 percent imperviousness. We conclude that although agricultural land uses often degrade stream fish communities, agricultural land impacts are generally less severe than those from urbanization on a per-unit-area basis.