Summary of the Effects of Land Use on Water Quality, Aquatic Habitat and Biota
Final

John A. Magee
Fish Habitat Biologist
New Hampshire Fish and Game Department
April 22, 2009

Submitted to: HB 1579 "Land Use" Commission
HB 1295 "Stormwater" Commission

Studies over the last three decades have clearly demonstrated that land use has direct and indirect impacts on watershed hydrology, water quality, stream characteristics, aquatic habitat, macroinvertebrates, and fish (e.g., references in Brown et al., 2005 and Hughes et al., 2006, DeGasperi et al. 2009). Although the exact mechanisms for these impacts at specific sites is not always immediately obvious, the impacts have been demonstrated to be due to altered hydrology and its attendant water quality and aquatic habitat, both at the individual site and at the watershed scale. The two books cited in this paragraph contain more than 1,000 pages of peer-reviewed manuscripts reporting the results of dozens of studies recently conducted throughout the United States. There are hundreds of other recent manuscripts on this topic, some of which are cited here. It is the intent of this short paper to provide a summary of the effects of land use on the aquatic environment, and in doing so, a relatively small number of books and manuscripts has been cited. Some additional resources are contained in the Other References section. Inherent to land use is the fact that humans alter the hydrology of watersheds.

Degradations in the hydrology (DeGasperi et al. 2009), channel morphology (e.g., Konrad et al., 2005), water quality (Morse and Kahl, 2003), macroinvertebrates (Morse et al., 2003) and fish (e.g., Deacon et al., 2005; Kennen et al., 2005; Walters et al., 2005; Stranko, et al., 2008) are common with increasing impervious area within a watershed. Overall, channel morphology and aquatic habitat become less diverse, nutrient and pollutant levels in streams increase, and macroinvertebrate and fish communities shift from those species that require high quality water to those that can tolerate degraded water quality and habitat conditions. Watershed hydrology is altered and culminates in a greater frequency and intensity of high flow events, such as floods (DeGasperi et al. 2009). Additionally, stream channels typically become larger in response to increased impervious area in a watershed, and this occurs though stream bed and bank erosion, which can directly affect private landowners and public infrastructure, such as the very roads that are part of the total impervious area.

Most studies have identified impervious surfaces as a quantifiable attribute of land use that is clearly linked to degradation of water quality, aquatic habitat and biota (e.g., Stranko et al, 2008; references in Brown et al., 2005 and Hughes et al., 2006). As more studies have been conducted throughout the United States and also in New Hampshire (see Deacon et al., 2005 and Madorma, 1997), the threshold at which impervious surfaces have been shown to cause impacts to stream channels, water quality and biota is about 4-5% (e.g., Wang and Kanehl 2003; Stranko et al, 2008, who showed that wild brook trout were completely eliminated from watersheds in which the impervious surfaces were only 4% of the total watershed area), although 10% has also been reported as a general threshold by an earlier summary report (CWP, 2003). Additionally, the impacts occur quite rapidly, on the order of a decade or perhaps even more quickly (Stranko et al, 2008). An important factor associated with impervious surfaces in New Hampshire is winter maintenance and the use of salt, calcium chloride and sodium chloride, on roads. Madorma (1997) found in the Waukewan Watershed in central New Hampshire that water quality degradation in surface waters was strongly correlated to the density of locally maintained roads (likely due to the use of road salt). Lake Waukewan serves as the public drinking water supply for the Town of Meredith, and the study was conducted in part to determine what can be done to protect this important public water supply. The USEPA has criteria for chloride concentrations in receiving waters, and routinely these standards are violated by stormwater runoff (Houle, 2008). A striking example of current conditions in New Hampshire is the level of impervious surfaces in forty-two coastal towns. Of the fifty HUC-12 watersheds (typically about 10,000 acres each) within those towns, 30 (60%) already exceed the threshold of 4% impervious surfaces, and 13 (26%) exceed the threshold of 10% impervious surfaces (Justice and Rubin, 2006). Additionally, Deacon et al., 2005, who studied ten streams in coastal New Hampshire, found that the percent urban land (similar to the definition of impervious surfaces) within 25 meters of study streams was negatively correlated with water quality, aquatic habitat and macroinvertebrates, thereby demonstrating the value of riparian buffers to protect these attributes. The value of riparian buffers to water quality and aquatic habitat has been demonstrated in many other studies. For example, Sweeney et al (2004) demonstrated that riparian forests are necessary for the retention of nitrogen within streams, and thus they preclude the movement of nitrogen to downstream ecosystems. They concluded that this is extremely important relative to very large and commercially important ecosystems such as the Chesapeake Bay, which has been plagued by high nutrient problems for decades, and this has in turn caused severe economic damage to a number of important fisheries (e.g., blue crab). Sobota (2007) and Warren et al. (2007) also demonstrated the importance of riparian buffers in terms of both nutrient retention within streams and aquatic habitat. In Warren et al. (2007), more phosphate was retained within streams with older riparian forests, and those streams had more wood within the stream, which created greater aquatic habitat diversity. In a study in Georgia, Walters (2002) found that the species richness, density, and prevalence of pollution-intolerant and endemic (native only to that area) species declined with urban land cover, with the greatest effects occurring in streams with >15% urbanization. The resulting fish communities were dominated by sunfish species that are tolerant of pollution and have only very general habitat requirements.

Recent and current stormwater regulations <u>may not</u> be protective of water quality, aquatic habitat, and biota (Stranko et al, 2008; references in Brown et al., 2005 and Hughes et al., 2006) because individual lots are often not regulated relative to stormwater. Because of this, land use activities cumulatively can and do lead to higher peak flood flows and increased flooding (Coles et. al., 2004; NRC, 2009), which can ultimately impact the public and infrastructure, and also aquatic habitat and organisms. The increased peak flows as well as the increased duration of peak flows often lead to stream channel enlargement and/or incision, which is manifested by streambank and streambed erosion due to the altered hydrology (Konrad et al, 2005).
Eroding streambanks are a loss of land to private landowners and can threaten private and public infrastructure (e.g., roads, culverts, bridges, sewers, pipelines, and buildings). Armoring an eroding bank may provide stabilization at the specific site, but may simply transfer the stream's

energy upstream or downstream to abutting properties and streambanks (Biedenharn, et. al, 1997). From biological and water quality perspectives, the intentional hardening of streambanks themselves is a poor substitute for natural, vegetated riparian buffers as the riparian vegetation provides shading, organic matter and food (e.g., insects) to fish and other animals in a stream and it serves to reduce nutrient inputs to the stream channel and instream nutrient processing (e.g., Warren et al., 2007). When channels incise (erode down into the landscape), the finer sediments are removed and larger sediment is left behind, effectively armoring the channel bed. The armored bed is often poor aquatic habitat. The result of channel widening and incising, in response to poor stormwater management practices, is that streams lose their characteristic pools and riffles (Booth, 1991, Sovern, et. al., 1997). Incised streams may be unable to fill floodplain wetlands in normal wet years, and therefore, the flood waters simply move downstream faster and cause higher flood levels downstream. An unnoticed, yet important aspect of incising streams is that this affects groundwater. Streams in New Hampshire generally control groundwater levels nearby. Therefore the lower the streambed, the lower the water level in the stream and thus the lower the groundwater levels nearby. This results in dewatered wetlands as well as reduced soil moisture available for floodplain plants. Groundwater serves as the domestic water supply for at least 60% of the New Hampshire population (NHDES Drinking Water and Groundwater Bureau data) and therefore dropping the groundwater can have consequences on the very urban populations that created the problem.

Literature Cited

Biedenharn, B. S., C. M. Elliott, and C. C. Watson, 1997, The WES Stream Investigation and Stream Stabilization Handbook, US Army Waterways Experiment Station, Vicksburg, MS

Booth, D. B., 1991, Urbanization and the Natural Drainage System Impacts, Solutions, and Prognoses, The Northwest Environmental Journal, 7(1), 93-118.

Brown, L.R., R.H. Gray, R.M. Hughes and M. Meador, editors. 2005. Effects of Urbanization on Stream Ecosystems. American Fisheries Society, Symposium 47, Bethesda, Maryland.

Center for Watershed Protection (CWP). 2003. Impacts of Impervious Cover on Aquatic Systems.

Coles, J.F., Cuffney, T.F., McMahon, Gerard, and Beaulieu, K.M., 2004, The effects of urbanization on the biological, physical, and chemical characteristics of coastal New England streams: U.S. Geological Survey Professional Paper 1695, 47 p.

Comprehensive Flood Management Study Commission. 2008. Final Report. New Hampshire House Bill 648, Chapter 179 Laws of 2007.

Deacon, J.R., S.A. Soule, and T.E. Smith, 2005. Effects of urbanization on stream quality at selected sites in the Seacoast region in New Hampshire, 2001-03: U.S. Geological Survey Scientific Investigations Report 2005-5103, 18 p.

DeGasperi, C.L., H.B. Berge, K.R. Whiting, J.J. Burkey, J.L. Cassin, and R.R. Fuerstenberg. 2009. Linking hydrologic alteration to biological impairment in urbanizing streams of the Puget Lowland, Washington, USA. Journal of the American Water Resources Association. 45(2): 512-533.

Houle, K. M., 2008, Winter Performance Assessment of Permeable Pavements: a Comparative Study of Porous Asphalt, Pervious Concrete, and Conventional Asphalt in a Northern Climate, University of New Hampshire, Department of Civil Engineering, MS Thesis, Durham, NH.

Hughes, R.M., L. Wang, and P.W. Seelbach, editors. 2006. Landscape Influences on Stream Habitats and Biological Assemblages. American Fisheries Society, Symposium 48, Bethesda, Maryland.

Justice, D. and F. Rubin. 2006. Impervious Surface Mapping in Coastal New Hampshire. A Final Report to The New Hampshire Estuaries Project. University of New Hampshire.

Kennen, J.G., Chang, Ming, and Tracy, B.H., 2005, Effects of landscape change on fish assemblage structure in a rapidly growing metropolitan area in North Carolina, USA: in Brown, L.R., Gray, R.H., Hughes, R.M., and Meador, M.R., eds., Effects of urbanization on stream ecosystems: American Fisheries Society, Symposium 47, Bethesda, Maryland, p. 39-52.

Konrad, C. P., D. B. Booth, and S. J. Burges (2005), Effects of urban development in the Puget Lowland, Washington, on interannual streamflow patterns: Consequences for channel form and streambed disturbance, Water Resour. Res., 41, W07009, doi:10.1029/2005WR004097.

Madorma, L.E. 1997. A GIS Approach to Determine the Relationship of Impervious Surface Cover to Water Quality and Macroinvertebrate Biodiversity of the Waukewan Watershed, Meredith, New Hampshire. M.S. Thesis. Plymouth State University, New Hampshire.

Morse, C., A. Huyrn and C. Cronan (2003). Impervious Surface Area as a Predictor of the Effects of Urbanization on Stream Insect Communities. Environmental Monitoring and Assessment 89(1): 95-127.

Morse, C. and S. Kahl. 2003. Measuring the Impact of Development on Maine’s Surface Waters. The University of Maine. George J. Mitchell Center for Environmental and Watershed Research.

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

Sobota, D.J. 2007. Linkages among Land Use, Riparian Zones, and Uptake and Transformation of Nitrate in Stream Ecosystems. PhD Dissertation. Oregon State University.

Sovern, D. T. and P. M. Washington, 1997, Effects of Urban Growth on Stream Habitat, in Effects of Watershed Development and Management on Aquatic Ecosystems, L. A. Roesner, (Editor), ASCE, Snowbird, UT.

Sweeney, B.W., T.L. Bott, J.K. Jackson, L.A. Kaplan, J.D. Newbold, L.J. Standley, W.C. Hession, and R.J. Horwitz. 2004. Riparian deforestation, stream narrowing, and loss of stream ecosystem services. The National Academy of Sciences of the USA. www.pnas.org/cgi/doi/10.1073/pnas.0405895101

Walters, D.M. Influence of geomorphology and urban land cover on stream fish assemblages in the Etowah River Basin, Georgia, PhD Dissertation. University of Georgia.

Walters, D. M., M. C. Freeman, D. S. Leigh, B. J. Freeman, and C. M. Pringle. 2005. Urbanization effects on fishes and habitat quality in a southern Piedmont river basin. Pages 69-86 in L. R. Brown, R. H. Gray, R. M. Hughes, and M. R. Meador, editors. Effects of Urbanization on Stream Ecosystems. American Fisheries Society, Symposium 47, Bethesda, MD.

Wang, L. and P. Kanehl. 2003. Influences of watershed urbanization and instream habitat on macroinvertebrates in cold water streams. Journal of the American Water Resources Association. 1181-1196.

Warren, D. R., E.S. Bernhardt, R.O. Hall, and G.E. Likens. 2007. Forest age, wood and nutrient dynamics in headwater streams of the Hubbard Brook Experimental Forest, NH. Earth Surface Processes and Landforms. 32:1154–1163.

Other References

http://water.usgs.gov/nawqa/urban/html/otherpublications.html (contains 17 citations)

http://water.usgs.gov/nawqa/urban/html/publications.html (contains 25 citations)

Davis, A. P. (2008). Field Performance of Bioretention: Hydrology Impacts. Journal of Hydrologic Engineering. 13:2, 90-95.

Dietz, M. E. (2007). Low Impact Development Practices: A Review of Current Research and Recommendations for Future Directions. Water Air and Soil Pollution, 186(1-4), 351-363.

Dietz, M. E., and Clausen, J. C. (2007). Stormwater runoff and export changes with development in a traditional and low impact subdivision. Journal of Environmental Management. 87(4):560-566.

Vermont Department of Environmental Conservation. (2006). "Total Maximum Daily Load To Address Biological Impairment in Potash Brook (VT05-11) Chittenden County, Vermont." Connecticut Department of Environmental Protection. (2007). "A Total Maximum Daily Load Analysis for Eagleville Brook, Mansfield, CT." Connecticut Department of Environmental Protection, Hartford, CT.