Sustainable River Flows for North Carolina

by

Mallory L. Dimmitt
Dr. Erika Weinthal, Advisor
April 2009

Masters project submitted in partial fulfillment of the
requirements for the Master of Environmental Management degree in
the Nicholas School of the Environment of
Duke University

2009

ABSTRACT. The drought of 2007-2008 focused the attention of North Carolina lawmakers and the environmental community on water use issues, prompting a statewide Water Allocation Study. The study did not specify the means by which to protect the flows of streams and rivers. With the goal of aiding protection of long-term ecological integrity, this master's project identifies the scientific and political processes necessary to develop and implement an environmental flows program for the surface waters of North Carolina. Specifically it recommends using the Indicators of Hydrologic Alteration (IHA) software to develop flow criterion, and integrating these into river basin planning models. It also suggests a potential path decision makers could use to formally authorize and adopt flow legislation and regulations in North Carolina.

TABLE OF CONTENTS

Introduction

Water use and water allocation decisions are one of the priorities for lawmakers in North Carolina in the 2009 legislative session, which surfaced in the wake of the prolonged and severe drought that affected portions of the Southeast in 2007 and 2008. The purpose of this master's project is to address one small, but critical, piece of water allocation – sustainable baseline flows for North Carolina's rivers. With the goal of protecting long-term ecological integrity, [1] this report identifies the scientific and political processes necessary to develop and implement an environmental flows program for the surface waters of North Carolina.

The Environmental Review Commission of the North Carolina Legislature tasked my clients -- the Nicholas Institute at Duke University and the School of Government at the University of North Carolina Chapel Hill -- to devise a potential framework for allocating freshwater resources statewide. The water allocation study (WAS) was finalized at the end of 2008 and evaluated supply, demand, and management of the state's water resources in order to formulate policy options for allocation regimes. The study summarized that "the state uses water like a person who has no budget spends money," and recommended developing a permit system for large water-withdrawals as well as "a proactive, adaptive, river basin–planning system that is led by local water suppliers and water users" to manage water resources in North Carolina for the present and the future.[2] Following the study, potential legislation incorporating recommendations from the WAS was created and submitted to NC legislative staff in early March 2009 for consideration in the current legislative session.

---

[1] Ecological integrity can be defined as "the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat," as written by Karr, J.R. and Dudley, D.R. 1981. Ecological Perspectives on Water Quality Goals. Environ. Manage. 5: 55-68.

[2] Whisnant, R., Holman, W., et al. 2008 Report of the Water Allocation Study of the N.C. Environmental Review Commission (Dec. 31, 2008). http://sogweb.sog.unc.edu/Water/images/4/40/2008NCERCWaterAllocationStudyFinalReport.pdf.

One vital component of allocating water resources is to protect optimal flows for streams and rivers. Sufficient flows are vital because they provide water for instream uses such as river channel processes, habitat for aquatic species, life-sustaining water for wildlife and plants, and for human uses such as recreation, hydropower, or wastewater assimilation. Instream flow level is simply the volume of water in a river or stream channel at any given time. This amount may not be adequate to provide any or all of the benefits mentioned above, and is generally not managed or regulated. A designated instream flow is one that recognizes and sets aside the minimum quantity of water needed for one, some, or all of the desired instream uses for a particular reach, so that this water cannot be withdrawn for other uses outside of the stream channel. Even designated instream flows can be insufficient to protect natural ecological processes, so the concept of environmental flows has emerged in the literature and in practice.

Environmental flows can be defined as "the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems."[3] These flows are typically the result of a formal process: "the negotiated outcome to balance human and ecological needs for water management of reservoirs, diversions, and other human works" which "are protected or administered under a permit, water right, or other legally recognized means."[4] Environmental flows are also known as ecological flows or e-flows.

Environmental flows are an important tool for the long-term protection of viable populations of aquatic species, which have suffered as a result of human consequences in the United States and around the world. In fact, "the top four groups of U.S. species at risk –

---

[3] Global Environmental Flow Network. "Terminology and Definitions Adopted by eFlowNet." http://www.eflownet.org/viewinfo.cfm?linkcategoryid=4&linkid=13&siteid=1&FuseAction=display.

[4] Davis, M. M. In prep. Instream Flow Protection: An overview of legal, planning, financial, and scientific support for state programs with examples from southern states. A web report for the Southeast Aquatic Resource Partnership, Southern Instream Flow Network. www.sarpaquatic.org.

freshwater mussels, crayfishes, amphibians, and freshwater fish – all depend upon healthy, functioning freshwater ecosystems."[5] In the current global extinction crisis that plagues our planet, where record numbers of species are going extinct due to human activities,[6] "the steepest biodiversity declines disproportionately affect freshwater species."[7] This has led the International Union for Conservation of Nature (IUCN) to characterize freshwater species, globally, as "extremely threatened," propelling them to make the following recommendation: "Management of water resources must take account of the requirements of freshwater species. This approach is encapsulated within the Environmental Flows concept, which aims to ensure that there is enough water to maintain environmental, economic and social benefits."[8]

The implementation and administration of designated instream flows or environmental flows across a geographic area constitutes an instream flow program. Such a program was recently developed for Pennsylvania, and the authors of that report had the following to say about the scientific complexity of their assignment:

> "The development of environmental flow criteria that can be applied across broad spatial scales is the central challenge of implementing an instream flow protection program. There are a wide variety of methodologies available for determining site-specific environmental flow needs, each with their strengths and weaknesses. In contrast, very few methodologies exist, or have been applied, across the regional spatial scale (i.e., of a state or large river basin). This report focuses on an integrated approach for the development of scientifically sound, implementable environmental flow criteria statewide."[9]

---

[5] Ibid.
[6] International Union for Conservation of Nature. 2008. IUCN Red List: State of the World's Species. http://cmsdata.iucn.org/downloads/state_of_the_world_s_species_factsheet_en.pdf.
[7] Davis, M. M. In prep. Instream Flow Protection: An overview of legal, planning, financial, and scientific support for state programs with examples from southern states. A web report for the Southeast Aquatic Resource Partnership, Southern Instream Flow Network. www.sarpaquatic.org.
[8] International Union for Conservation of Nature. 2008. IUCN Red List: Freshwater Biodiversity – A Hidden Resource Under Threat. http://intranet.iucn.org/webfiles/doc/SpeciesProg/FBU/IUCN_WCC_Freshwater_Factsheet.pdf.
[9] Apse, C., DePhilip, M., Zimmerman, J., and Smith, M.P. 2008. Developing Instream Flow Criteria to Support Ecologically Sustainable Water Resource Planning and Management. http://www.depweb.state.pa.us/watershedmgmt/lib/watershedmgmt/water_allocation/pa_instream_flow_report-_tnc_growing_greener-_final.pdf.

Even if flow criteria can be agreed upon, there is the added challenge of securing the legal and financial support for managing and regulating environmental flows using the political process, by formally adopting a flow program at the state legislature. Developing and recommending the implementation of a plan to navigate these scientific and political processes in North Carolina is the main objective of this master's project.

Methods

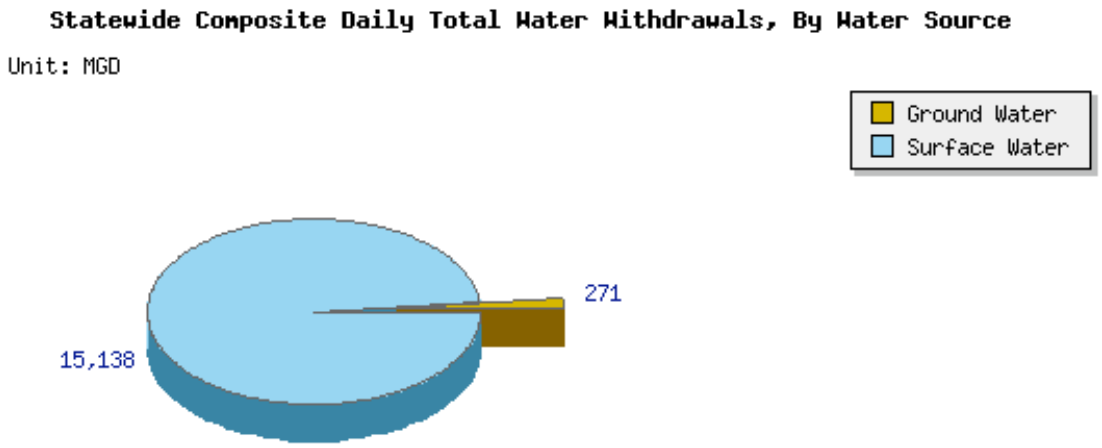
Developing these recommendations requires knowledge and research of the legal, institutional, and political framework supporting instream flow adoption in other states, and an understanding of the current state of freshwater resource management in North Carolina. It also requires evaluating the state's capacity for developing and managing instream flows. The methodology is two-part. It includes a literature review of the relevant papers and case studies describing instream flow program adoptions, opportunities, or challenges in other states similar to North Carolina, and researching or reviewing existing conditions in NC. This included researching the powers and chain of command of the state agency that manages flow programs -- North Carolina Department of Environment and Natural Resources, Division of Water Resources, Instream Flow Unit -- and the legislation that granted their authority. The second part of the methodology was participatory. I participated in Southern Instream Flow Network (SIFN) workshops and web casts, attended conferences, convened a meeting with the N.C. instream flow team participating in SIFN, and conducted meetings or conversations with various other experts to learn from their experience with ecological flows or North Carolina water resource management.

Background

North Carolina's Surface Water Overview

North Carolina's waters are under increasing pressure as population grows, but water use and withdrawal have historically been only minimally regulated in the state. Water supplies have traditionally been abundant, since North Carolina averages between 40 and 55 inches of precipitation a year in the piedmont and coastal regions. The mountains, which receive more than 90 inches of rainfall a year in places, are some of the wettest locales east of the Mississippi River.[10] Demands for use of this water rely heavily on withdrawal of surface waters from lakes, rivers, and streams across the state.

Figure 1

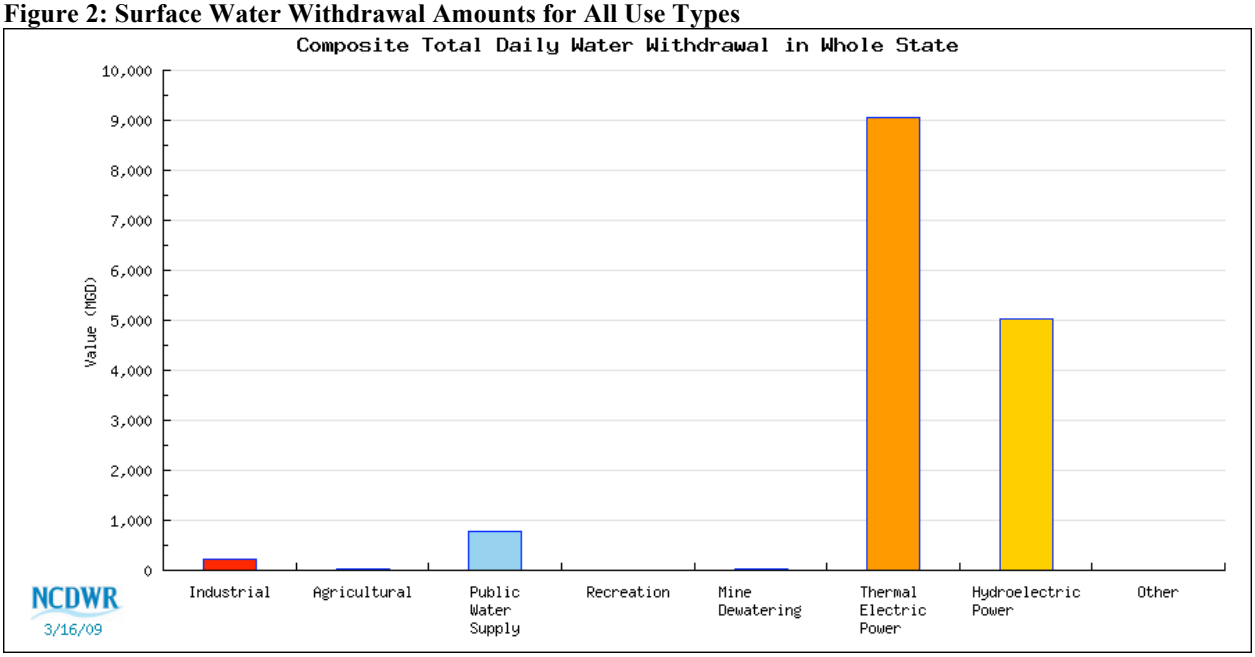


Source: Division of Water Resources, NC Department of Environment and Natural Resources.

Water is withdrawn from surface waters or groundwater sources for a variety of uses. Figures 2 and 3 below depict the off-stream uses for surface waters only.

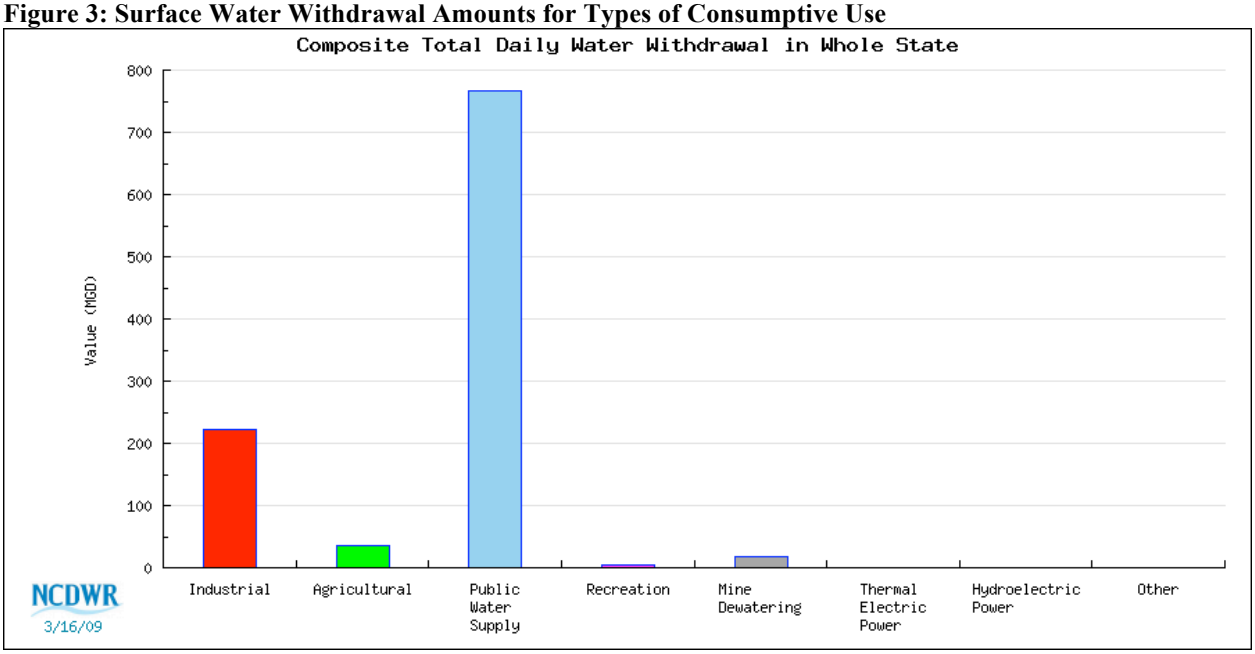
[10] State Climate Office of North Carolina. Overview: Precipitation. http://www.nc-climate.ncsu.edu/climate/ncclimate.html#precip.

Figure 2: Surface Water Withdrawal Amounts for All Use Types



Source: Division of Water Resources, NC Department of Environment and Natural Resources.

Figure 3: Surface Water Withdrawal Amounts for Types of Consumptive Use



Source: Division of Water Resources, NC Department of Environment and Natural Resources.

As you can see in Figure 2, power generation requires the largest volume of surface water withdrawals in North Carolina, but a large proportion of that water is returned to the same water body after use, since it is not consumed in the process. Figure 3 eliminates these mostly non-consumptive uses, showing that of the remaining consumptive uses, public water supply uses by

far the largest amount of water, followed by industrial and agricultural uses. One important caveat is that these graphs depict total withdrawals reported, but users who withdraw less than 100,000 gallons per day are not required to report their water withdrawal or use under North Carolina law, and this reporting threshold is increased to 1,000,000 gallons a day for agricultural users in most of the state (outside of the Capacity Use Area). It is therefore likely that the bars depicted, especially the red and green bars for industrial and agricultural withdrawals, would be higher if these were accurate illustrations of water use, but the exact volume of water withdrawn from North Carolina's surface waters is unknown.

Freshwater biodiversity may be threatened by these withdrawals,[11] and flow protection mechanisms are non-existent in many stream segments or water reaches. Where they do exist, they may be insufficient for sustaining species assemblages or maintaining physical and biotic processes. Continuing without instream flow protection is a risk for North Carolina because conflicts arising over water use and management will likely increase as more people move into the state and the region, and demand for water intensifies. North Carolina is currently in a legal battle with South Carolina over water issues, and the state also previously challenged, unsuccessfully, Virginia's ability to transfer water from the Roanoke River to Virginia Beach.[12] In fact the Catawba-Wateree River was named as America's Most Endangered River in 2008, threatened by "outdated water supply management."[13] American Rivers summarized this finding by saying, "The population explosion in the Charlotte region has left decision makers in both

[11] The North Carolina Wildlife Action Plan lists hydrologic alteration as the second threat to North Carolina freshwater biodiversity [North Carolina Wildlife Resources Commission. 2005. North Carolina Wildlife Action Plan. p. 278. http://www.ncwildlife.org/pg07_WildlifeSpeciesCon/WAP_complete.pdf]. More information on the status and threats to NC aquatic species, including fish, mollusks, and crayfish species, is included in Appendix1-2.

[12] See State of South Carolina v. State of North Carolina, No. 138, Original, United States Supreme Court; State of North Carolina v. City of Virginia Beach, 951 F.2d 596 (4th Cir. 1991); and Jehl, D., A New Frontier in Water Wars Emerges in East. The New York Times. March 3, 2003.http://www.nytimes.com/2003/03/03/national/03RIVE.html.

[13] American Rivers. 2008. Catawba-Wateree: America's Most Endangered River. http://www.americanrivers.org/site/DocServer/CatawbaFINAL.pdf?docID=7521.

North and South Carolina flummoxed when it comes to water policy. Neither state has anything that resembles a sustainable long term water plan."[14] A sustainable plan that keeps enough water in the river would be beneficial to the people who depend on that river for power production, industrial uses, drinking water supply, recreation, and for the economic impact and jobs that each of those human uses support, in addition to protecting the instream environment.

Even with associated benefits to people, dedicated instream flows will be a controversial component of adopting comprehensive water allocation and management policies for the state, since it requires regulating water withdrawals. North Carolina, South Carolina, and Alabama are the only three states in the South that have not adopted water withdrawal regulations. "The debate about ecological flows has been the single greatest political obstacle in South Carolina to legislative enactment of a water resources management system including regulation of water withdrawals, and will likely be the greatest obstacle in North Carolina and Alabama" as well.[15]

Large water users, those who withdraw more than 100,000 gallons a day from surface water sources, will be affected by a proposed water allocation system, since they will be required to obtain a permit for their withdrawals from the state Division of Water Resources. These users are currently required to report their withdrawals, but do not yet have to seek a permit before they can commence withdrawing water. Agricultural users will also be affected, since they are not required to report water withdrawals unless they withdraw in excess of 1 million gallons per day (mgd). The water allocation study recommended a water withdrawal permit system that institutes a standard 100,000 gallons/day threshold for all surface water users, and proposed legislation to institute this recommendation will face opposition by agricultural producers and agricultural interest groups.

---

[14] American Rivers. 2008. Catawba-Wateree: America's Most Endangered River. http://www.americanrivers.org/site/DocServer/CatawbaFINAL.pdf?docID=7521.

[15] Holman, W. Personal communication. March 2, 2009.

Proponents of a water allocation system that reserves a portion of flows to protect ecological integrity include the environmental community and most state and federal natural resource or wildlife agencies. The environmental community in North Carolina includes an informal coalition of seven non-profit organizations that have voiced support for environmental flows in response to the WAS, including American Rivers, Clean Water for NC, Conservation Council of NC, North Carolina Conservation Network, Neuse Riverkeeper Foundation, Southern Environmental Law Center, and the Western NC Alliance. The Environmental Defense Fund and The Nature Conservancy are active in environmental flow issues in North Carolina and elsewhere, and have made a commitment to fund a pilot study to test a methodology for developing flow prescriptions in this state. Local, place-based environmental or water resource interest groups are also likely to support the protection of river flows and lake levels. The Catawba Riverkeeper Foundation and Lake Wylie Marine Commission submitted comments to the WAS in this vein. The U.S. Fish and Wildlife Service is supportive of e-flows, since they protect habitat for threatened and endangered species under their jurisdiction. The North Carolina Wildlife Resources Commission and the NC Department of Environment and Natural Resources both acknowledged their support for the efforts to protect the health and integrity of state water resources.

Not all parties are clear winners or losers in proposed water allocation schemes that include flow protections. For example, electric power companies are large water users who would not favor additional or more stringent restrictions on needed withdrawals, but they also generate hydropower that is critically dependant on adequate volumes of water. Both Duke Energy and Progress Energy submitted comments to the WAS generally supportive of flow regulations, so long as their existing authority to withdraw water under Federal Energy

Regulatory Commission (FERC) license is preserved. Municipalities and water suppliers also fall into this middle category, since they are already regulated by the state, and more robust basin-wide planning could help ensure adequate water supplies. It's possible to characterize parties who do not have environmental protection central to their mission yet depend on water availability as cautiously optimistic about flow regulation for the certainty it provides, but the "devil is in the details" for these each of these entities.

Given the controversy and complexity described above, flows were only minimally addressed in the WAS, to allow flexibility and time for interested parties to work out the details for a comprehensive flow program.[16] The study recommended enhancing the laws and institutions governing water allocation in North Carolina for multiple reasons, including the ability to reserve flows needed to safeguard the integrity of the state's surface waters. It did not outline tools, methods or mechanisms to accomplish these tasks. Instead it recommended gathering additional information, by including the following question in the "critical research and study needs" section of the report: "How exactly should the state implement the instream flow goal … pursuant to the [study's other] recommendations?"[17]

Decision makers in North Carolina faced with answering that question could follow one of three broad courses of action to meet this goal.

1. Convinced that sufficient information exists, introduce legislation and supporting regulations detailing an instream flow program, or
2. Task a group of experts to study and debate instream flow options and report back with a recommended approach, or

[16] Whisnant, R. Personal communication. October 6, 2008.
[17] Whisnant, R., Holman, W., et al. 2008 Report of the Water Allocation Study of the N.C. Environmental Review Commission (Dec. 31, 2008). http://sogweb.sog.unc.edu/Water/images/4/40/2008NCERCWaterAllocationStudyFinalReport.pdf.

3. Take a hybrid approach. Create new legislation that requires ecological flows as a standard for NC rivers, and requires regulations to follow.

The alternative, which is to take no action and continue with business as usual, is not included because it does not aid in the goal of developing and implementing a flow policy as described in the water allocation study. The three options given above can be described using a football analogy. The first option is a Hail Mary – where the quarterback, under pressure, lobs the ball for the end zone, but how it comes down and if it will be successful is anyone's guess. The second option is equivalent to punting – delaying pro-active scoring opportunities until the next turn. The third option is akin to a sustained drive, where the immediate goal is to secure a first-down, moving closer to the end zone and setting up additional plays. While all three approaches are legitimate options, this paper favors the latter strategy and provides guidance toward that end.

Each option has potential pitfalls that merit mention. The Hail Mary pass is a long shot, has little chance of success, and is therefore the least desirable approach. For environmental flows, this could be the result of the legislature setting some arbitrary political process in place to determine flows, rather than a tested, science-based approach or seeking recommendations from an objective panel of experts. It is unlikely that the legislature would go this route, but they may feel pressure to pass a bill before the legislative session ends. The legislature could also act rashly if they deem that probable infighting amongst the proponents of flow legislation is undesirable and could be solved by passing such a bill.

The option to punt and delay decisive action until the next turn is appealing, in the hope that some of the controversy gets resolved in the ensuing break in action. In practice this would be the equivalent of taking no action on flow legislation during the 2009 legislative session, other than tasking a panel to study the issue and report back once they have developed

recommendations. This stall tactic might be desirable for those who favor passing water allocation legislation by separating out the more controversial section regarding flow regulation. While this could be politically preferable for people intent on passing some components of a flow program as a first step, like withdrawal permits, it increases the risk of falling short of the ultimate objective to protect the ecological integrity of North Carolina's streams and rivers. Favoring short-term gains over the long-term goal can undermine the desired outcome, and in this case is putting the cart before the horse. It would be backwards to develop a permit system, which gives entities a right to withdraw water from streams, before setting a baseline ecological flow against which to measure all other withdrawals.

As previously mentioned, this paper favors a hybrid approach of legislation that requires setting environmental baseline flows before withdrawal permits are issued, but does not prescribe the method for determining these flows. This strategy is also not without risks. The biggest risk is the potential inability to pass overarching legislation authorizing e-flows, which could be made more difficult without the details describing what a flow program would entail. Disagreement over setting environmental baselines could stymie passage of the rest of the components of a water allocation program and vice-versa. However, the risk is worth the trade-off to the environmental community because environmental flows are "the heart of the issue – the 10 percent that makes the other 90 percent [of a water allocation regime] useful."[18] Without including e-flows, the environmental organizations would almost certainly oppose new water management legislation. The hybrid approach then, is the tactic of choice. To employ it, it is helpful to first describe the end goal in terms of flow regimes, next to evaluate the state's current approach to flow protection, and finally to identify guidelines to navigate the divide separating the two in a strategic manner.

[18] McNaught, D. and Pearsall, S. Personal Communication. February 23, 2009.

Desired Results

The outcome desired by the environmental community is to establish an environmental baseline flow standard, defined as a hydrologic regime sufficient to support the ecological integrity of North Carolina's streams and rivers on a continuing basis. This paradigm acknowledges that prescribed flow regimes will, at times, be subject to sporadic and extreme events which will stress the systems the flow regime is designed to protect, as occurs naturally in unaltered streams, but that these events will be very rare. The environmental baseline will be different for each river basin or sub-basin, but the methods for determining, implementing, and monitoring the flow regimes should be standardized across the state. The resulting baseline will not be a static year-round flow, but will adjust to season and across years to mimic natural inter-annual and intra-annual fluxes. Nevertheless it will serve as a floor that cannot be undermined by other water allocation decisions. The baseline represents a first order or highest priority call on water use when the water is allocated. For this reason, it is important that legislation recognizing baseline environmental flows is adopted in concert with other water allocation mechanisms, such as a permit system for withdrawals. Baselines should be developed before lasting allocation decisions are made. Adopting such a system will allows North Carolina to balance human and ecosystem water needs for now and into the future.

Existing Flow Governance in North Carolina

Certain activities in or adjacent to NC Rivers require maintaining minimum flow levels as a condition of the permit necessary to construct or operate the project. Minimum flow stipulations are included in a handful of laws and regulations, which are administered by a variety of state or federal agencies, depending on the type of project proposed. The types of

activities, regulatory authorities, and agencies responsible for administering permits and monitoring for compliance

are shown in Figure 4.

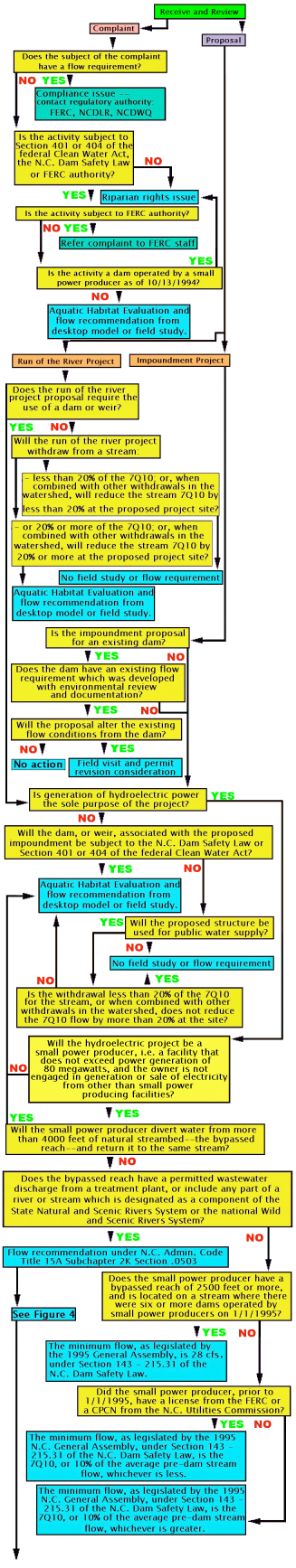
Figure 4

Project Type	Regulation	Agency	Jurisdiction
Dam construction*	Dam Safety Law	Division of Land Resources, DENR	State
Public water supply	State Environmental Policy Act	Division of Environmental Health, Public Water Supply Section, DENR**	State
Hydroelectric generation	Federal Power Act	FERC	Federal
Hydroelectric generation	Certificate of Public Convenience and Necessity	NC Utilities Commission	State
Wetlands	Clean Water Act, Sect. 404	Army Corps of Engineers	Federal
Wetlands	Clean Water Act, Sect. 401	Division of Water Quality, DENR	State

* For dams over 15 ft in height not subject to FERC authority

Source: Adapted from Instream Flow Unit, NC Department of Environment and Natural Resources

Figure 4



It is difficult to determine the percentage of the surface waters in North Carolina that are subject to some minimum flow requirement, but piecemealing these segments from various regulations together does not provide comprehensive coverage. In addition to the varying authorities and administering agencies, the process used for determining the required minimum flows also varies by project proposal. Figuring out what proposed projects are required to consider and who governs each step of the process can be confusing for citizens and natural resource managers alike. The Division of Water Resources Instream Flow Unit has created a flowchart for their website to guide people through the process. Even the flowchart, shown at left in Figure 5, is complex. The current system for protecting flows in North Carolina is reactive instead of proactive, has spotty and incomplete coverage, suffers from an inefficient management structure where various agencies are responsible for requiring and monitoring flows, and yields inconsistent results, since it employs multiple techniques to determine minimum flows depending on project type. This is not a criticism of the Instream Flow Unit of DWR that conducts the flow studies and makes flow determinations, but rather a criticism of their operating constraints, as a result of piecemeal rules and regulations. In contrast, a more useful scenario should be created that eventually

Source: Instream Flow Unit, NC Department of Environment and Natural Resources

designates a uniform process to determine e-flows for each of North Carolina's 17 river basins proactively, and is administered and enforced by a single state agency.

Current Methods for Determining Instream Flows

In the absence of a comprehensive flow program that evaluates ecosystem flow needs, the methods for regulating flows in North Carolina rely on either a percentage of flow or percentage of available habitat approach. Projects are evaluated according to a decision tree shown in the flow chart (Figure 5), which determines if a flow study is required, and whether that study can be accomplished using existing information (desktop model) or requires a field study. Most often, the measure for determining if a study is required is the 7Q10. The 7Q10 identifies the lowest stream flow in that reach for a seven-day period in the last ten years, and uses that volume to allocate discharge permits into that water body, so that pollutants will be assimilated without exceeding threshold concentrations.

> "All point source dischargers in North Carolina have conditions in their permits which are based on stream flows. The permit limits provide wasteload assimilation through effluent dilution and reoxygenation of the stream. All wastewater discharges are required to be treated so that water quality standards will still be met when the stream flow is as low as the 7Q10, the lowest flow expected to occur on a particular stream for 7 consecutive days once every 10 years. Obviously this is a very low flow which under natural conditions is the result of drought. Flows less than the 7Q10 may be the result of drought, but also can be caused by water withdrawals or dams which impound water. When stream flow falls below the 7Q10, water quality violations may occur. The Division of Water Quality sets water quality standards and permit limits, and is responsible for enforcement."[19]

The 7Q10 method is clearly intended for water quality control, but in practice, it is a measure for regulating streamflows in North Carolina. This is because a percentage of 7Q10 also determines whether water withdrawal projects trigger the need for instream flow review:

> "No instream flow study is required if the water withdrawal for the proposed project is less than 20% of the 7-day, 10-year low flow (7Q10). Withdrawals of this size relative to stream flow are considered to have

[19] North Carolina Department of Environment and Natural Resources, Division of Water Resources, Instream Flow Unit. "Permitted Discharges". www.ncwater.org/About_DWR/Water_Projects_Section/Instream_Flow/introduction.htm#permitteddischarges.

> minimal impacts on physical aquatic habitat. Withdrawals that are 20% of the 7Q10 or more will require additional analysis. The location of the proposed project and the habitat rating of the downstream aquatic habitat will determine whether a desktop analysis or site-specific instream flow study is used to determine the flow."[20]

Requiring larger withdrawals to undergo review to determine impacts on instream flow makes sense, but exempting smaller withdrawals from engaging in the instream flow process is potentially a mistake, since it impedes analysis of cumulative impacts. The Instream Flow Unit of the Division of Water Quality acknowledges the need to include incremental impacts in the flow studies it undertakes, but relying on voluntary, optional reporting for smaller diversions undermines the robustness of data used for decision-making.

If a flow study is required, the decision to use a desktop method or field study depends on the quality of the aquatic habitat in the project area, as determined by a habitat classification made by the NC Wildlife Resouces Commission.[21] This step is necessary because "the cost and time associated with conducting a field study to recommend a minimum flow will only be required where the quality of aquatic habitat is good or there is some other special resource value."[22] If the habitat is moderate or poor, a desktop regression analysis is used to determine required minimum flows.[23] If a field study is warranted, it can be done using either the Wetter Perimeter model or Instream Flow Incremental Methodology (IFIM). The Wetted Perimeter model was developed by DWR, but can be used and run by developers, consultants, or agencies engaged in project development or review. If the project involves high quality habitat, is likely to be

---

[20] North Carolina Department of Environment and Natural Resources, Division of Water Resources, Instream Flow Unit. "Offstream Uses". http://www.ncwater.org/About_DWR/Water_Projects_Section/Instream_Flow/introduction.htm#offstreamuses.

[21] The Aquatic Habitat Classification is described in more detail at http://www.ncwater.org/About_DWR/Water_Projects_Section/Instream_Flow/habrate.htm.

[22] North Carolina Department of Environment and Natural Resources, Division of Water Resources, Instream Flow Unit. "Aquatic Habitat Classification". http://www.ncwater.org/About_DWR/Water_Projects_Section/Instream_Flow/habrate.htm.

[23] For more information on the desktop regression models, go to http://www.ncwater.org/About_DWR/Water_Projects_Section/Instream_Flow/sec.0502.htm#4variable.

controversial, or needs to respond to multiple flow scenarios, such as fluctuating demand for electric power generation, then IFIM is used. This process involves the combined and coordinated efforts of the project consultant, who "must have current training in IFIM field techniques and physical habitat simulation (PHABSIM) modeling," DWR, The NC Wildlife Resources Commission, and the US Fish and Wildlife Service, who partake in making the final recommendation to develop and operate the project in a manner designed to protect aquatic habitat while meeting the project goals.[24] Both the Wetted Perimeter and IFIM process descriptions were prepared by Jim Mead at the DWR in 1988, and revised in 1998, so these have been standard protocol for developing flow recommendations in North Carolina for 10 years or more. While they are appropriate tools for application at a specific locale, they are not easily or practically expandable to develop flow regimes for entire river systems. Instead, the state of North Carolina uses another tool (OASIS) to model river basins for planning purposes, but has not standardized a process to determine the environmental baseline to incorporate into the OASIS models.

OASIS stands for Operational Analysis and Simulation of Integrated Systems, and was developed by water resource consulting firm, HydroLogics, Inc, who espouses:

> OASIS' combination of a graphical user interface and OCL™ (Operation Control Language) enables data to be entered as a series of easily stated rules and constraints… The HydroLogics-patented software routine at the heart of HydroLogics' OCL enables users to frame weighted operating objectives in a way that parallels intelligent human behavior, while at the same time dealing with the millions of combinations of conditions that can the drive decision-making process in water-resource management. When combined with OASIS software for modeling water systems, it forms a powerful tool that allows unprecedented decision-making and planning for the future.[25,26]

---

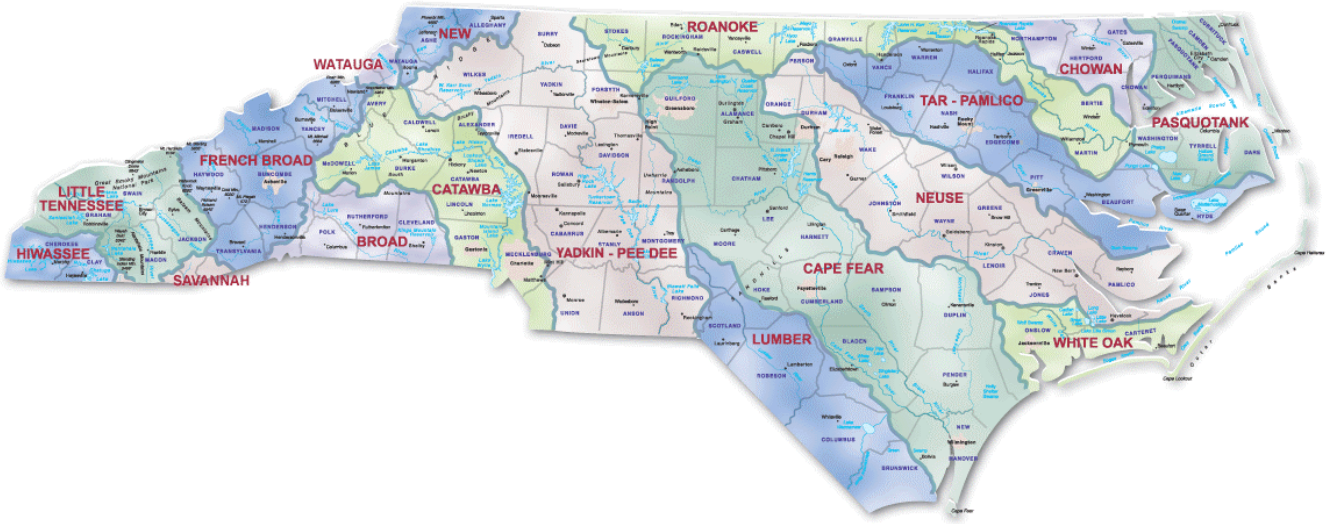
[24] North Carolina Department of Environment and Natural Resources, Division of Water Resources, Instream Flow Unit. "Procedures for Instream Flow Studies: Wetted Perimeter and Instream Flow Incremental Methodology". http://www.ncwater.org/About_DWR/Water_Projects_Section/Instream_Flow/ifimproc.htm#ifim.

[25] HydroLogics. OASIS: Introduction. http://www.hydrologics.net/oasis.html.

[26] For more information, see "What is OASIS with OCL" at http://www.hydrologics.net/oasis_ocl.html.

This tool has already been used in North Carolina to develop a river basin planning model for the Neuse River Basin, and is now in process for the Cape Fear River basin. Development and use of river basin planning models for all 17 river basins in North Carolina (see Figure 6) is one of the recommendations from the Water Allocation Study.

Figure 5



Source: Office of Environmental Education, NC Department of Environment and Natural Resources

OASIS can be used for many purposes, but for environmental flows in particular, it has the ability to do the following three useful tasks:

1. Use the entire period of record to determine the hydrologic regime of a river basin, then use that hydrologic baseline to experimentally establish a biological baseline for that river, based on a set of biological conservation targets
2. Use the model to test whether a proposed withdrawal or other action will violate the established ecological baseline
3. Use the model to forecast the ability to continue to meet or uphold the biological baseline into the future.

The current limitations of OASIS is that it does not include groundwater, which may be desired where groundwater – surface water interactions need to be accounted for, and it does not take climate change into account. It may be possible to tweak the software to do both of these things in the future, but at present, those abilities do not exist. Another potential issue with OASIS is the necessary human capacity to support it. If the use of OASIS is potentially expanded to run or test all water allocation decisions in North Carolina, it will take considerable human resources dedicated to this from both the instituting agency and from HydroLogics in support of this use.[27]

Results

Recommended Method for Determining Instream Flows

There are several additional methods or rules that North Carolina could potentially use for prescribing instream flows, and many papers have described and compared these in detail.[28] A recent report from a 22-scientist independent review panel in South Carolina assessed four potential minimum flow rules for suitability in their state. Their description of the pros and cons of each of these rules is directly applicable to North Carolina as well, and they are therefore included in Appendix 3. The panel did not recommend a single rule, but rather gave guidance to the South Carolina legislature on factors to consider in developing a rule. They state:

> Based on our knowledge and experience, we conclude that the national trends identified by the National Academy of Sciences' National Research Council are useful in South Carolina. Their review of a state-wide system (National Research Council, 2005, *The Science of Instream Flows: A Review of the Texas Instream Flow Program*) identified the following increasingly common principles that apply in South

---

[27] Pearsall, S. Personal Communication. February 23, 2009.

[28] See Appendix 1 in Apse, C., DePhilip, M., Zimmerman, J., and Smith, M. P. 2008. Developing Instream Flow Criteria to Support Ecologically Sustainable Water Resource Planning and Management. http://www.depweb.state.pa.us/watershedmgmt/lib/watershedmgmt/water_allocation/pa_instream_flow_report-_tnc_growing_greener-_final.pdf. See also Konrad, C. 2009. ELOHA Toolbox: Tools for Building a Hydrologic Foundation. ConserveOnline. http://conserveonline.org/workspaces/eloha/documents/tools-for-building-a-hydrologic-foundation and Konrad, C. 2008. ELOHA Toolbox: An Overview of Hydrologic Models. ConserveOnline. http://conserveonline.org/workspaces/eloha/documents/an-overview-of-hydrologic-models.

Carolina:

- Avoid single numbers applied statewide, develop a formula instead
- Include protection of wetlands and flood plains
- For environmental health, focus on ecosystems rather than individual species
- Employ a wide range of considerations: water supply and quality, and water rights, as well as hydrology, biology, and geomorphology[29]

These guiding principles are relevant and important for North Carolina to follow as well. To go further and encourage North Carolina to select a robust scientific methodology for use across the state, I recommend employing the Indicators of Hydrologic Alteration (IHA) software package. IHA should be used to develop hydrologic flow recommendations that adhere to the National Research Council's guiding principles mentioned above, then integrate these recommendations into the existing river basin planning process using the OASIS model previously described.

> Indicators of Hydrologic Alteration (IHA) is a free software program … which provides useful information for developing environmental flow recommendations and understanding the impacts of human activities on water flows.[30] This program was developed by scientists at the Nature Conservancy to facilitate hydrologic analysis in an ecologically-meaningful manner. This software program assesses 67 ecologically relevant statistics derived from daily hydrologic data. For instance, the IHA software can calculate the timing and maximum flow of each year's largest flood or lowest flows, then calculates the mean and variance of these values over some period of time. Comparative analysis can then help statistically describe how these patterns have changed for a particular river or lake, due to abrupt impacts such as dam construction, or more gradual trends associated with land- and water-use changes.[31]

IHA is a widely used tool, in the United States and around the world,[32] and has been described by one practitioner in North Carolina as the "best statistical package available" for evaluating flow criteria.[33] A long-awaited mechanism to correlate the two tools is under development, and should be available shortly for integration into OASIS. HydroLogics states, "Numerous clients have asked about performing IHA (Indicators of Hydrologic Alteration) analyses on OASIS output. We are in the process of integrating the two software packages so that OASIS results are

---

[29] South Carolina Independent Science Review Panel for Minimum Instream Flows. 2009. Minimum Flow Rules for South Carolina Rivers.
[30] The Nature Conservancy. Changing Water Policies to Protect Environmental Flows. http://www.nature.org/initiatives/freshwater/strategies/flows.html.
[31] The Nature Conservancy. Indicators of Hydrologic Alteration (IHA): Software for Understanding Hydrologic Changes in Ecologically-Relevant Terms. http://www.nature.org/initiatives/freshwater/conservationtools/.
[32] The Nature Conservancy. Indicators of Hydrologic Alteration (IHA): Software for Understanding Hydrologic Changes in Ecologically-Relevant Terms. http://www.nature.org/initiatives/freshwater/conservationtools/.
[33] Pearsall, Sam. Personal Communication. February 23, 2009.

automatically loaded into IHA when the user pushes a button in the OASIS GUI [graphical user interface]."[34] This link will be beneficial to North Carolina's efforts to develop a science-based e-flows program, and is especially timely since a core group of organizations are interested in testing new, alternative methods for use in this state in the next few months.[35] IHA is the best tool for evaluating hydrologic indicators, and it makes sense to incorporate this advanced instrument into a statewide program. However, it is important to recognize that IHA is an excellent for evaluating hydrologic alteration, but not biological baselines. Further work needs to be done to develop and integrate flow alteration - ecological response relationships[36] into a methodology for use statewide, and to incorporate existing ecological data into the pilot project for evaluating flow methodology described below.

Recommended Next Steps: Scientific Process

What follows are step by step suggestions of a potential way forward by selecting, testing, refining, and adopting a method for developing instream flows, which can then be implemented across the state. This scientific process is suggested to take place concurrently with efforts to influence the political processes.

1. *Select a method to test*

   I suggest that the core group of stakeholders convene a planning meeting, to elucidate the purpose of the pilot study to all participants, to bring everyone on the same page regarding timeline, the selected sub-basin, and the budget, and most importantly, to develop consensus regarding which potential method(s) to test. I recommend testing IHA, and if available, testing the IHA-OASIS link to incorporate the results into the existing river basin model for the Neuse River watershed.

   Participants: NC DENR Division of Water Resources, NC Wildlife Resources Commission, US Fish & Wildlife Service, US Geological Survey (USGS)*,

[34] HydroLogics. What's New: OASIS - IHA Link. http://www.hydrologics.net/news.html.
[35] McNaught, D. and Pearsall, S. Personal Communication. February 23, 2009.
[36] For more information on these relationships, see http://conserveonline.org/workspaces/eloha/documents/flow-ecology-relationships-0.

Environmental Defense Fund, The Nature Conservancy, and others with technical expertise in environmental flows in N.C. *The USGS has not been active in the core group working on NC flows, but are active in stream flow development in other locations, and should be invited to participate in this process if they choose.

2. *Initiate a pilot study*

   The pilot study is essentially a desktop modeling exercise, but an important one that has real significance to inform the potential future formal procedures used statewide. It is an opportunity to learn by doing, and will require cooperation of the participants who already have pre-conceived opinions about the best process or tools for developing or evaluating instream flow recommendations. For these reasons, I recommend using a facilitator with scientific expertise and experience using the selected method, to guide the participants through the process and help navigate hurdles encountered along the way. I also recommend incorporating a de-brief session at the conclusion of the workshop to capture participants opinions of the experience which will feed into the next step.

   Participants: In addition to the participants from the first step above, I suggest adding a facilitator and, if the IHA-OASIS link is used, a representative from HydroLogics for technical support.

3. *Refine chosen method*

   The recommendation to develop a statewide flow program using IHA as the core method should be re-visited and possibly revised following the pilot study. It is essential to incorporate lessons learned about the method(s) and process used and the quality of the results generated from the flow experiment. Addressing recurring or important concerns from the workshop participants is also a part of this step.

4. *Recommend the revised method for use state-wide*

   The revised method should be finalized and formally recommended to state decision-makers by the workshop participants willing to do so. This could be via a written recommendation sent in letterform to the ERC, which is a standing committee of the North Carolina legislature. Copies should also be sent to the relevant authorities at the Department of Environment and Natural Resources (DENR).

Recommended Next Steps: Political Process

The political process for securing environmental flow protections in North Carolina is tied to the process for adopting broader water allocation policies. It is extremely difficult to predict the fate

of proposed legislation, so this potential path is merely a starting place that will most certainly evolve in the coming weeks, and could become obsolete at any step along the way.

1. *Introduce legislation that creates a water allocation system subject to baseline flows*

   Potential legislation consistent with the recommendations of the Water Allocation Study was drafted by Richard Whisnant and submitted to legislative staff in early March 2009. On March 25th, Senator Clodfelter introduced Senate Bill 907, the Water Resources Policy Act of 2009, which was referred the following day to the Committee on Agriculture, Environment, and Natural Resources. On April 6, 2009, Representative Allen introduced companion bill H. 1101, which passed on first reading the following day, and was referred to the House Committee on Water Resources and Infrastructure.

2. *Meet with interest groups regarding legislation*

   After the legislation is introduced and before the committee processes begin is the ideal time for the water allocation team to meet with a variety of stakeholders to explain the provisions of the bills, answer questions, and estimate the level of support or opposition to provisions in the proposed legislation.

3. *Build support for this approach*

   It may be prudent for my clients to meet again with key supporters of environmental flows and water allocation before or during the committee process to continue to build the base of support for the proposed legislation. The environmental non-profits could also spearhead this on their own to foster agreement on key provisions, and to utilize their networks to voice support for the bills to their members and the media.

4. *Consideration by House and Senate, consensus process*

   If the bills survive their respective committee processes, they would then be considered in the Senate and the House. If they are approved, then there will need to be a consensus committee process to deal with inconsistencies in the bill provisions approved in each legislative house before the Act becomes law.

Discussion

Describing a process to safeguard the ecological integrity of North Carolina's surface waters by balancing human and ecosystem water needs suggests some additional general recommendations for the conservation community, and those that support e-flows.

1. *Integrate biological data into flow development process*

   To better integrate biological data into flow recommendations for North Carolina requires an understanding of ecological flow needs of relevant species, and further analysis of potential methods to integrate these parameters with the hydrologic data to develop flow recommendations.

2. *Recognize that these flows are minimum thresholds, not desired levels*

   Conservationists and water policy specialists should consistently voice and reiterate that required flows are minimum floors, not targets to be attained. The optimal flow is the full, unaltered volume of runoff that nature provides. E-flows are an attempt to balance human and ecosystem needs, and the concept of balance does not equate to shorting one side of the scale while the other gets unimpeded volumes of water. In addition to flow legislation, balance requires a full suite of water use regulations, including stronger conservation and efficiency measures to curb escalating human uses in North Carolina.

3. *Incorporate Adaptive Management*

   Practitioners should incorporate adaptive management – a structured, iterative process for optimal decision-making in the face of uncertainty, one that aims to reduce the uncertainty over time with better system monitoring. Similarly, conservationists will need to incorporate climate change adaptation strategies into the selected processes and incorporate climate change projections into river basin planning tools.

4. *Persevere*

   Finally, I advocate perseverance to those who seek environmental flows for North Carolina. If flow legislation is not successful this year, I encourage the conservation community to re-tool to move the debate forward next year and beyond, until it is ultimately successful. In the meantime, seek consensus on the scientific methods, test and refine them, and work collectively to strengthen the foundation described in this master's project into even better eventual outcomes, where human and ecosystem needs can be balanced in a way that ensures long term sustainability of river flows.

This report describes the most important steps that need to be addressed to pursue environmental flow legislation for North Carolina. While many people will be opposed to legislation that adds additional regulations to water use, the effort to protect ample flows must persist until triumphant. Securing environmental flows is crucial to sustaining the surface waters of the state of North Carolina, and the human and environmental life that these rivers foster and support.

References

American Rivers. 2008. Catawba-Wateree: America's Most Endangered River. http://www.americanrivers.org/site/DocServer/CatawbaFINAL.pdf?docID=7521.

Apse, C., DePhilip, M., Zimmerman, J., and Smith, M. P. 2008. Developing Instream Flow Criteria to Support Ecologically Sustainable Water Resource Planning and Management. http://www.depweb.state.pa.us/watershedmgmt/lib/watershedmgmt/water_allocation/pa_instream_flow_report-_tnc_growing_greener-_final.pdf.

Davis, M. M. In prep. Instream Flow Protection: An overview of legal, planning, financial, and scientific support for state programs with examples from southern states. A web report for the Southeast Aquatic Resource Partnership, Southern Instream Flow Network. www.sarpaquatic.org.

Global Environmental Flow Network. "Terminology and Definitions Adopted by eFlowNet." http://www.eflownet.org/viewinfo.cfm?linkcategoryid=4&linkid=13&siteid=1&FuseAction=display. Accessed on September, 18, 2008.

Holman, W. Personal communication. March 2, 2009.

HydroLogics. OASIS: Introduction. http://www.hydrologics.net/oasis.html.

HydroLogics. What's New: OASIS - IHA Link. http://www.hydrologics.net/news.html.

International Union for Conservation of Nature. 2008. IUCN Red List: Freshwater Biodiversity – A Hidden Resource Under Threat. http://intranet.iucn.org/webfiles/doc/SpeciesProg/FBU/IUCN_WCC_Freshwater_Factsheet.pdf.

International Union for Conservation of Nature. 2008. IUCN Red List: State of the World's Species. http://cmsdata.iucn.org/downloads/state_of_the_world_s_species_factsheet_en.pdf.

Jehl, D. A New Frontier in Water Wars Emerges in East. The New York Times. March 3, 2003. http://www.nytimes.com/2003/03/03/national/03RIVE.html.

Karr, J.R. and Dudley, D.R. 1981. Ecological Perspectives on Water Quality Goals. Environ. Manage. 5: 55-68.

Konrad, C. 2009. ELOHA Toolbox: Tools for Building a Hydrologic Foundation. ConserveOnline. http://conserveonline.org/workspaces/eloha/documents/tools-for-building-a-hydrologic-foundation

Konrad, C. 2008. ELOHA Toolbox: An Overview of Hydrologic Models. ConserveOnline. http://conserveonline.org/workspaces/eloha/documents/an-overview-of-hydrologic-models.

McNaught, D. and Pearsall, S. Personal Communication. February 23, 2009.

North Carolina Department of Environment and Natural Resources, Division of Water Resources, Instream Flow Unit. "Aquatic Habitat Classification". http://www.ncwater.org/About_DWR/Water_Projects_Section/Instream_Flow/habrate.htm.

North Carolina Department of Environment and Natural Resources, Division of Water Resources, Instream Flow Unit. "Offstream Uses". http://www.ncwater.org/About_DWR/Water_Projects_Section/Instream_Flow/introduction.htm#offstreamuses.

North Carolina Department of Environment and Natural Resources, Division of Water Resources, Instream Flow Unit. "Permitted Discharges". http://www.ncwater.org/About_DWR/Water_Projects_Section/Instream_Flow/introduction.htm#permitteddischarges.

North Carolina Department of Environment and Natural Resources, Division of Water Resources, Instream Flow Unit. "Procedures for Instream Flow Studies: Wetted Perimeter and Instream Flow Incremental Methodology". http://www.ncwater.org/About_DWR/Water_Projects_Section/Instream_Flow/ifimproc.htm#ifim.

North Carolina Department of Environment and Natural Resources, Division of Water Resources, Instream Flow Unit. "Regulations and Contacts". http://www.ncwater.org/About_DWR/Water_Projects_Section/Instream_Flow/introduction.htm#regulations.

North Carolina Department of Environment and Natural Resources, Office of Environmental Education, Instream Flow Unit. "Discover North Carolina's River Basins". http://www.eenorthcarolina.org/public/ecoaddress/riverbasins/riverbasinmapinteractive.htm.

North Carolina Office of Administrative Hearings. North Carolina Administrative Rule Process. http://www.oah.state.nc.us/rules/flowchart.pdf.

North Carolina Wildlife Resources Commission. 2005. North Carolina Wildlife Action Plan. Raleigh, NC.

Pearsall, S. Personal Communication. February 23, 2009.

Postel, S., and Richter, B. 2003. Rivers for Life: Managing Water for People and Nature. Island Press, Washington, D.C.

South Carolina Independent Science Review Panel for Minimum Instream Flows. 2009. Minimum Flow Rules for South Carolina Rivers.

State Climate Office of North Carolina. Overview: Precipitation. http://www.nc-climate.ncsu.edu/climate/ncclimate.html#precip.

The Nature Conservancy. Changing Water Policies to Protect Environmental Flows. http://www.nature.org/initiatives/freshwater/strategies/flows.html.

The Nature Conservancy. Indicators of Hydrologic Alteration (IHA): Software for Understanding Hydrologic Changes in Ecologically-Relevant Terms. http://www.nature.org/initiatives/freshwater/conservationtools/.

Vörösmarty, C. J., Green, P., Salisbury, J., and Lammers, R. 2000. "Global water resources: Vulnerability from climate change and population growth." Science, 289, 284 –288.

Whisnant, R. Personal communication. October 6, 2008.

Whisnant, R., Holman, W., et al. 2008 Report of the Water Allocation Study of the N.C. Environmental Review Commission (Dec. 31, 2008). http://sogweb.sog.unc.edu/Water/images/4/40/2008NCERCWaterAllocationStudyFinalReport.pdf.

Appendices

Appendix 1: North Carolina Wildlife Action Plan, Aquatic Species Overview

Biodiversity in Aquatic Ecosystems

The southeast region has the highest aquatic species diversity in the entire United States (Burr and Mayden 1992, Taylor et al. 1996, Warren et al. 2000, Williams et al. 1993). Southeastern fishes make up 62% of the United States fauna, and nearly 50% of the North American fish fauna (Burr and Mayden 1992). Molluscan diversity in the region is 'globally unparalleled', with 91% of all United States mussel species found in the southeast (Neves et al. 1997). Crayfish diversity and global importance in the region rivals that of mollusks (Taylor et al. 1996). Crayfish in the southeast comprise 95% of the total species found in all of North America (Butler 2002a). North Carolina freshwaters support a significant proportion of that diversity with at least 240 fish, 125 mollusk, and 45 crayfish species.

Unfortunately, patterns of imperilment are similar. Greater than two-thirds of the nation's freshwater mussel and crayfish species are extinct, imperiled, or vulnerable (Williams et al. 1993, Neves et al. 1997, Master et al. 1998). The majority of these at-risk species are native to the southeast. The number of imperiled freshwater fishes in the southeast (84) is greater than any other region in the country and the percentage of imperiled species is second only to the western United States (Minckley and Deacon 1991, Warren and Burr 1994). Twenty-eight percent of southeastern freshwater and diadromous fishes have a status of extinct, endangered, threatened, or vulnerable, which represents a 125% increase in 20 years (Warren et al. 2000). North Carolina ranks third among southeastern states in number (21) and percentage (11.5%) of imperiled fishes (Warren et al. 1997). Freshwater mollusks are suffering even greater declines. Thirty-six mussel species and 26 snail species that formerly occurred in the southeast (13% of all United States mussel species and 8% of southeastern snails) are presumed extinct (Neves et al. 1997). By state, between 34% and 71% (mean = 58%) of mussel species, or populations of species, are imperiled in the southeast, which represents 98% of all rare mussel species in the United States (Neves et al. 1997). Fifty-nine percent of freshwater mussel species in North Carolina are imperiled (Neves et al. 1997). Assessments of North Carolina mussel populations in the 1990's reported 62 of 147 known populations (42%) to be "in poor or very poor condition" (Rader 1994) and only 51 populations (35%) are likely to maintain viable populations over the next 30 years (Alderman et al. 1992). Among crustaceans listed as endangered or threatened in the United States, 54% are from the southeast (Schuster 1997). Twelve species (26%) of North Carolina crayfish are listed as species of concern or rare in the state (Clamp 1999, LeGrand et al. 2004).

Causes of declines among all aquatic taxa are widely attributed to habitat destruction and degradation, and the introduction of nonindigenous species (Williams et al. 1993, Taylor et al. 1996, Etnier 1997, Warren et al. 1997). Fishes inhabiting medium-sized rivers and creeks rely on coarse substrates that are relatively silt-free; however, these streams are often heavily impounded and have altered substrates. Habitat alteration from nonpoint source pollution and flow alteration (i.e., impoundments) are the primary cause of population declines for 72% of southeastern fishes considered imperiled (Etnier 1997). Not surprisingly, nonpoint source pollution and the effects of dams and impoundments are also the leading historic and current threats to freshwater mollusks (Bogan 1993, Neves et al. 1997, Richter et al. 1997). The complex life cycles and habitat requirements of mussels make them especially vulnerable to these perturbations (Adams 1990, Bogan 1993, Neves et al. 1997). The small native range of many crayfish species is a primary factor in their vulnerability to habitat loss and competition (Clamp 1999, Taylor et al. 1996). Threats to crayfish include pollution and impoundment, but competition with nonindigenous species is also a primary threat to many species (Taylor et al. 1996).

In North Carolina, threats to biodiversity are similar to those listed above and include point and nonpoint source pollution, hydrologic alteration, physical habitat manipulation, and biological pollution. In recent decades, water quality has improved in many waters that were historically polluted primarily by point-source discharges; however, overall habitat degradation continues to

threaten the health of aquatic communities. Increased development and urbanization, poorly managed crop and animal agriculture, and mining impact aquatic systems with point and nonpoint source inputs. Impoundments on major rivers and tributaries drastically alter the hydrologic regime of many North Carolina waterways and result in habitat fragmentation, blockage of fish migration routes, and physical habitat alterations.

Source: North Carolina Wildlife Resources Commission. 2005. North Carolina Wildlife Action Plan. Raleigh, NC.

Appendix 2: North Carolina Endemic Aquatic Species List

NORTH CAROLINA ENDEMIC ANIMAL LIST

Scientific Name	Common Name	Status N.C.	Status U.S.	Rank N.C.	Rank Global
	FRESHWATER FISHES				
Etheostoma perlongum	Waccamaw Darter	T	FSC	S1	G1Q
Fundulus cf. diaphanus	Lake Phelps Killifish	SR	FSC	S1	GUQ
Fundulus waccamensis	Waccamaw Killifish	SC	FSC	S1	G1
Lythrurus matutinus	Pinewoods Shiner	W2	FSC	S3	G3
Menidia extensa	Waccamaw Silverside	T	T	S1	G1
Notropis mekistocholas	Cape Fear Shiner	E	E	S1	G1
Noturus furiosus	Carolina Madtom	T	FSC	S2	G2
	MOLLUSKS: FRESHWATER BIVALVES				
Alasmidonta sp. 1	a bivalve (Upper Yadkin River system)	---	-	SU	GXQ
Alasmidonta sp. 2	a bivalve (Uwharries region)	SR	-	S1?	GNR
Elliptio judithae	synonymous with Roanoke Slabshell (formerly Plicate Spike)	---	-	SNA	G1Q
Elliptio marsupiobesa	Cape Fear Spike	SC	-	S3	G3Q
Elliptio steinstansana	Tar River Spinymussel	E	E	S1	G1
Elliptio sp. 2	File Spike	W3	-	SU	GUQ
Elliptio sp. 4	a bivalve (Deep River system)	---	-	SU	GUQ
Lampsilis fullerkati	Waccamaw Fatmucket	T	FSC	S1	G1Q
Lampsilis sp. 2	Chameleon Lampmussel	SR	-	S1	G1
Lampsilis sp. 3	a bivalve (Deep River system)	W3	-	S1?	GU
	MOLLUSKS: FRESHWATER GASTROPODS				
Amnicola sp. 1	Waccamaw Snail	SC	-	S1	G1
Cincinnatia sp. 1	Waccamaw Siltsnail	SC	-	S1	G1
Helisoma eucosmium	Greenfield Rams-horn	E	FSC	S1	G1Q
Planorbella magnifica	Magnificent Rams-horn	E	FSC	S1	G1

Source: North Carolina Natural Heritage Program. 2008. Natural Heritage Program List of the Rare Animal Species of North Carolina. http://www.ncnhp.org/Images/2008-animal-book-complete.pdf. 101-102.

Appendix 3: South Carolina Analysis of Potential Minimum Flow Rules

Below are the panel's comments on four potential minimum low flow rules. *In each case, the rule is applied to a particular site or river reach*, and uses data from stream flow measurements that are presently available.

Rule: 7Q10

General Definition: Low flows must be at least equal to the lowest seven-day average encountered in the stream gage record of the last ten years.
Data Used for Calculation: Measured mean annual flow from the last 10 years.
Existing Mandate in South Carolina: Used in water quality regulations
Seasonal Variation: Not included in the rule. A single rule or formula serves for the entire year.
Geographic Variation: Not included in the rule. A single rule or formula serves for the entire state, with individual values calculated at specific places.
Comments: General application would result in allowing users on some streams to withdraw so much water that flows could decline to zero; does not account for important variation from one season to another; rule is advantaged because it already is in use for water quality work; likely to damage ecosystem health and not protect the rights of existing users; often uses only 10 years of data, a period that is too short to account for climatic variation; simplistic, easily understood by stakeholders, and easily applied by regulators; in general, application would be likely to result in the greatest withdrawals from streams; lack of seasonal variation greatly limits use of this rule.

Rule: 20 Percent of Mean Annual Flow

General Definition: Low flows must be at least equal to 20 percent of the mean annual flow
Data Used for Calculation: Measured mean annual flow from the entire record
Existing Mandate in South Carolina: None
Seasonal Variation: Not included in the rule. A single rule or formula serves for the entire year.
Geographic Variation: Not included in the rule. A single rule or formula serves for the entire state, with individual values calculated at specific places.
Comments: General application would insure that allowable flows would not decline to zero, but does not account for those river reaches that

"naturally" decline to zero; data show that because this method does not vary by month, it may be too low in winter months for realistic application. Because the rule is based on a mean value from the *entire* record, the rule is insensitive to normal climatic variations with dry, average, and wet periods of several years duration. All streams do not have records of the same length, so that the reliability of the rule (which is sensitive to length of record) is likely to be highly variable. Simple idea behind the rule, so it is easily understood by stakeholders and easily implemented by regulators; robust as possible because the rule uses the entire flow record. Rule does not consider seasonal effects such as needs for higher flows in winter months. Rule may require more instream flow than necessary in some summer low flow months. Lack of seasonal variation in the rule limits its use.

Rule: 5 Percentile-Monthly

General Definition: Stream flow is equal to or greater than the prescribed value 95 percent of the time; or stated differently, stream flow is less than this value only 5 percent of the time.

Data Used for Calculation: Measured monthly mean flows from entire record
Existing Mandate in South Carolina: Specified in drought regulations

Seasonal Variation: Included because of the use of monthly data, and flows are specified on a monthly basis.

Geographic Variation: Not included in the rule. A single rule or formula serves for the entire state, with individual values calculated at specific places.

Comments: General application would result in low flows that follow "naturally" defined seasonal flows because of the use of a monthly calculation; would always result in a prescription that is greater than zero except where "natural" flows have always been zero in the record; application would be advantaged because the rule already exists in drought regulations; seasonality is an advantage in protecting rights of existing users and ecosystem health. Rule is robust as possible because it uses the entire flow record; reasonably understandable for stakeholders and use by regulators; generally would be most protective of instream flows among alternative rules; more demanding of stakeholders and regulators in terms of data and calculations than rules using only annual data.

Rule: Variable, 20/30/40 Piedmont and 20/40/60 Coastal Plain

General Definition: In the Piedmont region of the state, flows in winter months must not be less than a flow equal to 20 percent of July-November flows in the record; May, June, and December flows equal no lower than 30 percent of average flow; and January-April flows no lower than 40 percent of the average The same definition is used for streams in the Coastal Plain, except the respective are 20, 40, and 60 percent.

Data Used for Calculation: Measured monthly mean flows from entire record

Existing Mandate in South Carolina: None

Seasonal Variation: Included in the calculation that uses monthly data

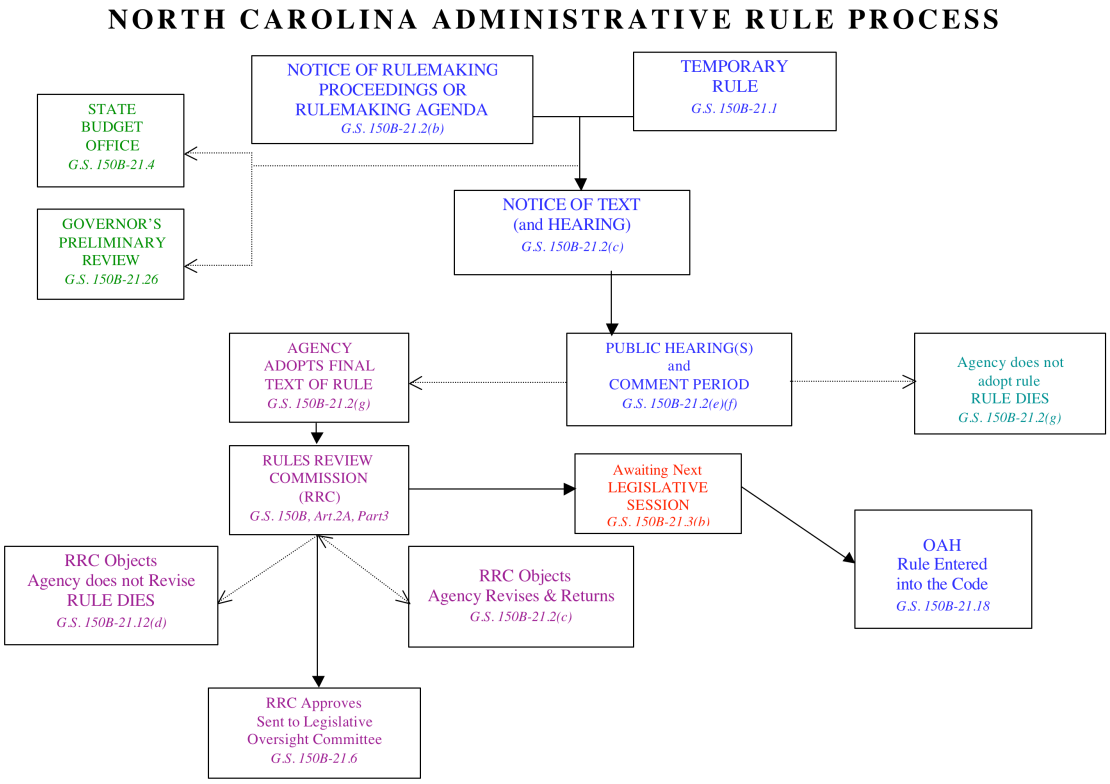
Geographic Variation: Included by definition

Comments: May be difficult to implement. General application results in summer low flows that in most streams are higher than those generated by the 5-percentile-monthly method, but not always; in the majority of cases provides maximum protection for existing users and ecosystem health; considers natural seasonal flows, but less so than the 5-percentile monthly rule; robust in using entire stream flow record; reasonably understandable by stakeholders; provides a balance among the needs of users and ecosystem needs; because the rule simplifies natural seasonal flows in streams by using season-long averages, certain stream may have minimum flows set too high, and others too low; geographical component of the rule may not be at an appropriate scale—flows might be best specified for the eight separate hydrologic basins in the state. In some formulations, the percentiles used in this rule are calculated using mean annual flows, but use of annual base data would obscure important seasonal variation.

It is possible to combine some minimum flow rules, such as specifying that flow must "equal or exceed the 5 percentile flow or the Regional-Seasonal Rule, which ever is greater," and there are many other potentially useful minimum flow rules that South Carolina might adopt. The rules outlined above as examples are primarily oriented to deal with drought conditions rather than the maintenance of the long-term health of aquatic and riparian ecosystems, and they may not be sufficient to avoid damage to the state's aquatic resources. This damage is likely to be in the form of the loss of habitats resulting from periods of low flow that are extended by withdrawals and that occur more frequently. Summer flows across the entire state and winter flows in piedmont streams are particularly at risk in this regard.

Source: South Carolina Independent Science Review Panel for Minimum Instream Flows. 2009. Minimum Flow Rules for South Carolina Rivers.

Appendix 4: North Carolina Administrative Rulemaking Process Flowchart



Source: North Carolina Office of Administrative Hearings. North Carolina Administrative Rule Process. http://www.oah.state.nc.us/rules/flowchart.pdf.