

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

DRAFT

Montane Cold Water Stream Communities

Ecosystem Group Description:

This Ecosystem Group includes cold water stream systems in the Blue Ridge physiographic province. Often these cold water streams are headwater systems, but the upper portions of some large rivers may be considered cold water, particularly if they are influenced by hydroelectric projects. The cold water designation is based upon two general principles: fish community structure and temperature regime. Cold water streams generally have a fish species composition that includes: brook, brown, and rainbow trout, mottled sculpin, longnose dace, blacknose dace, and central stoneroller. This list is not inclusive and provides general guidance on community structure. Temperature regime can also be used to help classify cold water streams, where summer water temperatures typically do not exceed 20 degrees Celcius (68 degrees Fahrenheit). This is a suggested temperature that will typically support the fish community structure (US Army Corps of Engineers 2003). Examples include: Peachtree Creek, Fires Creek, Tellico Creek, Nantahala River, Davidson River, Spring Creek, Big Crabtree Creek, Helton Creek, and Wilson Creek.

Ecosystem Level Effects:

Predicted Impacts of Climate Change:

Climate Change Factor:	Likelihood:	Effect:	Magnitude:	Comments:
Flooding	High	Neg	High	Increased severity and frequency of storm events, similar to hurricanes, will have impacts.
Drought	High	Neg	High	Lower water levels during dry times will increase stress to the system.
Hot Spells	Med	Neg	Med	Low dissolved oxygen associated with hot spells may increase fish kills.
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; however, increased air temperature may have varying effects on these cold water systems due to factors such as the degree of groundwater influence, amount of shading by riparian vegetation, and watershed aspect. Hot spells can have the same effect as overall increased air temperatures but on a much more acute scale and problems such as increased evaporation and therefore lower amounts of flowing water will vary depending on factors such as groundwater influence, as mentioned above. Increased water temperature can alter the distribution of native species, particularly brook trout, which are generally intolerant of temperatures exceeding 20 degrees Celsius (68 degrees Fahrenheit) and are already at the southern end of their range and occur often in the highest elevations due to displacement by brown and rainbow trout. Increased temperatures may cause a decline in the extent of cold water streams. Some aquatic Ecosystem Groups could experience a shift in habitat; however, it is likely this Ecosystem Group will

shrink (DeWan et al., 2010; Karl et al., 2009; Band and Salvensen, 2009; U.S. EPA, 2010; Flebbe et al., 2006; U.S. Army Corps of Engineers, 2003).

Changes in precipitation may have numerous and varied effects. Severe and prolonged droughts may decrease streamflow, decrease groundwater recharge, and increase evaporation, although these impacts may vary depending on site-specific conditions in these cold water systems. 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 and landslides, which are of particular concern in mountainous, high-elevation areas. Landslides lead to increased sediments and contaminants into aquatic systems, in addition to major disruption to channel design and hydrodynamics, potentially upsetting the physical, chemical, and biological structure of streams (Band and Salvensen, 2009).

Predicted Ecosystem Responses:

Ecosystem Response:	Likelihood:	Effect:	Magnitude:	Comments:
Acreeage Change	High	Neg	Med	Warming temperatures at higher elevations may cause the complete loss of these systems.
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; decline or loss of trout species.
Channel Hydrodynamics	Med	Neg	High	Changes in flow regime will likely result in changes in the overall stream morphology and transport of sediment.

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 cold water streams, many of which are headwater streams and may be protected by national forest land. However, development has increased in high elevation areas on private lands and erosion and sedimentation from ground disturbance is possible, in addition to increased runoff from impervious surfaces. Increased sediment in these systems may alter overall channel design and have a negative effect on biota due to habitat changes and increased turbidity.

Trout populations in NC are already at the southern end of their range and perturbations to the aquatic

systems, particularly increases in stream temperature, lowered dissolved oxygen, or increased turbidity could lead to significant declines or extirpation of native brook trout, in addition to the non-native and stocked brown and rainbow trout. Typically trout are unable to survive in waters where summer temperatures rise above 20 – 24 °C. Because of the already limited range of trout, particularly native brook trout, in North Carolina it is unlikely these fish will be able to seek refuge from warming water temperatures. Currently they typically occupy the most headwater streams in the Southern Appalachian mountains of North Carolina, and therefore few populations have the ability to migrate to cooler waters. Along with temperature changes, there likely will be changes in hydrology, riparian vegetation, and land cover patterns which can affect trout population size and their overall survival (Flebbe et al., 2006).

In addition to trout, other aquatic species could experience shifts in their range or distribution and sensitive species may experience decline or extirpation. Because these are cold water streams, the fauna may not tolerate warming temperatures and there is no ability for species to migrate to cooler waters. Therefore, this Ecosystem Group will likely experience a decrease in size due to these cold water streams becoming cool water streams. There may be some species, such as freshwater mussels, inhabiting montane cool water systems that could move into these cold water systems if temperatures increase. Freshwater mussels rarely overlap habitat with trout; however, with changes to the temperature regimes in these systems, trout may be extirpated and freshwater mussels could expand or shift habitats. Therefore, these systems could 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 cold water streams although not very high in these systems. However, with increases in water temperature, some invasive species may be better suited to move into these cold water habitats. 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 and Broad River Basins, yet has been introduced to the Little Tennessee River Basin. Its range could potentially expand into these cold water systems with warmer water temperatures.

Habitat Level Effects:

LHI Guilds:

Species Level Effects:

Plants

Species:	Element Rank:	Endemic	Major Disjunct	Extinction/Extirpation Prone	Status: US/NC	Comments:
Aspiromitus appalachianus	G1/S1	Yes		Yes	FSC/SR-L	In NC, this species is known only from the type locality in Toxaway River Gorge, not seen since 1960.

Megaceros aenigmaticus	G2G3/S2S3	/SR-L	Apparently very sensitive to changes in water quality such as sedimentation, run-off from farms, and increased water temperatures due to canopy removal in adjacent forests. Undisturbed streams within the species' small range have thriving populations, while nearby streams in farmed and developed areas lack or have very reduced populations.
Fissidens appalachensis	G2G3/S2S3	/W7	Grows submerged in rapids of high elevation mountain streams.
Hygrohypnum closteri	G3/S1	/SR-T	
Ephebe solida	G3G4/S1	/SR-P	
Peltigera hydrothyria	G4/S3	/W1	
Ephebe lanata	G5/S1	/SR-D	

NC does not have many rare aquatic plants in mountain streams, but those that do occur here tend to be extremely rare in NC. Plants growing in mountain streams may be sensitive to changes in hydrology that would cause the habitat to be too dry or to 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:
Cambarus tuckasegee	G1G2/S1S2			Yes	/SR/P	
Stygobromus carolinensis	G1G2/S1			Yes	FSC/SR/	
Cambarus parrishi	G2/S1				FSC/SC/P	
Zapada chila	G2/S1S2				/SR/	
Rhyacophila amicus	G2/S2				/SR/	
Cambarus lenati	G2/S2				/SR/P	
Megaleuctra williamsae	G2/S1				/SR/	
Elimia christyi	G2/S1				FSC/E/	
Cambarus georgiae	G2/S2S3				/SC/P	
Cambarus chaugaensis	G2/S2				/SC/P	
Erimonax monachus	G2/S1			Yes	T/T/P	
Barbaetis benfieldi	G2G4/S1				/SR/	
Moxostoma sp. 2	G2Q/S1				C/T/P	

Cambarus reburrus	G3/S3	FSC/SR/P
Cambarus spicatus	G3/S2	/SC/P
Percina squamata	G3/S2	FSC/SC/P
Etheostoma vulneratum	G3/S1	FSC/SC/P
Macromia margarita	G3/S2S3	FSC/SR/
Cambarus howardi	G3/S3	/SR/
Leptoxis dilatata	G3/S1	/T/P
Cambarus hiwasseeensis	G3G4/S3S4	/W2/P
Ichthyomyzon bdellium	G3G4/S1	/SR/
Phenacobius teretulus	G3G4/S2	FSC/SC/P
Cryptobranchus alleganiensis	G3G4/S3	FSC/SC/P
Ichthyomyzon greeleyi	G3G4/S3	//P
Etheostoma inscriptum	G4/S1	/T/P
Percina oxyrhynchus	G4/S1	/SC/P
Noturus eleutherus	G4/S1	/SC/P
Erimystax insignis	G4/S2	//P
Bolotoperla rossi	G4/S3	/SR/
Percina aurantiaca	G4/S3	/W2/P
Etheostoma kanawhae	G4/S3	/SR/P
Hybopsis rubrifrons	G4/S1	/T/P
Cambarus nodosus	G4/S2	/SR/P
Exoglossum laurae	G4/S2	/SR/P
Matrioptila jeanae	G4/S3	/SR/
Lampetra appendix	G4/S1	/T/P
Ephemerella berneri	G4/S3	/SR/
Attaneuria ruralis	G4/S2S3	/SR/
Ameiurus brunneus	G4/S4	//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/
Sternotherus minor	G5/S1	/SC/P
Necturus maculosus	G5/S1	/SC/P
Drunella lata	G5/S3	/SR/
Isoperla frisoni	G5/S3	/SR/
Cottus carolinae	G5/S1	/T/
Palaeagapetus celsus	G5/S2	/SR/
Notropis photogenis	G5/S3	/W5/P
Notropis volucellus	G5/S2	/SR/P
Pimephales notatus	G5/S3	//P
Notropis micropteryx	G5/S2	/SR/
Moxostoma collapsum	G5/S5	//P
Luxilus chrysocephalus	G5/S2	/SC/P
Moxostoma breviceps	G5/S2	/SR/
Clinostomus funduloides	G5/S5	//
Percina sciera	G5/SX	/E/
Micropterus coosae	G5/S1	/SR/
Percina nigrofasciata	G5/S1	/T/P
Percina caprodes	G5/S1	/T/P
Clinostomus sp. 1	G5T3Q/S3	FSC/SC/P
Skistodiaptomus carolinensis	GNR/S1?	/SC/
Notropis sp. 1	GNR/S2	/SR/P

The native brook trout should be a species considered vulnerable to extinction in this Ecosystem Group.

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.
Lack of riparian vegetation	1	Loss of riparian vegetation causes numerous problems.
Pollution	2	Point and Nonpoint sources - runoff, endocrine disrupting chemicals - are threats.
Cattle in Streams	2	Nutrient and sediment inputs; bank destabilization.
Climate Change	3	Cold water systems may shrink in habitat and extent.
Water Withdrawals	4	Irrigation withdrawals pose a threat to flow regime.
Conversion to agriculture/silviculture	4	Christmas tree farming is established and growing in this Ecosystem Group.
Invasive Species	5	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.

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.

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. Other invasive species, such as the exotic pest, hemlock woolly adelgid, may be a significant factor in cold water stream communities because of the important role that hemlock plays in these riparian areas. If hemlocks are removed from the system, nutrient inputs and temperature regimes may be disrupted and therefore disrupt aquatic organism life cycles and cues. 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).

In several cold water stream watersheds, Christmas tree farming is a popular and widespread practice. This is a very intensive form of agriculture that uses high amounts of herbicides and pesticides, some of which are known to persist in soil for long periods of time. Effects to aquatic systems are unknown at this time, but could be significant.

Recommendations for Action:

Interventive Measures:

Intervention:	Importance:	Feasibility:	Comments:
Water Resources Management	Mediu	Medium	
Bridge/Culvert Design	Mediu	Low	
Stormwater Management	High	Medium	
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	
Research and Monitoring	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. Planning for a New Energy and Climate Future). 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).

Trout Stocking

Numerous literature studies have shown that stocked or introduced salmonids have negatively impacted native salmonids through predation, emigration, habitat use, competition, and production (as referenced in Weaver 2010). Stocked salmonids, along with other factors, have certainly contributed to the decline of native Southern Appalachian brook trout in North Carolina; however, stocked salmonids have not been shown to have negative effects on nongame fish species (Weaver 2010). Weaver (2010) examined the effects of trout stocking on native nongame fishes in a newly stocked river and also compared other streams that are annually stocked with trout paired with unstocked reaches to investigate long-term effects from trout stocking. There were no significant differences found in fish density, species richness, species diversity, or fish microhabitat use associated with short-term effects of trout stocking. Additionally, there were no significant differences found in fish density, species richness, species diversity, or population size structure associated with long-term effects of trout stocking.

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:

Cold water stream communities contain several rare species that are vulnerable to extinction. Their rarity makes them vulnerable to changes in habitat. While climate change is not the most severe threat to these systems, it, in conjunction with development and lack of riparian corridors, could stress these systems to the point where several species are unable to persist. Because of their elevation and location within the watershed (usually as headwater streams), many species will not be able to respond by migrating to cooler temperature streams, thus resulting in possible extinction of several species.

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