

# North Carolina Ecosystem Response to Climate Change: DENR Assessment of Effects and Adaptation Measures

*DRAFT*

## Coastal Plain Large River Communities

### **Ecosystem Group Description:**

These systems are composed of the largest and highest order rivers in the Coastal Plain. Many of these rivers originate in the Piedmont, but after passing over the fall line transition into more typical Coastal Plain rivers with sandy substrates and wider floodplains. Examples include: Cape Fear River, Neuse River, Roanoke River, and Chowan River.

### **Ecosystem Level Effects:**

#### **Predicted Impacts of Climate Change:**

Climate Change Factor:	Likelihood:	Effect:	Magnitude:	Comments:
Sea Level Rise -- Inundation	High	Neg	High	Sea level rise will impact these systems.
Increased Temperature	High	Neg	High	Chronically warmer temperatures and lower dissolved oxygen levels may increase stress on organisms.
Hot Spells	High	Neg	High	Low dissolved oxygen associated with hot spells may increase fish kills.
Sea Level Rise -- Salt Intrusion	High	Neg	High	Salt water wedge will move upstream.
Flooding	High	Neg	High	Increased severity and frequency of storm events, similar to hurricanes, will have impacts.
Drought	High	Neg	Med	Lower water levels during dry times will increase stress to the system.

Increased air temperatures may lead to increased water temperatures and potentially lower dissolved oxygen levels. This Ecosystem Group consists large coastal plain rivers that are likely more buffered to temperature effects than the smaller systems of the coastal plain. However, because of the low gradient of these rivers, sufficient mixing may not occur and they could experience low dissolved oxygen levels. Hot spells can have the same effect as overall increased air temperatures but on a much more acute scale. Algal blooms are possible in these systems and can exacerbate dissolved oxygen problems, particularly when flows are low. Increased water temperature, resuspension of bottom sediment during storms, and increased nutrient content of freshwater and coastal waters can increase pathogen replication, persistence, survival, and transmission (DeWan et al., 2010; Karl et al., 2009; Band and Salvensen, 2009; U.S. EPA, 2010).

Potential changes in precipitation have numerous and varied effects. Severe and prolonged droughts may

decrease streamflow, decrease groundwater recharge, and increase evaporation, resulting in some impacts to rivers of this theme, although their larger size will likely mitigate many of these impacts. Decreases in overall summer precipitation will likely cause reduced water flows due to decreased tributary input, which will further contribute to warmer water temperatures and further stress water quality. This is particularly important in the context of seasonal droughts because during low-flow periods, nutrients may become concentrated and flush out of systems more slowly (DeWan et al., 2010; Karl et al., 2009; Band and Salvensen, 2009; U.S. EPA, 2010).

Increased storm intensity can lead to flooding and therefore increased stormwater runoff and increased erosion. With increased stormwater runoff there is an increase in loading of sediments, nutrients and contaminants into streams and potential negative effects on biota. With a change in intensity and variability of rainfall, there are potential changes to streamflow patterns, channel hydrodynamics, lake levels, and the volume of groundwater from aquifers. (Band and Salvensen, 2009; U.S. EPA, 2010; Bakke 2008). An increase in the number of tropical events can lead to flash flooding, which causes many of the above-mentioned responses. Effects such as increased sediments and contaminants into aquatic systems, in addition to major disruption to channel design and hydrodynamics, potentially upset the physical, chemical, and biological structure of streams. In this theme, tropical events may exacerbate problems associated with salt water intrusion (Band and Salvensen 2009).

Sea level rise is likely to impact this theme as coastal inundation is predicted to varying degrees. The combined increase of inland flooding due to higher precipitation events with elevated sea levels will exacerbate coastal inundation. Additionally, salt water intrusion into currently freshwater streams is a possibility as sea level rises. This theme will likely be the most impacted system with sea level rise and salt water intrusion as many of these rivers currently transition from freshwater to brackish water as they meet the sounds. The chemical composition of currently freshwater systems could change and freshwater wetlands could be converted to salt marshes as salt water moves further upstream into these rivers (Band and Salvensen, 2009; U.S. EPA, 2010; Bakke 2008; Burkett et al., 2000).

**Predicted Ecosystem Responses:**

Ecosystem Response:	Likelihood:	Effect:	Magnitude:	Comments:
Acreage Change	High	Neg	Low	Rising sea level and salt water intrusion will turn the lower reaches of these rivers into estuarine systems. Rising sea level and salt water intrusion will reduce the extent of these freshwater systems near river mouths.
Phenological Disruption	Low	Neg	Med	Uncertain if disruptions in organismal interactions (mussel-fish host relationship) will be affected.
Sediment Transport	High	Neg	High	Changes in streamflow could change overall sediment transport dynamics, leading to altered habitat composition.
Exotic species invasion	Low	Neg	Med	Uncertain how exotic species will affect these systems.
Compositional Change	High	Neg	High	Changes in species composition from freshwater to more salt-tolerant species are expected.
Structural Change	High	Neg	High	Salt intrusion will cause peat to dissolve which could widen mouths to rivers.
Flow Regime	High	Neg	Med	Flashiness of the system may increase with more storm events, thus changing overall habitat composition.
Channel Hydrodynamics	High	Neg	High	Changes in flow regime will likely result in changes in the overall stream morphology and transport of sediment.

Potential increased air temperatures and therefore increased water temperatures can lead to algal blooms in aquatic systems, which diminishes stream oxygen availability. The increased water temperature alone can

cause a decline in dissolved oxygen and any decline in DO can lead to fish kills, whether as a direct result of increased water temperature or as a secondary effect of algal blooms. Coastal Plain large rivers may not be as susceptible to low DO levels as small streams and swamps, however, this phenomenon may not be lost on the large rivers and may only be exacerbated with climate change (DeWan et al., 2010; Band and Salvensen, 2009).

Because of potential changes in storm frequency and intensity, it is likely that channel hydrodynamics will be altered. Associated with channel hydrodynamics are changes in flow regime, sediment transport, and overall channel design. Most rivers in these systems will have relatively slack water and comparatively few riffles and runs, but may exhibit a shifting of sand bars, for example, which could cause changes in aquatic species' habitats. Additionally, storms may cause the felling of riparian trees, particularly in areas with narrow riparian areas. Increased woody debris in these streams will also change channel hydrodynamics as well as available habitat. How, or if, these species adapt to changing habitats will require close monitoring to observe trends and help inform future management decisions (Bakke 2008).

Increased stormwater runoff will amplify the loading of nutrients, sediment and contaminants into streams, rivers, and reservoirs. The increased loads could affect water quality and habitat for aquatic species, as well as drinking water for municipalities. Stormwater controls and retrofits will become increasingly important (Band and Salvensen, 2009).

Aquatic species could experience shifts in their range or distribution and sensitive species may experience decline or extirpation due to changes in water quality and habitat. Aquatic species are particularly sensitive to temperature cues and recent research has shown that many species of freshwater mussels may already be living at the upper thermal tolerances of their early life stages (glochidia and juveniles) (Pandolfo et al. 2010). Extreme temperature events could be especially harmful. These systems may experience a change in species composition due to various changes in habitat and water quality.

Because of the link between freshwater mussels and fish, phenological disruptions are a possibility, but exact mechanisms or effects are unknown at this time. Freshwater mussel larvae, called glochidia, are dependent on a host fish for transformation into juveniles. Host fish species are known for some mussel species, yet unknown for others. Temperature cues play a large role in the release of glochidia from female mussels and also in the movement and migrations of fish. Therefore, with changing temperatures predicted with climate change, there could be phenological disruptions affecting the reproductive capacity of freshwater mussels.

Exotic species invasion is a concern, yet effects on this theme are largely unknown. Asian clam (*Corbicula fluminea*) is found in aquatic systems throughout the state. However, its effects on native mussels are largely unknown. Red swamp crayfish (*Procambarus clarkii*) is prevalent in the Coastal Plain and although effects on native crayfish are not fully understood, it is likely that competition for resources such as food and space are potential impacts. Flathead catfish (*Pylodictis olivaris*) are a concern because of direct predation on native species. The introduction of any invasive species is cause for concern and the prevalence of warmer water temperatures may increase the likelihood of additional exotic species that were previously thought to be non-threatening because the winters were too cold for survival.

The Coastal Plain could experience additional changes in terms of species composition due to increased risk of salt water intrusion. This phenomenon is expected to impact large rivers initially and the extent to which salt water will reach small streams and swamps is yet to be determined. As a salt wedge moves up into these large rivers, it is likely that existing freshwater fauna may be replaced with more brackish water

species and if salinity levels increase gradually, there could be adaptation by some freshwater species to this change. Additionally, freshwater species could migrate upstream to escape the increased salinity if suitable habitat and water quality parameters are available in smaller systems.

## Habitat Level Effects:

### LHI Guilds:

---



---

## Species Level Effects:

### Plants

Species:	Element Rank:	Endemic	Major Disjunct	Extinction/Extirpation Prone	Status: US/NC	Comments:
Lilaeopsis carolinensis	G3G5/S2		Yes		/T	
Hottonia inflata	G4/S1				/SR-O	
Heteranthera multiflora	G4/S1			Yes	/SR-P	Widespread outside of NC, but historically known from a few locations in NC; currently present at only one site.
Sagittaria stagnorum	G4G5/SH				/SR-P	
Luziola fluitans	G4G5/S2				/SR-P	

Rare aquatic plants in the Coastal Plain tend to be under-surveyed. Most rare aquatic plants in this theme occur in relatively stable systems and are not expected to be highly threatened by climate change. However, the rarest species may be particularly vulnerable to extirpation in the state, due their rarity here (i.e., random events that affect individual populations can have major effects on the species' already-limited range within the state).

### Aquatic Animals

Species:	NHP Rank:	Endemic	Major Disjunct	Extinction/Extirpation Prone	Status: US/NC/WAP	Comments:
Elliptio folliculata	G2G3Q/S1				/SC/P	
Acipenser brevirostrum	G3/S1				E/E/P	
Leptodea ochracea	G3G4/S1				/T/P	

Elliptio marsupiobesa	G3Q/S3	/SC/P
Ligumia nasuta	G4/S1	/T/P
Dolania americana	G4/SH	FSC/SR/
Anodonta implicata	G5/S1	/T/P
Triaenodes marginatus	G5/S3	/SR/
Carpiodes cyprinus	G5/S1	/SR/P
Carpiodes sp. cf. velifer	GNR/S1	/SC/

## Combined Threats and Synergistic Impacts:

### Importance of Climate Change Factors Compared to Other Ecosystem Threats:

Threat:	Rank Order:	Comments:
Development	1	Direct, secondary, and cumulative effects from development.
Climate Change	2	Sea level rise, as a result of climate change, is a major threat to large coastal plain rivers.
Flood Regime Alteration	2	Alterations such as dams reducing flooding and impervious surfaces increasing flashy flow in combination with changes in precipitation will have a big effect on these systems.
Water Withdrawals	3	Irrigation, water supply, and energy development withdrawals pose a threat to flow regime.
Pollution	3	Point and nonpoint sources - runoff, endocrine disrupting chemicals - are threats.
Lack of riparian vegetation	3	Loss of riparian vegetation causes numerous problems.
Energy development	4	Hydropower impoundments could become more prevalent.
Invasive Species	4	Invasive plants and animals are potential problems, although specific interactions are unknown.

Aquatic systems have been under threat from a variety of perturbations in the past and many of those continue today. Conversion of land, both from forest to agriculture or silviculture, as well as from development projects, continues to threaten stream integrity resulting in increased sediment, bank erosion, and stormwater runoff containing sediment and other potentially toxic materials.

Erosion and the resultant sedimentation are the largest sources of nonpoint source pollution in most all aquatic systems. Sources of erosion include disturbance from development activities and agriculture. Residential development can increase erosion during the construction process, but also as a secondary result of increased impervious surfaces in the watershed. Development pressure is likely to increase in this area of the Coastal Plain, which will lead to an increase in impervious surfaces, leading to increased runoff, stream and bank erosion, and pollution inputs. Confined animal operations are common in this theme and may have significant impacts on water resources. Animal waste lagoon discharges are a potential source of contamination if not properly managed and maintained. Another source of erosion includes timber harvest if proper erosion controls are not used and maintained, in addition to poorly constructed and maintained

timber roads.

Many of the water quality and water quantity impacts resulting from climate change are analogous to impacts from economic development and population growth in North Carolina. Climate change is predicted to decrease rainfall and therefore limit water supply; however, growth and development have been and continue to increase water supply demands. Historical streamflow patterns are projected to be altered due to climate change impacts; however, these are already being altered due to rapid urbanization. An increase in impervious surfaces due to roads, parking lots, homes, and businesses increases the amount and speed of runoff being delivered into aquatic systems. Additionally, decreased groundwater recharge between storms due to impervious surfaces leads to a decrease in stream baseflow. Runoff from urban areas often contain higher concentrations of nutrients, such as nitrogen and phosphorus, sediment, metals, hydrocarbons, and microbes. An increase in frequency and intensity of storms due to climate change will have a similar impact on stream systems by increasing pollutant loading. Therefore, challenges to water quality and water quantity as related to climate change are similar to those being confronted to accommodate growth and development. Adaptation strategies for water resource management could limit negative effects of both climate change and continuing development (Band and Salvensen, 2009).

Invasive plants in the riparian area can have negative impacts on stream systems by often times creating a monoculture with poor nutrient inputs, reducing bank stability, and allowing too much sunlight and therefore warmer stream temperatures. Aquatic invasive plants, such as alligatorweed, currently cause problems in this theme by creating floating mats that disrupt dissolved oxygen levels. Asian dayflower, hydrilla, water hyacinth, and giant Salvinia could pose more of a threat to these systems with a warm climate. Invasive aquatic animal species, such as Asian clam and red swamp crayfish, may have negative effects on native species, such as competition for space and resources. However, specific interactions are largely unknown at this time.

Recent studies have shown that endocrine disrupting chemicals (EDC) in treated wastewater can inhibit reproduction and cause feminization of mussels and fish. Although little is known about the effects of EDCs, additional studies are being conducted to document the levels of EDC's in discharges, and measures are being identified to reduce or eliminate EDC's from wastewater prior to discharge, should those discharge studies show increases in EDC levels (Conn et al. 2006; Kim et al. 2007; Kasprzyk-Hordern et al. 2008; Joss et al. 2006; Kolpin et al. 2002; Nowotny et al. 2007).

As humans seek to adapt to climate change by manipulating water resources, streamflow and biological diversity are likely to be reduced. During droughts, recharge of groundwater will decline as the temperature and spacing between rainfall events increase. Responding by increasing groundwater pumping will further stress or deplete aquifers and place increasing strain on surface water resources. Increasing evaporation and plant water loss rates alter the balance of runoff and groundwater recharge which is likely to lead to saltwater intrusion into shallow aquifers. Water withdrawals can be problematic, particularly in streams with already low 7Q10 flows, because they may reduce available habitat for aquatic species.

## Recommendations for Action:

### Interventive Measures:

Intervention:	Importance:	Feasibility:	Comments:
Water Resources Management	Mediu	Medium	
Research and Monitoring	Mediu	High	
Restore/Maintain Hydrology	High	Medium	
Stormwater Management	High	High	
Reduce groundwater extraction	High	Low	
Preservation of Riparian Buffers/Floodplains	High	Medium	
Limit Impervious Surfaces	High	Medium	
Conduct Surveys and Population Studies of R	Mediu	High	Most rare plants associated with this theme are poorly understood.
Restore/Maintain Landscape Connections	High	Low	
Species Reintroduction/Augmentation	High	High	
Increased Open Space	High	Medium	
Eliminate/Prevent Pollution	High	High	
Control Erosion	High	High	

#### Erosion Control

Erosion control is critical to protecting waterways from excessive sedimentation. Slowing storm runoff before it enters a stream dissipates energy and allows more time for sediment deposition outside the stream channel (Shuford et al. 2010). There are numerous actions that can be taken to aid in erosion control. Streambank erosion is much more likely in areas where riparian vegetation is scarce or lacking altogether. The preservation or restoration of riparian vegetation is crucial to the maintenance of stable streambanks, in addition to the role that riparian vegetation serves to dissipate water runoff energy and allow for sediment deposition. The implementation of various types of agriculture and forestry best management practices (BMPs) can aid in erosion control. For example, fencing livestock to prevent direct access to streams prevents accelerated erosion with higher stream flows. Typically areas used for livestock access have exposed banks and are devoid of vegetation, therefore precipitation events can lead to increased scour, and hence erosion and sedimentation. In addition to helping with erosion control, the fencing of livestock can reduce nutrient inputs to the aquatic system (NC Wildlife Resources Commission 2005).

#### Bridge and Culvert Design

The effects of climate change impacts, particularly increases in precipitation, should be taken into consideration when designing bridges and culverts to allow for stream movement and aquatic organism passage. Design standards may need alteration to accommodate environmental changes due to climate change (Transportation Research Board, 2008).

#### Protect Floodplains and Wetlands

Floodplains and wetlands are critical in this theme as floodplains tend to be very wide, compared to floodplains in other themes. Additionally, wetlands and swamps are very common and serve a critical role in this topographically flat region. Floodplains and wetlands are natural features designed for flood control and dissipating flood waters. Floodplain development interferes with this natural capacity and worsens

downstream flooding, scour, and erosion. Floodplain and wetland protection and preservation provides a natural and economical means for flood water attenuation, which can save human lives and property, in addition to sustaining aquatic ecosystems. Changes in flood patterns (frequency and duration) and flooded lands may necessitate the need to periodically update flood maps to ensure protection of life and property (Band and Salvensen, 2009).

#### Support Land Conservation

Land conservation or preservation can serve numerous purposes in the face of anticipated climate change but overall it promotes ecosystem resilience, such as: protecting watersheds for clean water, flood attenuation, and decreased erosion and sedimentation; providing ecological corridors for species movement throughout the landscape in response to changing habitats; preserving existing habitats to help prevent forced migration (Band and Salvensen, 2009). With potential changes in habitats, connectivity that allows for species and ecosystem migration is crucial and can be accomplished through protection of potential migration corridors. Another important benefit of land conservation is the role that natural areas can play in carbon sequestration. Land conservation tools to be used include easements, use-value taxation, and fee simple purchase (Shuford et al. 2010). Additionally, many rivers of this theme have organic soils and woody biomass in their floodplains which can sequester carbon if not disturbed or drained.

#### Land Use Planning

Land use planning and land conservation go hand in hand. Green infrastructure is a tool to be used in planning to set aside such things as natural areas, habitat corridors, and recreational areas for a community. Carbon sequestration by natural landscapes can slow or inhibit its atmospheric concentration. Therefore, conservation activities such as preserving forests and open space, farm land and rural landscapes, park lands, managing open lands, and planting trees and vegetation in urban areas can aid in carbon sequestration (Shuford et al. 2010).

#### Aquatic Species Research

Monitoring of aquatic taxa is critical to assessing species and ecosystem health and in gauging resiliency of organisms to a changing climate. These monitoring efforts will inform future decisions on how to manage aquatic species. In addition to monitoring, there are several research questions that need to be answered about certain species or taxa of aquatic organisms. Many have unresolved taxonomic issues that should be studied before proper management can occur. Also, there are numerous aquatic species that lack life history information, which can be critical in determining future management and needs of a species (Band and Salvensen, 2009) (NC Wildlife Resources Commission, 2005).

#### Translocation/Propagation Techniques

Aquatic species propagation is an area of current and ongoing research. Developing techniques for propagation of species, particularly those that are rare, at high risk of extinction or extirpation, and are difficult to propagate in a laboratory setting, are critical for preserving those species and their genetic stock. Propagation facilities can serve as gene banks for aquatic species. Translocation, or moving aquatic species to different habitats, is another related area of needed research. Translocation can involve augmentation or reintroduction of species. Augmentation refers to adding a species to an area in which it already occurs, to aid in recruitment within the existing population. This technique can be useful for rare species populations that are too sparse for successful reproduction in the wild. Reintroduction refers to moving species to an area that currently does not support the particular species, but is within the historical range of the species. Augmentation and reintroduction are techniques that have been and are currently being used, for example, in areas where there have been significant improvements in water quality or available habitat for various reasons and species are either slow to or unable to recolonize the area on their own. Refinement of these

techniques and careful monitoring of habitats that may worsen or improve over time will allow for successful intervention and the hopeful continuation of a full suite of aquatic species. Introduction of species to streams or river basins outside of historical ranges is generally a poor practice and should be avoided unless there is sufficient justification for such management activities. Guidance for mollusk population restoration and conservation has recently been finalized for the Cumberlandian region (NC Wildlife Resources Commission, 2005; Cumberlandian Region Mollusk Restoration Committee, 2010).

#### Stormwater Management

Stormwater management serves the purpose of reducing the amount of sediment, nutrient, and volume of runoff that enters streams. It can be managed by human-made structures, natural means, or by taking actions within the watershed to reduce the amount of runoff. Stormwater management techniques should strive to restore or maintain the pre-development hydrograph. Riparian vegetation acts as a natural control for stormwater management by filtering sediment and pollutants from runoff and by dissipating the velocity of runoff before it enters a stream (Shuford et al., 2010). Structures such as bioretention cells (i.e., rain gardens), cisterns, permeable pavement, runnels, vegetated swales, and filter strips can be used in various ways as stormwater best management practices (BMPs). These types of structures promote infiltration and natural recharge of groundwater and also surface waters (Shuford et al., 2010). Because impervious surfaces are the cause of increased volume and velocity of runoff, imposing impervious surface limits is a way to combat the problem at its source. Research has shown that at levels of 8-12% imperviousness, major negative changes in stream condition occur (Wang et al., 2001). Impervious surface impacts on stream systems can be mitigated by the maintenance or establishment of natural forested areas in riparian zones (Miltner et al., 2004; Moore and Palmer 2005; Low Impact Development (LID) Practices, 2010).

#### Water Resources Management

Water resources management could be an area heavily impacted by varying conditions related to climate change. Many towns and municipalities receive their drinking water from surface water – either free-flowing or impounded rivers. If precipitation and flow patterns change, it could affect intake structures and the amount of water that can be removed from the system, while still maintaining adequate flow for aquatic life. Water treatment and wastewater treatment systems may require modifications to handle varying flows and conditions that may result due to climate change. Discharge permits may need revisions since they are based on flow conditions at the time of issuance; if flows decrease and the 7Q10 is lowered, discharge amounts may require modification to allow for sufficient dilution and mixing. Drought management may become increasingly important and water use efficiency will be imperative. Additionally, many reservoirs are used for hydropower and/or flood control. Changes in precipitation patterns may affect dam operations and require appropriate modifications to protect health, safety, and aquatic life. In addition to the above management options, other water resources management approaches (most of which have been discussed in previous sections) may include: green infrastructure, open space, native species plantings and/or xeriscaping, water conservation, and alternative water sources (Shuford et al., 2010)

#### Riparian Habitat

The riparian area, or area of land adjacent to waterbodies, serves numerous functions including many already mentioned above. The riparian area includes the floodplain, which in these coastal plain systems is typically quite extensive and serves a similar role as the riparian area. Riparian areas with forested vegetation have a greater capacity to serve these numerous functions, compared with riparian areas of grass, little mature vegetation, or no vegetation. Functions of riparian areas include: stabilize streambanks and therefore provide erosion control, allow for sediment and pollutant deposition (by dissipating energy from runoff and allowing for filtration), infiltration of water runoff to allow for groundwater recharge, stream temperature regulation by providing shade, flood control by attenuating storm flows, carbon sequestration by mature

woody vegetation, increase stream habitat complexity by contributing woody debris, provide habitat for terrestrial wildlife species, and serve as corridors for movement of terrestrial wildlife species (Seavy et al., 2009; NC Wildlife Resources Commission 2002; Wenger 1999).

Riparian areas are important for aquatic ecosystem health, in general, but they can also help mitigate for and provide resilience against climate change effects. Riparian vegetation is more resilient to flooding and drought than more upland vegetation and should be restored in areas where it is lacking to establish native vegetation and manage for genetic diversity. Habitat connectivity is a function of riparian areas already mentioned, but it becomes increasingly important in the face of climate change. Riparian areas can serve as movement corridors and because they occur along streams, often are oriented in a north-south direction which can increase connectivity between habitats and across elevational zones. There is a definite linkage between aquatic and terrestrial systems through the riparian area. Riparian vegetation traps pollutants and sediments and helps protect water quality, while the nutrient rich aquatic systems support vegetation and habitat for wildlife species. By maintaining or restoring these riparian areas, it increases the resiliency of both aquatic and terrestrial systems and makes them more resistant to climate change. Riparian areas serve as a thermal refugia because they provide stream shading but also because they have a higher water content than upland areas. Therefore, animals with thermoregulatory limitations have a refugia which will become increasingly important with anticipated increases in air temperatures. Riparian areas serve hydrological benefits because they promote water infiltration and help mitigate against flooding events. By maintaining the floodplain and restoring vegetation in these areas, flooding impacts can be lessened without using structural controls. In areas where riparian vegetation is lacking or does not consist of forested vegetation, riparian restoration or establishment is necessary. Because future conditions are unknown, it is suggested to plant riparian areas with vegetation with a broad elevational range within a particular watershed and also to plant vegetation with broad hydrologic tolerances to promote resiliency from climate change. Riparian areas can enhance ecosystem resilience and therefore mitigate against negative impacts from climate change (Seavy et al. 2009).

## **Ecosystem Group Summary:**

The lower reaches of coastal plain larger rivers are vulnerable to the effects of climate change because of rising sea levels and salt intrusion into freshwater riverine areas. Changes in salinity and tidal influence will likely change the overall species composition in these systems. Important actions to promote resiliency are to protect and maintain floodplains and riparian vegetation.

## References:

- Bakke, P. 2008. Physical Processes and Climate Change: A guide for biologists. Department of Interior, US Fish and Wildlife Service. Unpublished report. 28pp.
- Band, L. and D. Salvensen. 2009. The University of North Carolina at Chapel Hill: Climate Change Committee Report. UNC Institute for the Environment.
- Burkett, V., R. Ritschard, S. McNulty, J.J. O'Brien, R. Abt, J.Jones, U.Hatch, B. Murray, S. Jagtap, and J. Cruise. 2000. Potential consequences of climate variability and change for the southeastern United States. Retrieved July 20, 2010, from <http://www.usgcrp.gov/usgcrp/nacc/se-mega-region.htm>
- Conn, K.E., L.B. Barber, G.K. Brown, and R.L. Siegrist. 2006. Occurrence and Fate of Organic Contaminants during onsite wastewater treatment. *Environmental Science & Technology*. 40 (23): 7359-7366.
- Cumberlandian Region Mollusk Restoration Committee. 2010. Plan for the population restoration and conservation of freshwater mollusks of the Cumberlandian Region. V + 145 pp.
- DeWan, A., N. Dubois, K. Theoharides, and J. Boshoven. 2010. Understanding the impacts of climate change on fish and wildlife in North Carolina. Defenders of Wildlife, Washington, DC.
- Joss, A., S. Zabczynski, A. Gobel, B. Hoffmann, D. Loffler, C.S. McArdell, T.A. Ternes, A. Thomsen, H. Siegrist. 2006. Biological degradation of pharmaceuticals in municipal wastewater treatment: Proposing a classification scheme. *Water Research* 40(2006): 1686-1696.
- Karl, T.R; Melillo, J.M. and Peterson, T.C. 2009. Global Climate Change Impacts in the United States. Cambridge University Press
- Kasprzyk-Hordern, B., R.M. Dinsdale, A.J. Guwy. 2008. The occurrence of pharmaceuticals, personal care products, endocrine disruptors and illicit drugs in surface water in South Wales, UK. *Water Research* 42(2008):3498-3518.
- Kim, S.D., J. Cho, I.S. Kim, B.J. Vanderford, S.A. Snyder. 2007. Occurrence and removal of pharmaceuticals and endocrine disruptors in South Korean surface, drinking, and waste waters. *Water Research*. 41 (2007):1013-1021.
- Kolpin, D.W., E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, L.B.Barber, and H.T. Buxton. 2002. Pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999-2000: A national reconnaissance. *Environmental Science and Technology* 36(6): 1202-1211.
- Low Impact Development (LID) Practices for Storm Water Management. Retrieved August 23, 2010, from <http://www.toolbase.org/TechInventory/TechDetails.aspx?ContentDetailID=909>.
- Miltner, R.J., D. White, and C. Yoder. 2004. The biotic integrity of streams in urban and suburbanizing landscapes. *Landscape and Urban Planning*. 69:87-100.
- Moore, A.A., and M.A. Palmer. 2005. Invertebrate biodiversity in agricultural and urban headwater streams: implications for conservation and management. *Ecological Applications* 15(4):1169-1177.
- NC Wildlife Resources Commission. 2002. Guidance Memorandum to address and mitigate secondary and cumulative impacts to aquatic and terrestrial wildlife resources and water quality. NCRWC, Raleigh, NC.
- NC Wildlife Resources Commission. 2005. North Carolina Wildlife Action Plan. Raleigh, NC
- Nowotny, N. B. Epp, C. Von Sonntag, and H. Fahlenkamp. 2007. Quantification and modeling of the elimination behavior of ecologically problematic wastewater micropollutants by adsorption on powdered and granulated activated carbon. *Environmental Science and Technology* 41(6): 2050-2055.

Pandolfo, T.J., W.G. Cope, C. Arellano, R.B. Bringolf, M.C. Barnhart, and E.Hammer. 2010. Upper thermal tolerances of early life stages of freshwater mussels. *Journal of the North American Benthological Society* 29(3): 959-969.

Seavy, N.E., T. Gardali, G.Golet, F.Thomas Griggs, C.A. Howell, R. Kelsey, S. Small, J. Viers, and J. Weigand. (2009) why Climate Change Makes Riparian Restoration more important than ever: Recommendations for practice and research. *Ecological Restoration*. 27:3

Shuford, S., S. Rynne, and J. Mueller. 2010. Planning for a New Energy and Climate Future. American Planning Association, Planning Advisory Service, Report Number 558.

Transportation Research Board, Committee on Climate Change and U.S. Transportation. 2008. Potential impacts of climate change on U.S. Transportation. Transportation Research Board Special Report 290. Washington, D.C.

U.S. EPA. 2010. Overview of Climate Change Adaptation in the Southeastern U.S. with a Focus on Water and Coastal Resources – Draft Discussion Paper (1/26/2010). Stratus Consulting, Boulder CO.

Wang, L. J. Lyons, P. Kanehl, and R. Bannerman. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. *Environmental Management* 28(2): 255-266.

Wenger, S. 1999. A review of scientific literature on riparian buffer width, extent, and vegetation. Institute of Ecology, University of Georgia. Athens, GA.

---