

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

DRAFT

Montane Cool Water Stream Communities

Ecosystem Group Description:

This Ecosystem Group includes cool water stream systems in the Blue Ridge physiographic province. Typically, these are the larger rivers in the region. Many of these rivers originate in high elevation areas in the upper portion of watersheds and are therefore cold water, but transition to cool water with a decrease in elevation and addition of tributaries. The cool water designation is based upon two general principles: Fish community structure and temperature regime. Cool water streams generally have a fish species composition that includes: smallmouth bass, rock bass, walleye, sauger, creek chub, river chub, bluehead chub, whitetail shiner, white sucker, Tennessee shiner, mirror shiner, warpaint shiner, northern hog sucker, fantail darter, greenside darter, and greenfin darter. This list is not inclusive and provides general guidance on community structure. Temperature regime can also be used to help classify cool water streams where summer temperatures typically do not exceed 25 degrees Celsius (76 degrees Fahrenheit). This is a suggested temperature that will typically support the fish community structure (U.S. Army Corps of Engineers 2003). Examples include: Valley River, Hiwassee River (below Mission Lake dam), Little Tennessee River, Pigeon River (below the confluence of the East and West Forks Pigeon River), French Broad River (Below Nicholson Creek and Davidson River), Nolichucky River, New River, and Johns River.

Ecosystem Level Effects:

Predicted Impacts of Climate Change:

Climate Change Factor:	Likelihood:	Effect:	Magnitude:	Comments:
Hot Spells	Med	Neg	Med	Low dissolved oxygen associated with hot spells may increase fish kills.
Drought	High	Neg	High	Lower water levels during dry times will increase stress to the system.
Flooding	High	Neg	High	Increased severity and frequency of storm events, similar to hurricanes, will have impacts.
Increased Temperature	High	Neg	High	Chronically warmer temperatures and lower dissolved oxygen levels may increase stress on organisms.

Increased air temperatures may lead to increased water temperatures and potentially lower dissolved oxygen levels. This Ecosystem Group consists of the largest rivers in western North Carolina, but also numerous reservoirs; therefore, effects of increased air and water temperatures may vary among systems within this Ecosystem Group. Because rivers in this group are relatively shallow, thermal stratification will likely not be an issue; however, the reservoirs could experience stratification, algal blooms, and potential fish kills. Hot spells can have the same effect as overall increased air temperatures but on a much more acute scale. (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. The balance between surface flow and groundwater recharge may be altered. Decreases in overall summer precipitation may cause reduced water flows, which can further contribute to warmer water temperatures and water quality stressors (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, such as fish kills. With a change in intensity and variability of rainfall, there are potential changes to streamflow patterns, channel hydrodynamics, and the volume of groundwater (Band and Salvensen 2009; U.S. EPA, 2010; Bakke 2009). 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 (Band and Salvensen 2009).

Predicted Ecosystem Responses:

Ecosystem Response:	Likelihood:	Effect:	Magnitude:	Comments:
Phenological Disruption	Low	Neg	High	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.
Flow Regime	Med	Neg	High	Flashiness of the system may increase with more storm events, thus changing overall habitat composition.
Exotic species invasion	Low	Neg	Med	Uncertain how exotic species will affect these systems.
Compositional Change	Med	Neg	High	Changes in species composition a possibility.
Channel Hydrodynamics	Med	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 (DO) 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. Low dissolved oxygen levels may not be as frequent in streams of this Ecosystem Group as perhaps in the Piedmont or Coastal Plain, yet it is still a possibility, particularly in lower gradient larger rivers (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. The current pattern of riffles, runs, and pools, may be altered, therefore creating changes in aquatic species' habitats. How, or if, these species adapt to changing habitats will require close monitoring to observe trends and help inform future management decisions (Bakke 2008).

This Ecosystem Group consists of montane cool water streams, most of which are larger streams and rivers and many have wider valleys where land use is more intense than on steeper sloped headwater streams. Therefore, potential for sediment and stormwater effects are greater in these systems than in the cold water systems. Pools may become loaded with sediment and if flows decrease due to drought conditions, flushing may occur less frequently and allow for more accumulation. Row crops, agricultural grazing, and

urban/suburban development are more common in this Ecosystem Group than in the montane cold water systems and sedimentation, chemical inputs, and stormwater runoff are likely to have a negative effect. Stormwater runoff will amplify the loading of nutrients, sediment, and contaminants into streams, rivers, and reservoirs, which may alter overall channel design, have a negative effect on biota due to habitat changes, increased turbidity, and chemical exposure, and affect drinking water quality (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 warming waters could cause species in these cool water habitats to attempt moving upstream into cooler waters if there is suitable habitat. Some mussel species, for example, are limited in distribution because of cold water influences. Alternatively, species could become extirpated. These systems may experience a change in species composition.

Exotic species invasion is a concern, yet effects on this Ecosystem Group are largely unknown. Asian clam (*Corbicula fluminea*) and rusty (*Orconectes rusticus*) and virile (*Orconectes virilis*) crayfish are known from the mountains ecoregion and have been collected in cool water streams and rivers. Asian clam are extremely abundant in certain large rivers of this Ecosystem Group, such as the Little Tennessee River, and have been increasing significantly over the past few years. It is unknown what type of effects this exotic clam is having on the native mussel fauna, although there is research currently taking place to address that issue. There are also issues with species that are native to the state, yet non-native to particular river basins. Yellowfin shiner (*Notropis lutipinnis*), for example, is native to the Savannah River Basin, yet has been introduced to the Little Tennessee River Basin. Again, effects on native species are unknown, but changes in stream conditions could increase competition with fish species, in particular the federally threatened spotfin chub (*Erimonax monachus*).

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, predicted changing temperatures could cause phenological disruptions affecting the reproductive capacity of freshwater mussels.

Habitat Level Effects:

LHI Guilds:

Species Level Effects:

Plants

Species:	Element Rank:	Endemic	Major Disjunct	Extinction/Extirpation Prone	Status: US/NC	Comments:
Megaceros aenigmaticus	G2G3/S2S3				/SR-L	Limited to cool streams in NC, GA, & TN; reaches its northern limit in NC and this is the only species within this genus north of Mexico.
Platyhypnidium riparioides	G4/S1?				/SR-O	Widespread in North America, but in NC, this species is limited to only 4 current occurrences.
Peltigera hydrothyria	G4/S3				/W1	
Zosterella dubia	G5/S1?				/W3	Widespread in North America; reported from one county in NC, but not verified here.

Although NC does not have many rare aquatic plants in mountain streams, some that do occur here tend to be extremely rare in the state. Rare mosses and hornworts grow on rocks in rapids of cool mountain streams. Bryophytes and higher plants growing in mountain streams may be sensitive to changes in hydrology that would cause the habitat to be too dry or too wet, or that may disrupt the normal cycle of wet and dry seasons.

Aquatic Animals

Species:	NHP Rank:	Endemic	Major Disjunct	Extinction/Extirpation Prone	Status: US/NC/WAP	Comments:
Alasmidonta raveneliana	G1/S1	Yes		Yes	E/E/P	
Pegias fabula	G1/S1			Yes	E/E/P	
Villosa trabalis	G1/S1			Yes	E/SR/P	
Cambarus tuckasegee	G1G2/S1S2				/SR/P	
Stenelmis gammoni	G1G3/SH				FSC/SR/	
Erimonax monachus	G2/S1				T/T/P	
Percina williamsi	G2/SX				FSC/SC/P	
Cambarus georgiae	G2/S2S3				/SC/P	
Cambarus lenati	G2/S2				/SR/P	
Zapada chila	G2/S1S2				/SR/	

<i>Elimia christyi</i>	G2/S1			FSC/E/
<i>Percina burtoni</i>	G2G3/S1			FSC/E/P
<i>Homoeoneuria cahabensis</i>	G2G3/S2			/SR/
<i>Fusconaia barnesiana</i>	G2G3/S1			/E/P
<i>Pleurobema oviforme</i>	G2G3/SU			FSC/E/P
<i>Barbaetis benfieldi</i>	G2G4/S1			/SR/
<i>Moxostoma sp. 2</i>	G2Q/S1	Yes	Yes	C/T/P
<i>Lasmigona holstonia</i>	G3/S1			FSC/E/P
<i>Macromia margarita</i>	G3/S2S3			FSC/SR/
<i>Etheostoma acuticeps</i>	G3/S1			FSC/T/P
<i>Cambarus reburrus</i>	G3/S3			FSC/SR/P
<i>Leptoxis dilatata</i>	G3/S1			/T/P
<i>Percina squamata</i>	G3/S2			FSC/SC/P
<i>Alasmidonta varicosa</i>	G3/S1			FSC/E/P
<i>Lasmigona subviridis</i>	G3/S1			FSC/E/P
<i>Cambarus spicatus</i>	G3/S2			/SC/P
<i>Cambarus howardi</i>	G3/S3			/SR/
<i>Ophiogomphus howei</i>	G3/S1S2			FSC/SR/
<i>Etheostoma vulneratum</i>	G3/S1			FSC/SC/P
<i>Fusconaia subrotunda</i>	G3/S1			/SR/P
<i>Macdunnoa brunnea</i>	G3G4/S2			/SR/
<i>Cambarus hiwasseensis</i>	G3G4/S3S4			/W2/P
<i>Phenacobius teretulus</i>	G3G4/S2			FSC/SC/P
<i>Ichthyomyzon greeleyi</i>	G3G4/S3			//P
<i>Medionidus conradicus</i>	G3G4/SX			/EX/
<i>Ichthyomyzon bdellium</i>	G3G4/S1			/SR/
<i>Cryptobranchus alleganiensis</i>	G3G4/S3			FSC/SC/P

Ameiurus brunneus	G4/S4	//P
Percina oxyrhynchus	G4/S1	/SC/P
Ophiogomphus aspersus	G4/S1S2	/SR/
Erimystax insignis	G4/S2	//P
Moxostoma pappillosum	G4/S4	//P
Percina aurantiaca	G4/S3	/W2/P
Bolotoperla rossi	G4/S3	/SR/
Ephemerella berneri	G4/S3	/SR/
Matrioptila jeanae	G4/S3	/SR/
Etheostoma kanawhae	G4/S3	/SR/P
Ceraclea slossonae	G4/S1	/SR/
Noturus eleutherus	G4/S1	/SC/P
Cyprinella zanema	G4/S3	/SR/P
Exoglossum laurae	G4/S2	/SR/P
Polyodon spathula	G4/SH	FSC/E/
Villosa delumbis	G4/S3	/SR/P
Villosa vanuxemensis	G4/S1	/T/P
Lampetra appendix	G4/S1	/T/P
Attaneuria ruralis	G4/S2S3	/SR/
Alasmidonta viridis	G4G5/S1	/E/P
Cambarus acanthura	G4G5/S1	/SR/P
Notropis lutipinnis	G4Q/S1	/SC/P
Etheostoma jessiae	G4Q/SH	/SC/P
Erimystax insignis eristigma	G4TNR/S2	FSC/SR/
Carpionodes carpio	G5/S1	/SC/P
Pimephales notatus	G5/S3	//P
Moxostoma collapsum	G5/S5	//P

Cyclonaias tuberculata	G5/S1	/E/P
Notropis volucellus	G5/S2	/SR/P
Carpiodes cyprinus	G5/S1	/SR/P
Exoglossum maxillingua	G5/S1	/SC/P
Elliptio dilatata	G5/S1	/SC/P
Hiodon tergisus	G5/S1	/SC/
Lampsilis fasciola	G5/S1	/SC/P
Cottus carolinae	G5/S1	/T/
Potamilus alatus	G5/S1	/SR/
Strophitus undulatus	G5/S2	/T/P
Necturus maculosus	G5/S1	/SC/P
Notropis micropteryx	G5/S2	/SR/
Sympetrum obtrusum	G5/S1?	/SR/
Sternotherus minor	G5/S1	/SC/P
Aplodinotus grunniens	G5/S1	/SC/
Sander canadensis	G5/S2	/SR/
Clinostomus funduloides	G5/S5	//
Drunella lata	G5/S3	/SR/
Luxilus chrysocephalus	G5/S2	/SC/P
Ophiogomphus rupinsulensis	G5/S1?	/SR/
Ictiobus bubalus	G5/S1	/SR/P
Isoperla frisoni	G5/S3	/SR/
Ceraclea mentiea	G5/S2	/SR/
Noturus flavus	G5/S1	/E/P
Triaenodes marginatus	G5/S3	/SR/
Notropis photogenis	G5/S3	/W5/P
Moxostoma breviceps	G5/S2	/SR/

Ictiobus niger	G5/S1	/SR/
Percina caprodes	G5/S1	/T/P
Villosa iris	G5Q/S1	/SC/P
Clinostomus sp. 1	G5T3Q/S3	FSC/SC/P
Notropis sp. 1	GNR/S2	/SR/P

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.
Pollution	1	Point and nonpoint sources - runoff, endocrine disrupting chemicals - are threats.
Cattle in Streams	1	Nutrient and sediment inputs; bank destabilization.
Lack of riparian vegetation	1	Loss of riparian vegetation causes numerous problems.
Conversion to agriculture/sylvicu	2	Loss of forest cover can cause increased erosion and sedimentation and negatively impact aquatic systems.
Water Withdrawals	2	Irrigation and water supply withdrawals pose a threat to flow regime.
Flood Regime Alteration	2	Impoundments have direct and indirect effects.
Climate Change	3	Climate change effects will likely compound with other threats to increase the severity of several threats to aquatic systems.
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, particularly in steep slope areas, is of particular concern because of increased erosion. Livestock access to streams contributes heavily to bank erosion, sedimentation, and nutrient input. 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).

Riparian vegetation is critical to the overall stream and streambank stability. Lack of riparian vegetation or inadequate width of forested buffer can cause streambank erosion and sedimentation. In addition to stabilizing streambanks, riparian vegetation serves as nutrient input to the stream community and helps regulate stream temperature by providing shade.

Invasive plants in the riparian area can have negative impacts on stream systems by creating a monoculture (such as Japanese knotweed) with poor nutrient inputs, reducing bank stability, and allowing too much sunlight and therefore warmer stream temperatures. Invasive aquatic species, like Asian clam or rusty 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. Water withdrawals can be problematic, particularly in streams with already low 7Q10 flows, because they may reduce available habitat for aquatic species.

Impoundments have direct and indirect impacts on aquatic systems. Many rivers that were once free-flowing are now flooded by reservoirs, severely fragmenting habitat and often isolating populations of species above and below the impoundment. For the unimpounded reaches there are several indirect effects, such as disruption of natural thermal regimes, which often includes cold water releases below dams, disruption to natural hydrologic regimes, and potential low dissolved oxygen from hypolimnetic releases below dams.

Recommendations for Action:

Interventive Measures:

Intervention:	Importance:	Feasibility:	Comments:
Water Resources Management	Mediu	Medium	
Bridge/Culvert Design	Mediu	Low	
Stormwater Management	High	Medium	

Research and Monitoring	Mediu	High
Restore/Maintain Landscape Connections	High	Low
Species Reintroduction/Augmentation	High	High
Increased Open Space	High	Medium
Eliminate/Prevent Pollution	High	Medium
Control Erosion	High	Medium
Limit Impervious Surfaces	High	Medium
Preservation of Riparian Buffers/Floodplains	High	Medium

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 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 provide 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 periodically require updating 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).

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. 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, can increase connectivity between habitats and across elevational zones. There is a 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 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 tolerance 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:

Climate change is likely to have a synergistic effect with other, more impending threats to these systems, such as development and lack of/removal of riparian vegetation. Cool water stream systems will probably persist. Very few specific climate change-related impacts have been identified, and the rare species and their habitats are expected to persist.

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.
- 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.
- 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. Army Corps of Engineers, Wilmington District. (2003). Stream mitigation guidelines. Retrieved from www.saw.usace.army.mil/wetlands/mitigation/stream_mitigation.html.

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.
