

Commute Sheds as a  
Regional Water Management  
Decision Tool

by

Benjamin Young Landis

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Approved:

\_\_\_\_\_  
Dr. Randall Kramer, Advisor

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## ABSTRACT

In international water management, “virtual water” analysis has been a useful tool for discussing the flow of water resource benefits amongst nations. Conceptually, an analogy can be made with “commute shed” research – the geospatial analysis of workers and where they travel to for work, created for regional developers and labor economists. Based on the rationale that clean water supply and infrastructure “produce” healthy, able workers that can generate economic output, I argue that flows of labor are thus also flows of water supply benefits. Subsequently, workers who work outside of their water utility service area are exporting these embedded economic benefits. Commute sheds can thus represent the transfer of water supply benefits within a region.

Using *OnTheMap 3*, a recently developed software from the United States Census Bureau, I compile commute sheds for municipalities within and neighboring the Upper Neuse River Basin, North Carolina. I interpolate the water supply benefits embedded in these commute sheds, using estimated annual earnings as a proxy for economic output. Results show that within the Upper Neuse, there is a net flow of benefits from other cities into Durham. Also, there is a net flow of benefits into the Upper Neuse from cities supported by neighboring water systems, particularly by Jordan Lake.

To my knowledge, this is a novel demonstration of applying *OnTheMap* to regional water supply management and virtual water flows. *OnTheMap* can be used to illustrate aspects of interdependence amongst regional water users, improving decision making in water supply management efforts and help forecast future water demand by location. Complemented with benefit valuation research, commute shed analysis can inform negotiations on water transfer agreements and collaborative infrastructure financing.

**Keywords:** commute sheds, virtual water, regional analysis, water supply benefits, interbasin transfers, infrastructure financing, Falls Lake

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## INTRODUCTION

*Water supply is no longer just a function of individual communities. Clearly, it's a regional issue.*

Syd Miller  
Water Resources Program Manager  
Triangle J Council of Governments

The Upper Neuse River Basin in North Carolina is currently under close scrutiny by municipal water managers and local government leaders. Recent, severe droughts are forcing municipalities that rely on the Basin to adopt water conservation measures and negotiate water transfer sales. Municipal water supply and sewer treatment infrastructure in the Basin are aged – with some pipelines over 80 years old – and due for costly repairs, upgrades, and expansions to meet regulatory standards and future service projections (Holman 2008). Intertwined with these issues is the fact that the Upper Neuse Basin provides water resources for some of the most populous and economically-productive municipalities in North Carolina, and is facing heavy urban development pressures: Raleigh-Cary is now the fastest growing metropolitan area in the United States (Collins 2009).

The towns and cities of the Upper Neuse differ in their ability to respond to these issues. Hillsborough, a hamlet of 5,000, and Raleigh, the state capital with nearly 400,000 residents, will have very different bond ratings; sizes of budgets and tax revenue; and differences in the scale of capital repairs. Nevertheless, their respective, unresolved issues will affect the same, shared watershed. To appropriately allocate this single, scarce resource amongst towns of vastly different supplies and demands, Upper Neuse governments and stakeholders are beginning to cooperate in decision making efforts. Raleigh and Durham are particularly thirsty for water, and to sustain themselves for the long term, the two cities are looking to each other for possible water sharing arrangements. They are also looking to other Upper Neuse water sources and regional water sources for help. Now more than ever, municipal governments want to know “how much more water can I buy or sell, and is it worth the cost?” Water valuation studies and hydrologic modeling research can provide this answer, but often take tremendous amounts of time and funding, causing delays in stakeholder discussion efforts.

Throughout the nation, this scene is repeated in many urban watersheds. Stakeholders within a watershed or region share common problems and observe a need for collaborative, integrated watershed management agreements, but require timely access to information and analytical tools that are can be easily communicated and understood by all. Clearly, water resource managers need a toolkit of simple decision support methods that will help steer and educate regional dialogs and negotiations until more detailed data is available.

A conceptual framework from the field of labor economics may be a promising candidate for adaptation as a regional water management decision tool. “Commute shed analysis” may facilitate inquiries on the interconnectivity of human water usage within a watershed, and trace the source and sink of virtual benefits of water supply and water infrastructure. By visualizing these virtual flows, regional managers can better understand how water resources and benefits are already being shared and connected, informing cost and benefit analysis for new water transfer agreements or joint-financing of infrastructure projects.

Here, I investigate a recently-developed, publicly-accessible software application that generates commute shed data in detailed scale, and assess its utility for informing regional water management efforts. The Upper Neuse River Basin will serve as a case study.

### **Regional Water Management: Goals and Barriers**

Integrated watershed management (IWM) is a frequently-mentioned solution for optimized, regional water resources management. Alternatively termed as integrated river basin management, IWM is defined as “the management of all surface and subsurface water resources of the river basin in its entirety with due attention to water quality, water quantity and environmental integrity. A participatory approach is followed, focusing on the integration of natural limitations with all social, economic and environmental interests” (Jaspers 2003).

By definition, river basins and watersheds encapsulate all terrestrial, natural hydrologic processes of a locality, from source to drain, from overland to subsurface. By nature, quality and quantity impacts at the upstream of this nexus will have proportionate, interactive effects on the downstream. Likewise, uses and conditions of other natural resources linked to the water cycle – e.g. land development, deforestation – may also have cascading effects throughout the watershed (Pereira 1989; Bates, MacDonnell and Wilkinson 1998). Independent management of the parts, then, would not adequately serve the whole. As such, many consider the watershed as the appropriate scale for organizing water management, and suggest that collaboration amongst all stakeholders within the watershed will produce plans that tend to the whole.

However, some critics note that IWM rarely succeeds in the real world, due the fact that human engineering has blurred the boundaries of natural watersheds; that authoritative power and rights to participate associated with human, political boundaries are still formidable institutions to overcome; and that political and socioeconomic information helpful for decision analysis are lacking (Blomquist and Schlager 2005; Huang and Jia 2001). Engineered aqueducts and inter-basin water transfers have further complicated the definition of “the watershed.” To build successful agreements, IWM’s depend on stakeholder participation and consensus building, challenging tasks in their own. But who should be identified as stakeholders in a water system comprising of basins a hundred miles apart, yet linked by concrete waterways? Should the buyers in a water transfer have a say in the seller’s watershed management policies? IWM’s also require accurate information about shared basin resources and attributions of gains and ills generated – data that help stakeholders perform benefit-cost analysis and decide which policies and contracts are desirable.

Indeed, where partnerships or collaborative organization for water management have been achieved in North Carolina, some sort of financial cost analysis has usually been performed, which partners use to negotiate a mutually beneficial contract. For example, when the City of Creedmoor decided to merge its water and sewer services with the South Granville Water and Sewer Authority (SGWASA), it did so on the basis of cost effectiveness analysis, which showed that purchasing services from SGWASA would be cheaper than renovating and operating Creedmoor’s existing infrastructure (Henderson *Daily Dispatch* 2008). Similarly, agreements for many inter-city water supply transfers and sales in North Carolina are wholly financial decisions (Hughes 2009).

Negotiation facilitators for watershed planning recommend that potential partners engage in key activities, including joint fact finding, sharing of information, defining the present situation, and use of expert opinion (Smutko 2008). These tasks are easy enough if the decision and agreement frameworks are solely based around monetary terms and gallons of water, since utility managers have ready access to plant and operating cost information, and are well versed in operational and fiscal concepts. Problems arise, however, when negotiating terms extend beyond capital and debt valuation and venture into the realm of environmental externalities and embedded benefits. Unfortunately, concepts such as ecosystem service benefits, nonmarket valuation, and virtual water exports are not yet commonplace in the lingo of local utility managers. Cost accounting in public utility management rarely takes in account of external benefits and damages, yet these are important facets of water resource transactions (Hughes 2009).

However, industry attitude could be changing: at a recent infrastructure financing workshop educating utility managers in North Carolina, instructors promoted the consideration of externalities and resource benefits in management decisions (Hughes 2009). Furthermore,

the growing scarcity of water supply, new regulatory pressures on pollution sources, and increased awareness of source water protection and other ecosystem services should bring greater attention to these non-traditional foci of water management.

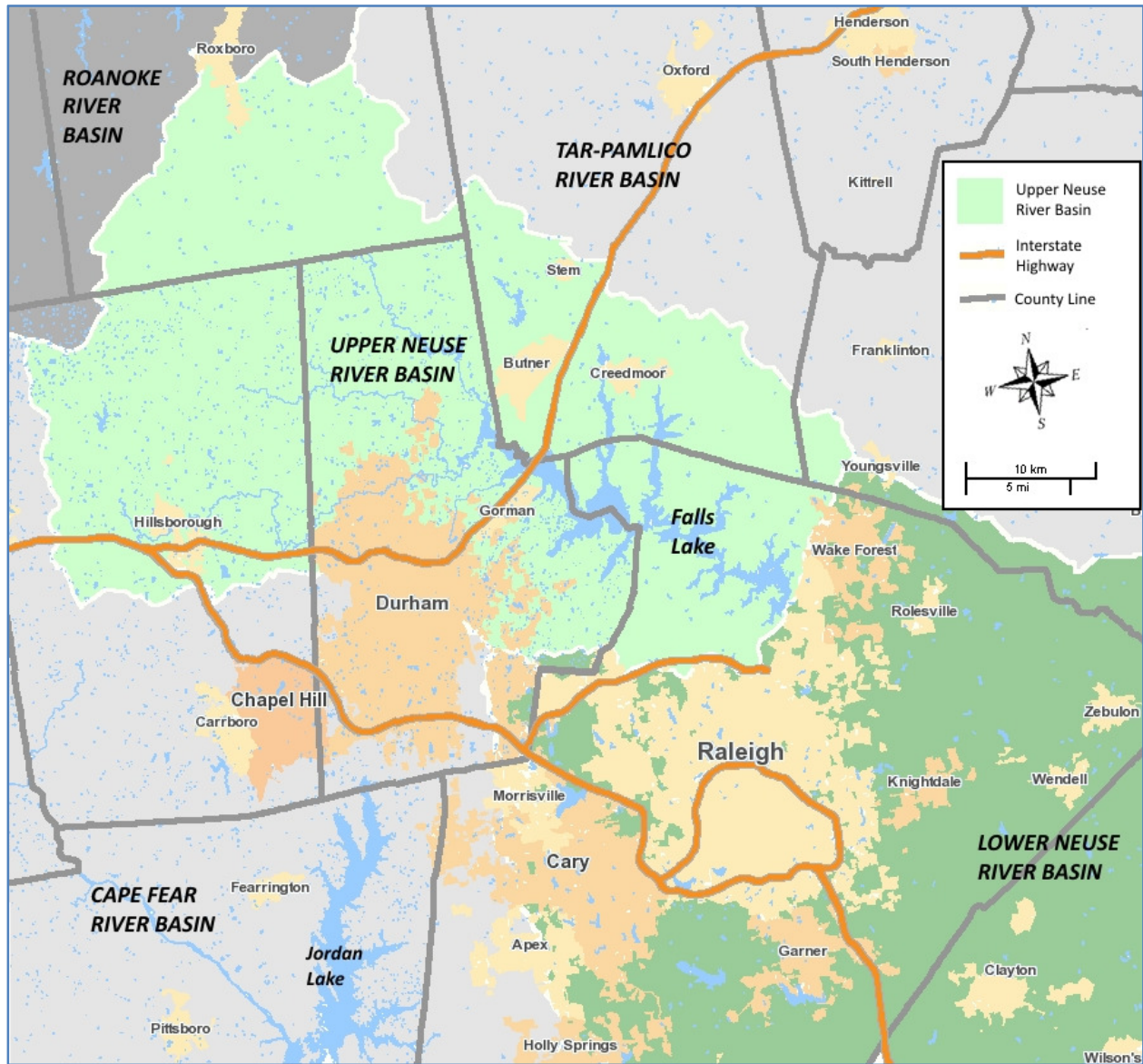
### **The Upper Neuse River Basin**

The Upper Neuse River Basin in North Carolina may be a watershed where municipal planners are open to comprehensive frameworks of water management, and accepting of new decision analysis tools. Completely encapsulating the headwaters of the overall Neuse River system, the 770-square mile watershed is demarcated by the Falls of Neuse Dam in Raleigh, NC. The impoundment created is Falls Lake, a popular outdoor recreation area and the primary drinking water reservoir for the City of Raleigh. Flowing into Falls Lake are a number of tributaries, each with a municipality relying on those surface waters for their own water supply and wastewater assimilation. Each municipality finances and manages its own water infrastructure, and aside from provisions for intra-basin water transfers, there is little cost sharing of capital costs amongst the parties. Groundwater supplies in the area are not significant, networked, nor used by the municipal utilities, making the surface water network crucial (Triangle J Council of Governments 2006).

The Upper Neuse River Basin in North Carolina may be embracing integrated watershed management as its cities respond to urgent water supply problems. The Upper Neuse has continued to undergo rapid population growth, despite suffering from two recent, severe droughts that forced municipalities to impose consumer water conservation measures. In 2009, Raleigh-Cary became the fastest-growing metropolitan area in the United States (Collins 2009), and with its entrenched education, medical, and technological industries, development in the Upper Neuse Basin continues. Municipal water managers within the Basin are struggling to meet the demands of new water users while reconciling the need for long-term water supply in a drought-prone region. A basin-wide stakeholder organization has been created to begin regional water management discussions (Upper Neuse River Basin Association 2009).

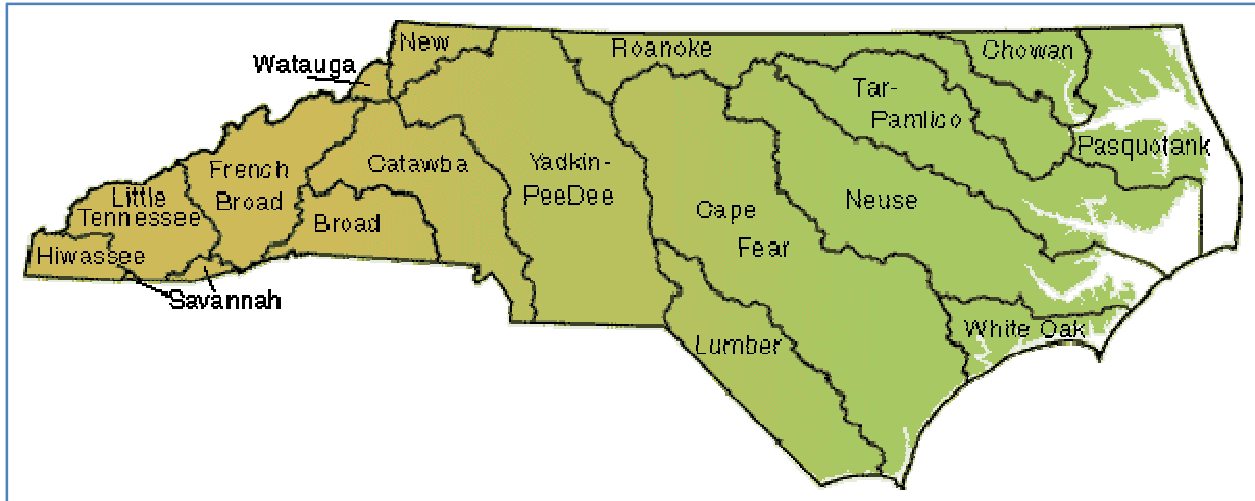
To secure water supply to meet growth needs, Durham, Hillsborough, and Raleigh already negotiate and participate in various sales of physical water transfers with one another. Upper Neuse municipalities are also exploring agreements with water utilities in the neighboring watersheds. The Orange Water and Sewer Authority (OWASA), which draws Cape Fear River Basin water to serve Chapel Hill and Carrboro, already has connections with the Hillsborough, an Upper Neuse town. Jordan Lake, a major reservoir also drawing Cape Fear water, is receiving heavy attention as a potential source for Upper Neuse development needs. Even the distant Kerr Lake, some 50-miles away on the Virginia-North Carolina border, is being targeted by Upper Neuse city planners as a future water source.

Figure 1: The Upper Neuse River Basin and Regional Setting



(Created by author using data from *OnTheMap 3*)

Figure 2: North Carolina River Basins



(Source: USGS 2009)

At a public forum on water conservation in 2008, a regional councilor emphasized to the audience that “water is no longer a function of individual communities,” and suggested that optimized, regional sharing of water supply will be a necessity in the long term (Will the Water Run Out 2008). Optimized water supply management at the regional level will require an integrated watershed management framework, and the success of regional water sharing in the Upper Neuse will rely on the availability of good information to collaborators. To agree on prices and volumes in these intra- and inter-basin transfers, managers must understand the value of their product to the buyer and to themselves. But as previously discussed, utilities should look beyond market prices and physical volumes and explore all benefits and valuation perspectives of water supply. Elucidating these hidden nuances to water transactions could give resource managers an improved decision toolkit as they decide whether to integrate or collaborate with their basin water partners.

### **Virtual Water and Commute Sheds**

Alternative accounting approaches that fully consider other influential facets of water transactions – such as virtual water flows– may be a useful tool to help municipalities evaluate the connectivity of water resources within a region.

Coined by John Anthony Allan at King's College in the United Kingdom, virtual water is "the amount of water that is embedded in food or other products needed for its production. For example, to produce one kilogram of wheat we need about 1,000 liters of water, i.e. the virtual water of this kilogram of wheat is 1,000 liters" (World Water Council 2008). The idea is often extrapolated to the concept of "water footprint", akin to "carbon footprint".

Normally, the virtual water concept is applied to agricultural goods and livestock. Production of these commodities is highly dependent on water; when crops and animals reach their marketable stage, each unit will have accrued a significant water investment over the course of their growth. Agricultural commodities and industrial products, of course, are traded between nations. When commodities are exported out of the watershed where they were produced, however, the embedded value of that water investment is then realized elsewhere. This results in a negative balance of benefits for the water resource of origin. In international water management, virtual water analysis has been a useful tool for conceptualizing the flow of water resource benefits amongst nations (Hoekstra and Chapagain 2003; Hoekstra and Chapagain 2007; Guan and Hubacek 2007).

I argue that an analogy can be made between the virtual water concept and newly-developed "commute shed" tools – the geospatial analysis of workers and where they travel to for work, created for regional developers and labor economists. Like crops, workers have value: instead of a fetching a selling price, workers add to the economic output of the employing city by working. Like crops need a field with irrigation, humans need homes with potable water and sewer connections: because humans cannot just rely on raw water, workers would decrease in health and their capacity for labor if water treatment and sanitation is not provided. Thus, by building water supply and sewer infrastructure, each city "grows" a population of workers and invests in their physical capacity for economic production. This statement is even more applicable when considering that North Carolina state code can legally require residences to connect to water and sewer lines (North Carolina General Statutes §160A-317).

However, people do not always work where they live – they form "commute sheds" by commuting daily from their location of residence to their location of work, much like the way that water flows from source to drainage in a watershed. But when workers "export" themselves from their home city to another city via commuting, a virtual outflow of benefits is created. Instead of reaping all the economic output sustained by its water supply and water infrastructure, the home city now loses part of that production to another city. So when a Durham resident works in Raleigh, he or she is exporting the benefits of Durham's water supply and sewer provisions out to Raleigh by exercising his or her capacity for labor there.

Under this conceptual framework, we equate the provision of potable water supply as the input, and worker economic productivity as the output. An investment of water supply and

infrastructure is embedded within each worker. When workers commute, they create a benefits flow between their home city, which supplied that investment, and their city of employment, which now gains the benefit of that investment. Thus, commute shed analysis could be used to visualize virtual flows of water supply benefits within a region.

Further discussion supporting this analogy can be found in Appendix 10.

### ***OnTheMap* Software**

Until recently, commute shed analysis itself was difficult to conduct. However, an innovative geographic information systems (GIS) tool developed specifically to analyze commute sheds has now been made available by the United States Census Bureau, and it holds promise for applications in the water management field.

Geospatial analysis of commuting patterns and labor demographics can be invaluable for regional development planning, and the commute shed analysis was borne out of the field of labor economics. Visualizing how different income groups move between locations can help local governments decide where to concentrate public transportation and other social services. This data can also inform corporate marketers on the concentration of industry talent in an area and whether a regional market is suitable for entry. However, compiling the requisite database can require exhaustive survey research, potentially receiving very low response rates due to the detail of confidential, personal employment information that will need to be collected. Indeed, such reports tend to be limited in data reported and localized in study area. No central database providing annual data on labor flows and demographics for large, contiguous regions previously existed, let alone a visualization tool that also allows for data analysis.

To meet this need, the United States Census Bureau Center for Economic Studies has developed a publicly-accessible online software application under their Longitudinal Employer-Household Dynamics Program (LEHD). Available free-of-charge, *OnTheMap* (3<sup>rd</sup> Edition; hosted at <http://lehmap3.did.census.gov/themap3/>) allows users to map the travel patterns of workers and identify regional workforce characteristics. In the few short years of project development, the *OnTheMap* tool has been widely promoted by state agencies as a planning tool, and has been profiled at a United Nations statistical research innovations seminar (Wu and Graham 2009). A full list of web resources for the *OnTheMap* application and its unique database can be found in Appendix 1.

Labor and demographic data was compiled for *OnTheMap* as part of the Local Employment Dynamics (LED) partnership between the Census Bureau and participating state labor agencies over forty-six states, from 2002 to 2006. Employment data are derived from

payroll tax (unemployment insurance) payment records, a ubiquitous program for which all partner states have data for. Payroll tax records are used to denote employer locations. Workers' home locations are assigned by the Census Bureau using data from multiple Federal agencies (specific sources undisclosed). Age, earnings, and industry profiles are compiled by the Census Bureau from state records and are supplemented with other Census Bureau sources (US Census Bureau 2009).

Final data compilations and confidentiality measures are performed by the Census Bureau (US Census Bureau 2009). To maintain confidentiality of sensitive, citizen information while retaining the geographic information of the source original data, raw demographic data is converted into "partially-synthetic microdata files" which blend actual data with multivariate-modeled distribution data to produce statistically representative spatial information (Wu and Abowd 2007). That is, while the labor demographic data ultimately used by *OnTheMap* cannot be attributed to individual respondents at their exact residence, the partially-synthetic data will bear the demographic characters of the original data points, while being placed in close vicinity to the original location.

To graphically project the labor data, *OnTheMap* uses geographic information – such as city boundaries, waterbodies, and roadways – from the Census Bureau's TIGER 2006 Second Edition database. This edition of TIGER data uses the NAD83 geodetic model, which *OnTheMap* depicts graphically using the Albers Equal Area Conic projection for Contiguous United States (US Census Bureau 2009). Graphic-interface functions within *OnTheMap* allow users to select political boundaries – county lines, ZIP codes, traffic analysis zones, et cetera – or a freehand-drawn area for analysis. Within the selected region of focus, users can ask the application to perform one of three research tasks:

- Compile worker demographic profile, such as age group, private versus public sector employment, earnings group, and industry group worked.
- Produce a "commute shed" report; that is, the cities and towns (or other geopolitical groupings) where the residents of the selected region commute to for work. This can be reported by age group, earnings group, and other worker demographic subsets.
- Produce a "labor shed" report; that is, the cities and towns (or other geopolitical groupings) where the workers of the selected region travel from and reside in. This can be reported by age group, earnings group, and other worker demographic subsets.

In this report, I propose a new application of *OnTheMap* by adapting software to illustrate the flows of water benefits embedded in the commuting workforce. Although water resource managers are encouraged to consider virtual and real water flows within their regional setting, virtual water, embedded benefits, and other conceptual frameworks are very difficult to visualize and illustrate. Given both the ease of use and the level of detail afforded by *OnTheMap*, its utility for the watershed management field must be explored.

## **PROBLEM DEFINITION**

Clearly, there is a great demand for good information and conceptual frameworks to help water planners construct a firm foundation towards regional water supply management. Local water and sewer utility managers are beginning to explore regional partnerships, and there will be a need for:

- Realizing the true boundaries of a given watershed, from the hydrologic units to the political delineations, and to more abstract borders shaped by the flows and sinks of water benefits embedded in water-dependent products (i.e. humans).
- Using this holistic view of the watershed boundary to identify all relevant stakeholders, even if their connection to this particular water resource is not readily apparent.
- Tracking and measuring the source and flow of these real resources and virtual services, to provide actionable information for all decision makers.

To date, few tools exist for water resource managers to assess the flows of virtual services and externalities. Non-market valuation techniques can estimate the social value of water quality and water supply benefits, but require time-intensive survey studies and statistical expertise to generate original data, or depend on the existence of comparable studies to utilize benefit transfer methods. Virtual water accounting methods are fairly standardized, but their intent is to quantify the volume of water investments embedded in consumable commodities and products.

Prospective partners have a need for comprehensive understanding of costs and benefits for proposed transactions when negotiating multi-party agreements, particularly when the transactions involve significant cost-bearing environmental projects such as water infrastructure investments. Water resource managers need new, simple decision support tools that will help steer and inform regional dialogs and negotiations and complement existing financial and environmental assessment methodology.

Could commute shed analysis offer this additional perspective for watershed managers? Given the extraordinary detail and customizable research options of the *OnTheMap* application, there is potential utility for this labor economic tool to be applied in the watershed management context. **The purpose of my project is to investigate the commute shed analysis functions in *OnTheMap*, and in the conceptual framework of virtual water benefits analysis, assess whether this online tool could provide data helpful to regional water management efforts in the Upper Neuse River Basin.**

## **METHODS**

In demonstrating the applicability of *OnTheMap* as a water resource visualization tool, I also outlined the analytical steps necessary to replicate this effort. My objectives were to use *OnTheMap* to generate commute sheds for specific pairings of cities within the scope of my analysis, and then develop a simple conversion rule to translate the number of jobs – which is the commute shed output – into an estimate of embedded water benefits. Finally, once the benefit figures were obtained, I wanted to balance the import and exports of benefits for all municipalities examined, and discern the net flows of benefits within the Upper Neuse River Basin, and across basin boundaries.

### **Units: Job**

The finest unit of data used by *OnTheMap* is the job, which probably owes to the fact that this database was compiled from unemployment filing records. *OnTheMap* provides two options for jobs: “All Jobs” or “Primary Jobs.” “All Jobs” reports all known jobs within an analysis area. “Primary Jobs” reports the job from which a person earns the most income from. Thus, “All Jobs” is an overlapping set that could double count an individual that has more than one job, whereas “Primary Jobs” equates to “Number of Workers.” “All Jobs” is probably a better representation of total economic output. But because “Primary Jobs” can be reconciled to an individual worker, and my rationale is that water provisions sustain individual workers, I elected to use “Primary Jobs”.

### **Treatment: City boundaries**

The treatment implemented in each analysis run is the paired area with which I instruct the software to analyze. The number of Primary Jobs recorded depends on the size and location of the area a researcher chooses to investigate, and *OneTheMap* provides a suite of pre-loaded options ranging from Traffic Analysis Zones (TAZ) to Metropolitan Areas. The administrative level I chose for the treatments is the “Cities/Towns” level.

Recall that the rationale for this report was to equate potable water supply and sewer provision with economic output. Also know that in each city, it is the water and sewer utility that governs and maintains the infrastructure and operation necessary for that supply, usually within a defined service area (the physical extent of all sewer and water service pipes). That service area is not necessarily the city’s borders. Often municipal service areas are larger than their actual city boundaries. So if I wished to generate a commute shed count for all Primary Job

workers supported by a specific service area, I would have to personally draw this service area outline in, freehand, which the software allows you to do.

However, I had difficulty obtaining service area maps from regional water utilities. Only SGWASA provided a map with sufficient detail. To keep with a standardized methodology, however, I ended up not using the SGWASA service map. Instead, for all municipalities analyzed in this report, I used “Cities/Towns” as the treatment resolution. I did this on the basis that for many locations, city boundaries are the same as water and sewer service. Also, this allows the method to be standardized. Because *OnTheMap* does not allow one to save custom-drawn areas, anyone replicating this methodology will have to trace my hand-drawn area exactly, or risk slightly different answers. Thus, “Cities/Towns” was chosen as a reliable proxy for service area.

## **Observables**

To recall our goals once more, it is to estimate the economic output generated by a commuter, and use that as the proxy for embedded benefits. The most common measure of economic output is gross domestic product (GDP). Interestingly, GDP at the local level is estimated and tracked by the United States Bureau of Economic Analysis. Unfortunately, it is only at the Metropolitan Area resolution, e.g. Raleigh-Cary, and does not allow the numbers to be parsed into their respective city shares.

Fortunately, *OnTheMap* reports several observables for each job analyzed, and one of them is monthly earnings. Annual earnings are an acceptable substitute for GDP. See Appendix 3 for full discussion on the conversion of *OnTheMap* earnings output and into estimates of annual earnings.

## **Setting**

The setting for this demonstration is the Upper Neuse River Basin in North Carolina. My analysis will be conducted on four municipalities in the Upper Neuse Basin that operate public water and sewer utilities:

- **The Town of Hillsborough**
- **The City of Durham**

- **The City of Raleigh**, which also provides water and sewer service for the Towns of Wake Forest, Rolesville, Knightdale, Zebulon, Wendell, and Garner. As such all these towns will be lumped with Raleigh in my analysis.
- **The Town of Butner, the Town of Stem, and the City of Creedmoor (hereafter “SGWASA”).** Water and sewer services for Butner, Stem, and Creedmoor are jointly operated by the South Granville Water and Sewer Authority (SGWASA), an independent public corporation permitted under the North Carolina Water and Sewer Authorities Act G.S. 162A-2(7); these three adjacent towns will thus be treated as a single labor source in this analysis.

Municipal water and sewer services in the Upper Neuse River Basin are pursuing physical connections and sales contracts with utilities in neighboring watersheds. Given this, I also generate commute sheds and benefit flows of Upper Neuse cities outward towards three important regional partners:

- **Chapel Hill and Carrboro (hereafter “OWASA”),** which relies on a series of small reservoirs located in the Cape Fear River Basin, with services operated by the Orange Water and Sewer Authority (OWASA). Chapel Hill and Carrboro are of particular interest because along with Raleigh and Durham, it is one of the economic pillars of the Triangle Region. Its massive education and private industry, along with its physical proximity to Hillsborough and Durham, could hint at a strong virtual nexus as well.
- **Cary, Morrisville, Apex (hereafter “Jordan Lake”),** all of which rely on the B. Everett Jordan Reservoir (“Jordan Lake”), located in the Cape Fear Basin, and with services operated by the Town of Cary. Jordan Lake is under heavy contention for its own nutrient pollution and water allocation problems, yet remains an important water source for the Triangle region.
- **Oxford, Henderson, and South Henderson (hereafter “Kerr Lake”)** all rely on the John H. Kerr Reservoir (“Kerr Lake”) located in the Roanoke River Basin, with services operated by Henderson and Oxford. Kerr Lake, despite being over 40 miles away, is being targeted by Raleigh and other Upper Neuse utilities as a future source for raw water purchases (Henderson Daily Dispatch 2008).

## **Commute Shed Analysis**

Before the embedded benefits of water and sewer provision can be calculated, we need to run the commute shed analysis to determine how many people are commuting from one city to another, and what their earnings bracket is. For detailed instructions on how to conduct a commute shed analysis using *OnTheMap*, see Appendix 2.

## **Interpretation of Water Supply Benefits**

I have drawn a parallel between the virtual water flow concept and the commute shed concept, using the flow of labor as a proxy for the exports and imports of water services. But while all workers require roughly the same provision of clean drinking water supply, not all workers have the same potential for economic activity. How then should we estimate the workers' earnings and productivity? It would be helpful to present water supply benefits in terms of monetary units, to provide water managers and city planners alike with a unit of measurement they are familiar with and can incorporate with existing financial decision-making methods.

Again, because city-level GDP was not available, we will use the estimated annual earnings generated by a labor force, because the availability of earnings data varies region by region. The Employment Security Commission of the State of North Carolina does maintain an employment and wage database, but its smallest reporting unit is by county (<http://eslmi23.esc.state.nc.us/oeswage/>). It does, however, report estimated number of workers for each specific industry, their estimated entry wage, estimated average wage, and estimated experienced wage. Raleigh reports average personal income, but the numbers are actually for the entire Raleigh-Cary metropolitan statistical area, reported by the United States Department of Commerce, Bureau for Economic Analysis (Raleigh 2008).

Neither database can answer my primary question: for a particular group of workers who commute from Town X to Town Y for employment, what are their total earnings? Or, in the context of this research, how much aggregate economic activity is being contributed to Town X by workers residing in Town Y?

Some extrapolation is possible using *OnTheMap*, which can report a tally of workers belonging to each earnings group, for a specific commute shed. Unfortunately, *OnTheMap* only reports worker earnings in three broad categories: \$1,200/month or less, \$1,201 to \$3,400/month, and more than \$3,400/month. Nevertheless, we can use this information to generate a relative estimate to compare respective commute sheds.

For detailed instructions on the annual earnings calculation steps, see Appendix 3.

## RESULTS

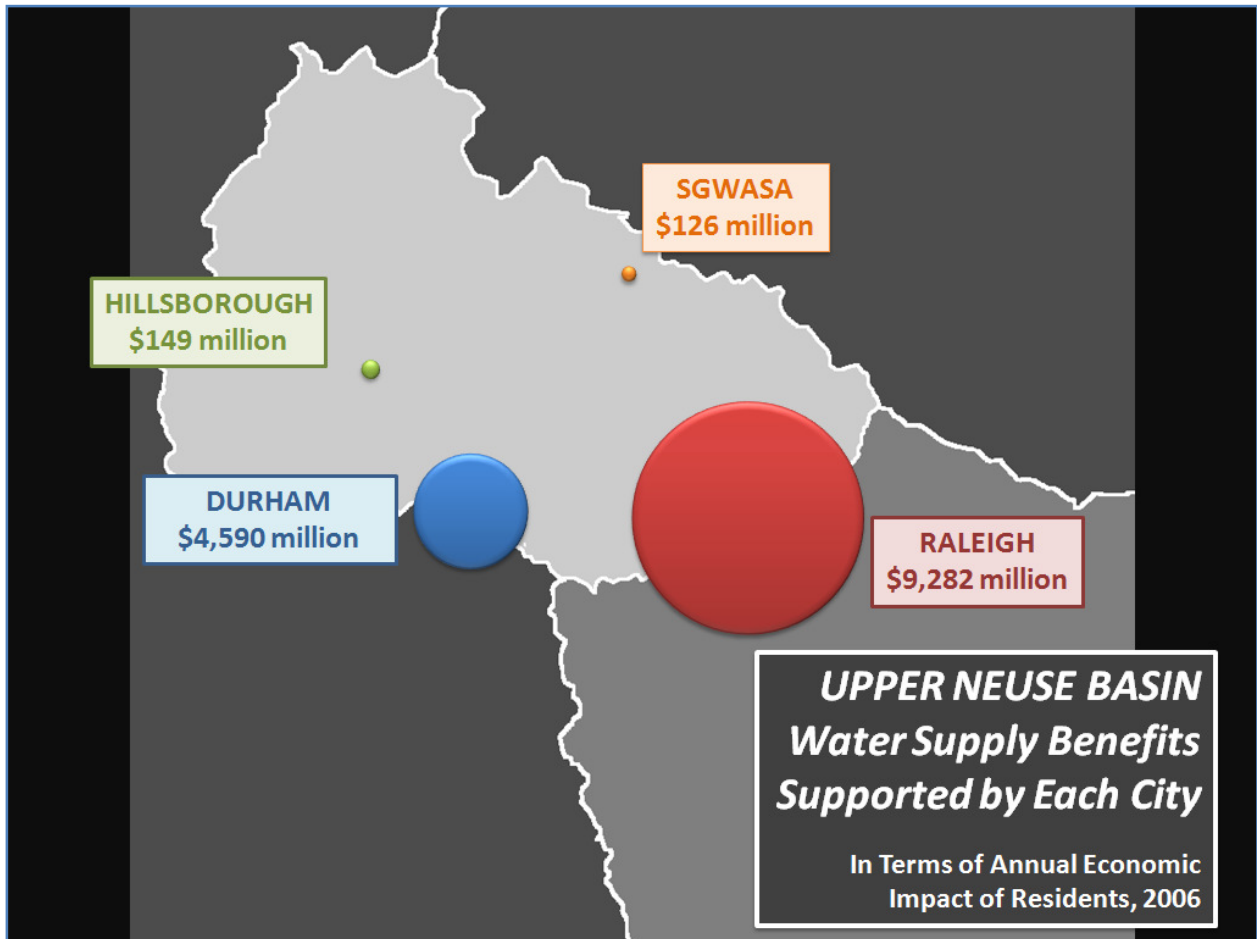
### Water Supply Benefits Supported by Upper Neuse Water Utilities

Upper Neuse cities were grouped according to the municipal water utility system they belonged to. I determined the number of workers residing within the 2006 boundaries of the cities within each water utility, using *OnTheMap*. Based on the monthly earnings category reported for each worker, I arithmetically interpolated the aggregate, annual earnings estimate for the total resident working population of each water system. Adapting the “virtual water” conceptual framework, I posit that these aggregate earnings estimates can be said to represent the economic benefits of potable water supply and the associated water supply and treatment infrastructure for each municipal water utility system.

Given these suppositions, the economic benefits supported by municipal water supplies and water infrastructures are as follows for each system (Figure 3 and Appendix 5):

Durham (Durham only):	\$4,589,841,600	(32%)
Hillsborough (Hillsborough only):	\$148,874,400	(1%)
Greater Raleigh (Raleigh and six other townships):	\$9,281,649,600	(66%)
SGWASA (Butner, Stem, Creedmoor):	\$126,112,800	(1%)
<hr/>		
UPPER NEUSE BASIN TOTAL:	\$14,146,478,400	

Figure 3: Water Supply Benefits Supported by Each City in the Upper Neuse Basin, 2006



Interpolated from LED *OnTheMap* data. See Appendix 2 and 3 for methods, and Appendix 5 for data.

### **Flow of Water Supply Benefits within the Upper Neuse**

Of the water supply benefits supported by each municipal water system, portions are exported to other municipal water systems as a result of residents commuting to those other systems for work. Using *OnTheMap*, I determined the number of resident workers that commute and identified the Upper Neuse city they commute to. These proportions are translated into the volume of water supply benefits exported by each water system. (See Figures 4, 5, 6, 7 and Appendix 5)

All four Upper Neuse water systems export a substantial portion of their water supply benefits to other water systems – i.e., all four water systems have a substantial number of residents who commute for work. Raleigh and Durham each export about 50% of their water supply benefits, whereas Hillsborough and SGWASA export at least 90% of their water supply benefits.

We can use Durham as an example to discuss these exports in further detail and illustrate the resulting relationships (Figure 4). Of the total \$4,590 million of benefits supported by Durham's water supply and infrastructure:

- \$2,304 million (50%) is retained by Durham, as a result of Durham residents who remain in Durham to work and do no commute elsewhere.
- \$22 million (0.5%) is exported to Hillsborough
- \$503 million (11%) is exported to Raleigh
- \$7 million (0.2%) is exported to SGWASA

There are also exports to systems outside of the Upper Neuse:

- \$500 million (11%) to OWASA
- \$205 million (4.5%) to Jordan Lake
- \$16 million (0.3%) to Kerr Lake

- \$1,033 million (22.5%) to all other water systems, attributed to Durham residents who commute to other North Carolina towns, other states, or Washington, D.C. for work.

Looking regionally, Durham exports prominent portions of its water supply and infrastructure benefits to the Raleigh and OWASA systems, at around \$500 million or 11% each – somewhat substantial considering that Durham only retains about 50% of the benefits its own water supply and infrastructures support. But how much impact does Durham’s exports of water supply benefits have for each receiving system?

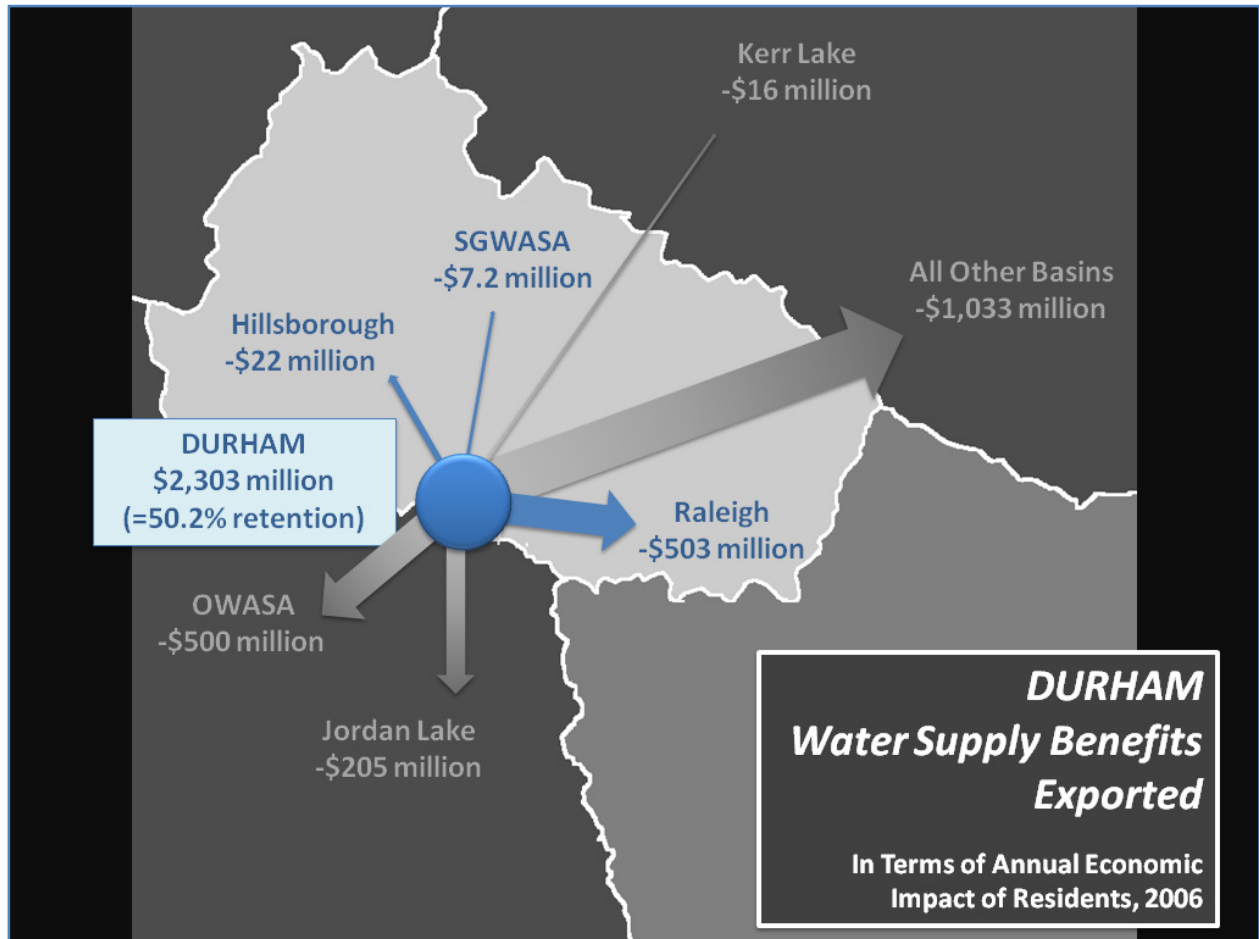
We can compare these contributions to the gross water supply benefits *imported* by each water system (Appendix 6). That is, the total volume of water supply benefits each system retains **plus** benefits gained as a result of commuters arriving from other systems. For example, while Durham only retains \$2,304 million of its own water supply benefits, it receives another \$4,706 million of benefits as a result of commuters coming to Durham to work.

Under this lense, Durham’s \$503 million export to Raleigh equals only **3.6%** of Raleigh’s \$13,961 million of total imports, although this still ranks Durham as one of Raleigh’s primary water supply benefactors in the region. Only Jordan Lake supplies more, at 8.6%. Raleigh’s own contribution (that which is not lost to commuters) is 34%.

Meanwhile, Durham’s \$503 million export to OWASA equals only **7.1%** of OWASA’s \$2,369 million of total imports, although Durham is still OWASA’s primary water supply benefactor. Raleigh and Jordan Lake each only supply about 5% of OWASA’s total imports. OWASA’s own contribution (that which is not lost to commuters) is 28%.

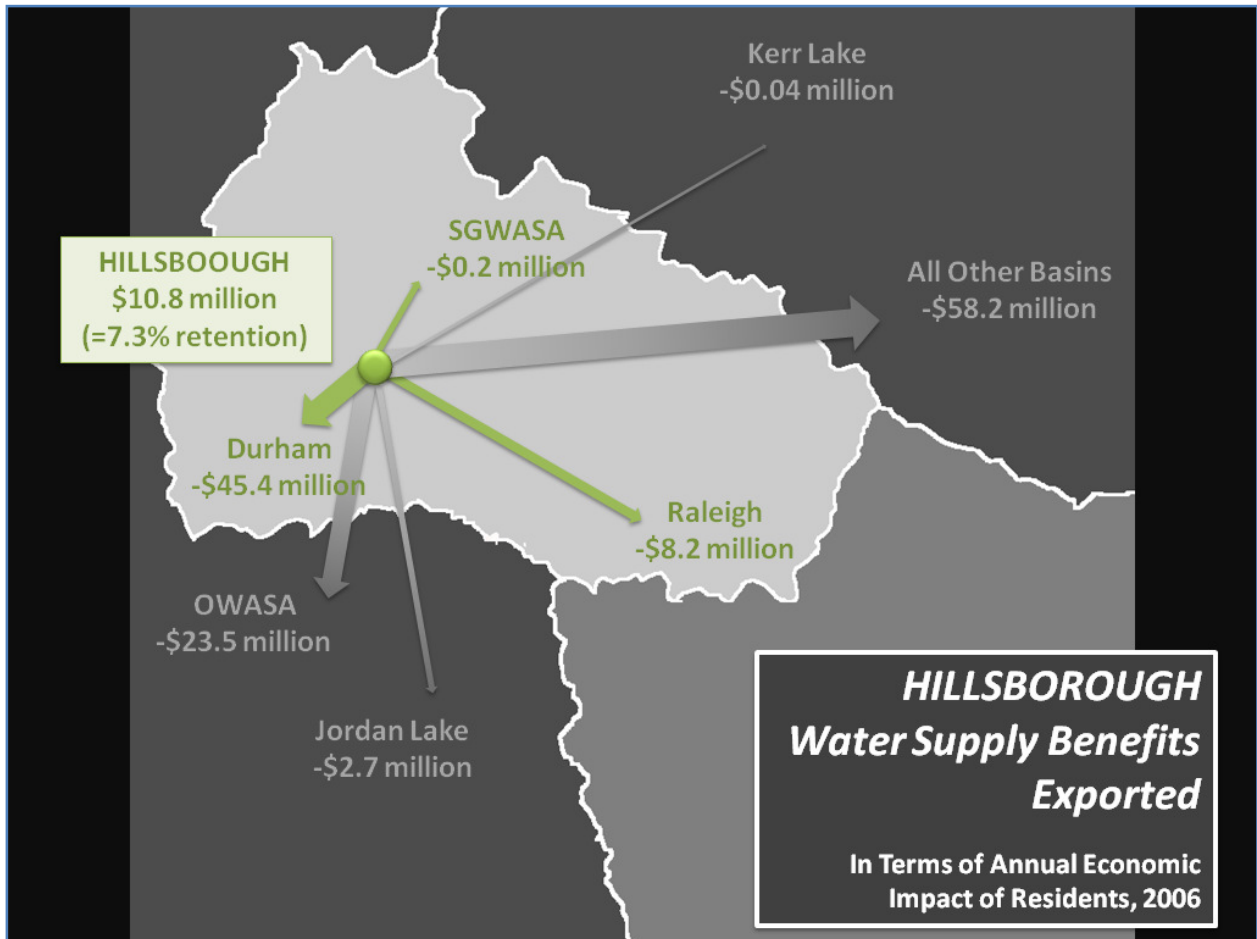
Additional results comparing water supply benefits exported to another city against the gross benefits imported by that other city can be found in Appendix 7.

Figure 4: Water Supply Benefits Exported by the City of Durham, 2006



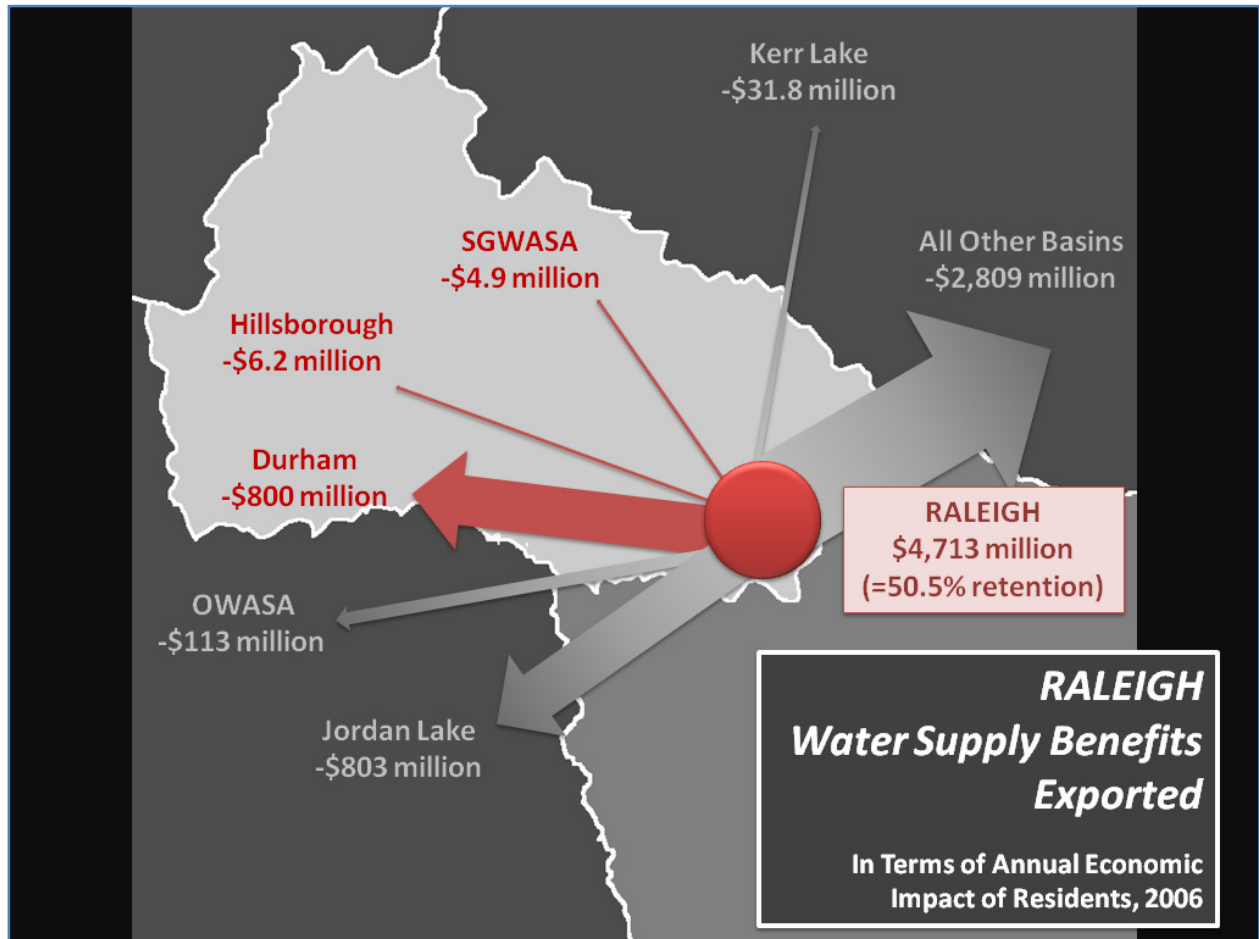
Interpolated from LED *OnTheMap* data. See Appendix 2 and 3 for methods, and Appendix 5 for data.

Figure 5: Water Supply Benefits Exported by Hillsborough, 2006



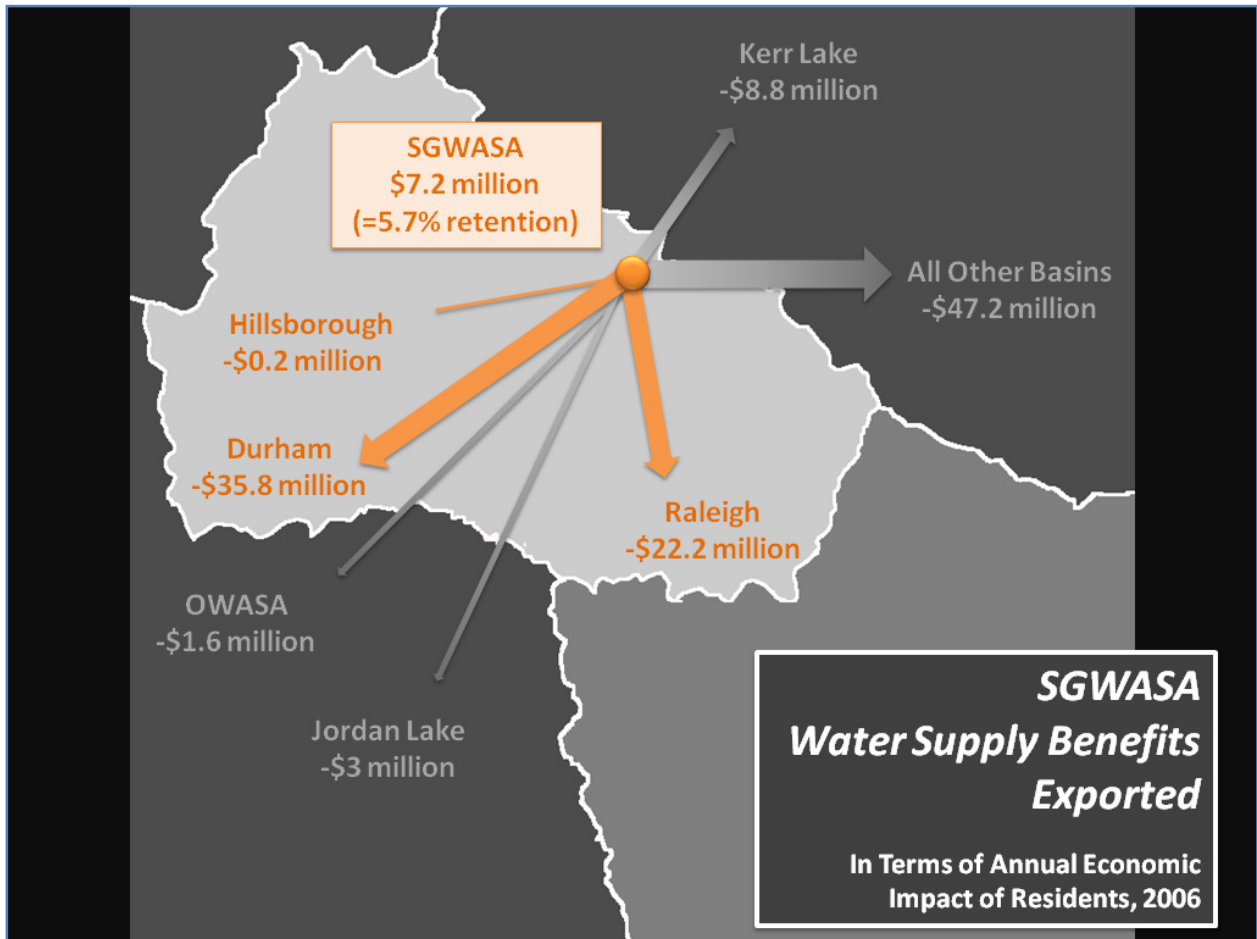
Interpolated from LED *OnTheMap* data. See Appendix 2 and 3 for methods, and Appendix 5 for data.

Figure 6: Water Supply Benefits Exported by Raleigh, 2006



Interpolated from LED *OnTheMap* data. See Appendix 2 and 3 for methods, and Appendix 5 for data.

Figure 7: Water Supply Benefits Supported by SGWASA, 2006



Interpolated from LED *OnTheMap* data. See Appendix 2 and 3 for methods, and Appendix 5 for data.

### **Net Direction of Water Supply Benefits within the Upper Neuse**

Gross exports of water supply benefits by each city are not particularly illuminating – after all, cities both send and receive commuters, and accordingly water supply benefits. What is more revealing and pertinent to the conversation on shared water resources and benefits, then, is the net direction of exports. If we balance the water supply benefit exports of all four municipal water systems in the Upper Neuse, we can observe the net direction of exports (Figure 8).

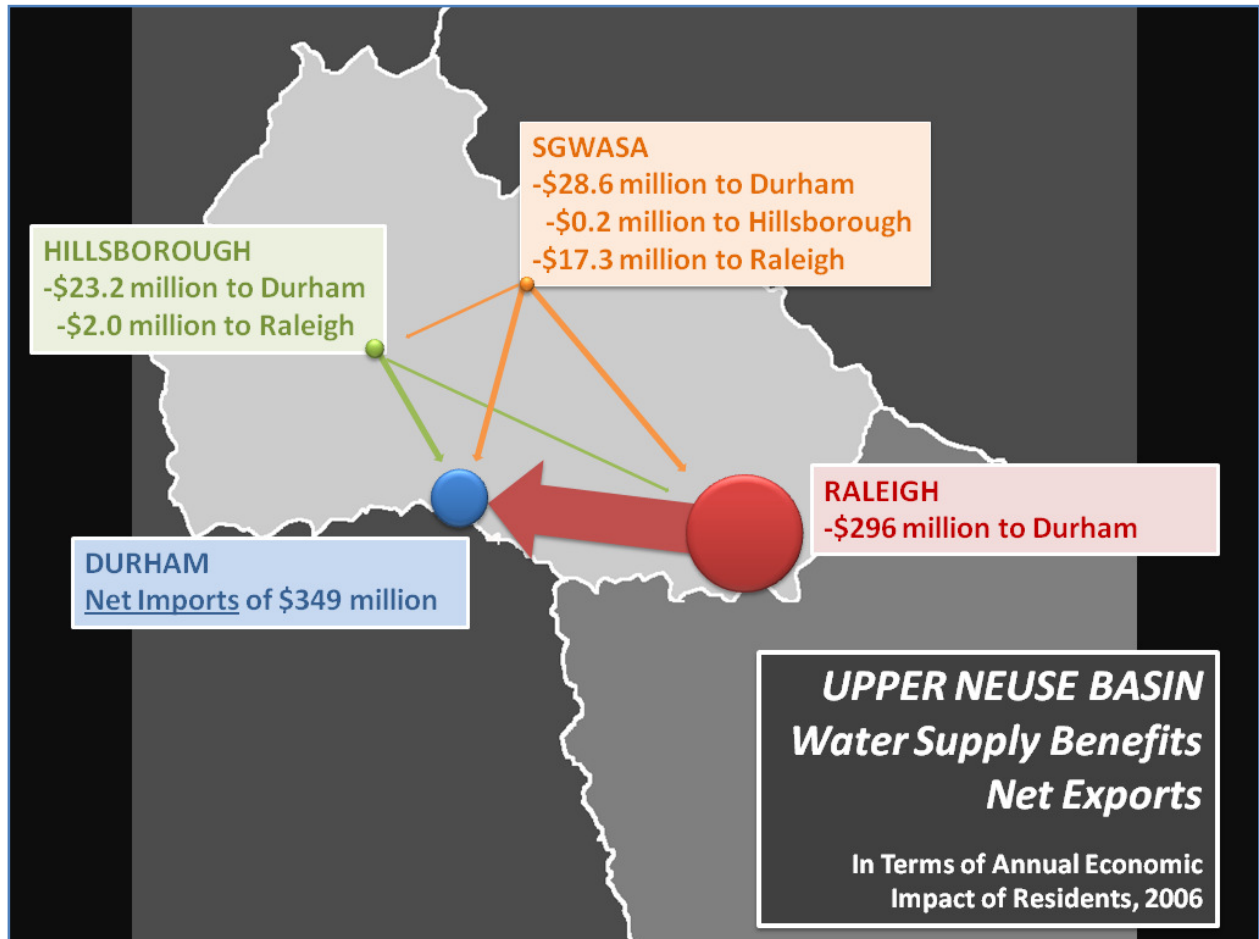
To do so, I balance the water supply benefits exported from City A to City B against the benefits imported by City A from City B. For example, Durham exports \$503 million of benefits to Raleigh, whereas it imports \$800 million of benefits from Raleigh. That is, Durham exports less water supply benefits to Raleigh than it imports from Raleigh, resulting in a net influx of about \$296 million in benefits to Durham.

Balancing all flows of water supply benefits, Hillsborough has net exports to Durham and Raleigh. SGWASA has net exports to Durham, Hillsborough, and Raleigh. Raleigh has net exports to Durham only. Durham has no net exports to any other Upper Neuse system. **All balanced, Durham is a net importer of water supply benefits within the Upper Neuse River Basin.** Durham exports less water supply benefits to each of the three other Upper Neuse systems than it imports from those systems. Essentially, Durham is a net importer of workers within the Upper Neuse, and the workers that Durham imports are supported by the water supplies and water infrastructures of other cities and systems.

We can compare this net import of \$349 million to Durham against what benefits Durham already supplies on its own. Compared to the \$2,304 million of water supply benefits that Durham retains after exports, \$349 million equals about 15%.

Two observations can be gleaned from Durham's net imports of water supply benefits. First, while Durham loses about 50% of all its water supply benefits to commuters, it also gains back a substantial amount of benefits through commuters received. **Second, while in the current political realm Raleigh is looking to buy water from Durham, it appears that Raleigh is currently donating some of its own water benefits to Durham.** Raleigh is steadily losing a portion of the benefits it supports with its scarce water supplies and aging infrastructure, and could lose more if more of its residents work in Durham.

Figure 8: Balance of Water Supply Benefit Exports within the Upper Neuse, 2006



Interpolated from LED *OnTheMap* data. See Appendix 2 and 3 for methods, and Appendix 8 for data.

### **Net Direction of Water Supply Benefits in the Region**

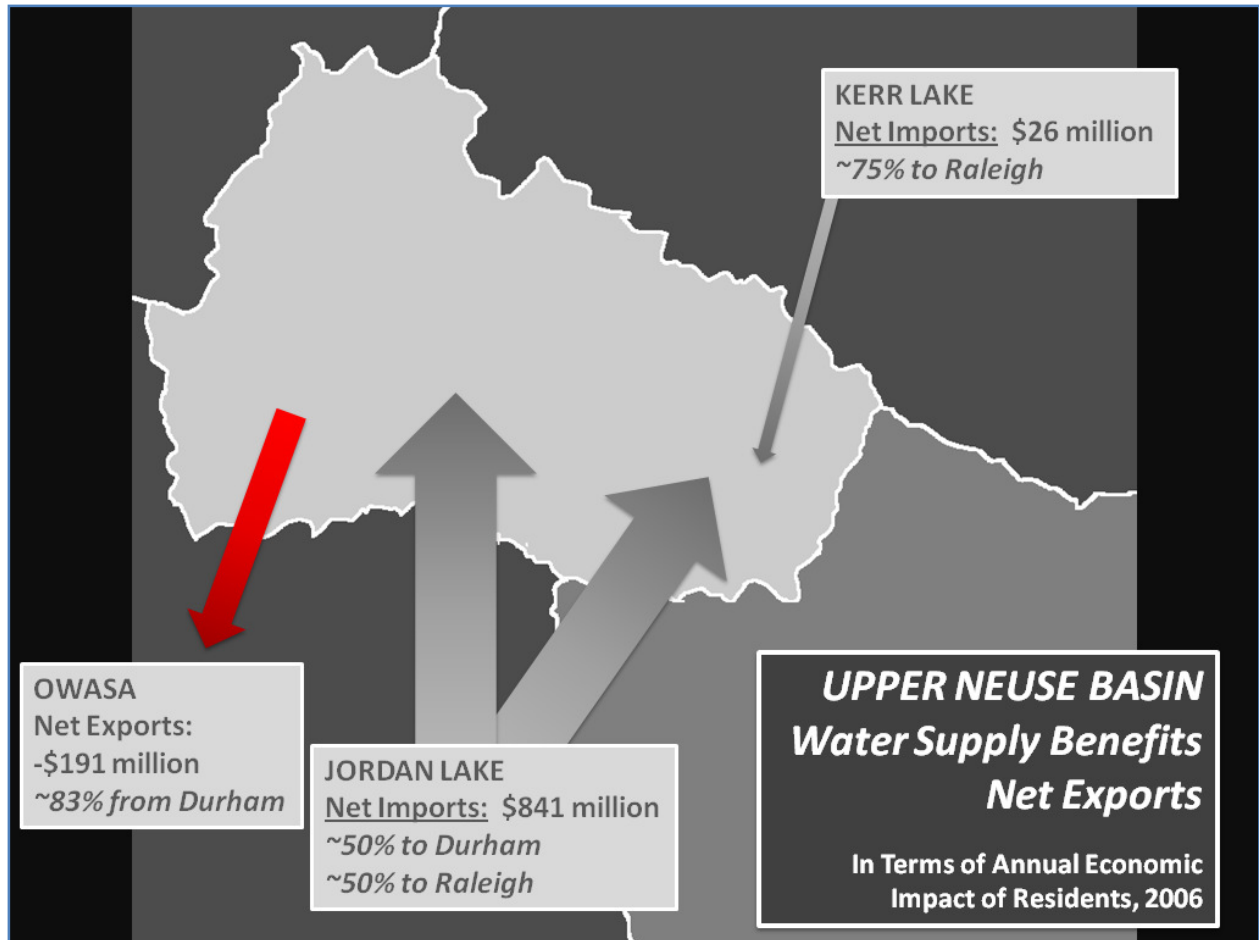
We can also balance the water supply benefit exports of the all Upper Neuse systems against the benefits exported by regional systems (Figure 9). To do so, we balance the benefits exported by Upper Neuse water systems to regional systems against the benefits imported by Upper Neuse water systems from regional systems.

Looking at the Upper Neuse Basin as a whole, its municipal water systems exports \$191 million of water supply benefits to the OWASA system. On the other hand, the Upper Neuse Basin receives imports \$841 million of water supply benefits from the Jordan Lake system and \$26 million from the Kerr Lake system. **All balanced, the Upper Neuse receives net imports of water supply benefits from its neighbors, most significantly from the Jordan Lake system.** The Upper Neuse exports less water supply benefits to each of the three other regional water systems than it imports from those systems. Essentially, the Upper Neuse is a net importer of workers in the greater Triangle Region, and the workers that the Upper Neuse imports are supported by the water supplies and water infrastructures of non-Upper Neuse cities and systems.

Some geographic affinities are apparent from these exports. For example, of the Upper Neuse exports to OWASA, about 83% or \$500 million can be attributed to Durham – i.e., many Durham residents commute to Chapel Hill and Carrboro for work. Such findings may not be surprising, given that politically, interconnectivity has been a specific goal encouraged for Triangle Region cities. Nevertheless, the figures highlight the flow of commuters – and their embedded water supply benefits – across natural watershed boundaries, under the inducement of commerce.

More importantly, this dependency has implications for Upper Neuse planners who seek to tap physical water connections with Jordan Lake. **Given the net direction of water supply benefits in the Triangle Region, it appears that Durham and Raleigh are already benefiting from the water supply and water infrastructure of the Jordan Lake system.**

Figure 9: Balance of Water Supply Benefit Exports Between Upper Neuse and Neighboring Systems, 2006



Interpolated from LED *OnTheMap* data. See Appendix 2 and 3 for methods, and Appendix 9 for data.

## **Notes, Limitations, and Biases**

I have estimated the economic benefit of potable water supply and water supply infrastructure in these exercises, using the rationale that potable water supply and infrastructure are essential for human ability to earn income and generate economic productivity, and in turn, this productivity is a benefit of water supply. However, a number of limitations and biases of this methodology should be noted:

### Precision of Water Supply Benefits

*OnTheMap* reports worker earnings in only three, very broad categories (<\$1,200 per month, \$1,201-\$3,400 per month, >\$3,400 per month). I chose the upper range of each earnings category (or twice the lower range in the case of the >\$3,400 category) as an approximation of actual earnings for two reasons: First, using the earnings of a worker's primary job already under-reports each worker's potential total earnings, since each worker may earn income from jobs other than their primary job. Second, the Triangle Region of North Carolina is heavily dominated by high-technology, government services, medical services, and higher education industries – all offering traditionally high-salary professions. I thus chose a higher figure to approximate the aggregate totals.

Nevertheless, using an arithmetic method (proportion multiplied by representative figure) to interpolate the actual aggregate earnings has shortcomings, particularly if the distribution of earnings is characterized by only three divisions. A higher number of divisions would have produced more accurate estimates. Alas, *OnTheMap* only reports earnings in three divisions. If a distribution function for regional earnings is available, however, it could be applied to the available data set to provide a more refined estimate.

At the least, as long as the same interpolation methods are applied to each region analyzed, the ratio of benefits traded will still provide useful information. These relative measures, of course, are unitless. Yet if one of the goals of applying commute sheds to regional water supply is to glean the balance or proportion of water benefits traded, relative measures are sufficient. These comparisons can still illustrate which one of two systems benefits more from the trade in water supply benefits.

### Issue of Water Supply Benefits Received by Commuters

When postulating that potable water supply for a residence is essential to worker health and ability to generate economic activity, a common criticism is that this ignores the water

supply that the commuter has access to while at work. Indeed, while most water usage occurs at home, commuters use water when at their workplace, and it can be said that part of the worker's full productivity can be attributed to water supplied by the city of employment. Any attempt to measure the volume of water supply benefits of a home city should thus be tempered accordingly.

As previously stated, the primary logic and justification for why home city water supply is absolutely an essential criteria of worker well-being (see Appendix 10), but another justification is possible. Again, one of the main goals of applying commute sheds to regional water supply is to glean the balance or proportion of water benefits traded, relative measures are sufficient. Even if a common factor was applied to water supply benefits to reflect at-work water use, this will not change any relative measures of benefits computed in the end.

#### Status of City Boundary Definitions

Using 2006 TIGER city boundaries may affect my results; the lag of up to three years could mean significant differences in residential and commuting patterns in such a dynamic, growing urban region. However, the fact that *OnTheMap* hosts annual data makes it far superior to standard U.S. Census data, which is only available by the decade.

There is also the possibility that city boundaries reported in TIGER do not actually correspond to current water utility service areas. Using city limits as bounds would omit residential areas that lie outside of city boundaries but served by a municipal water utility. This discrepancy is notable when analyzing water systems that serve multiple towns.

This said, *OnTheMap* currently does not offer a geospatial information layer that displays municipal water utility service areas; to perform a commute shed analysis on such an area, it must be drawn freehand during an analysis session. Unfortunately, this freehand boundary cannot be saved between sessions, and slight discrepancies in the boundary drawn could produce different results. Until *OnTheMap* makes "municipal utility service area" an available unit of analysis, using city boundaries may be the best alternative to ensure standardized, repeatable methodology.

#### Value-Added Impacts of Commuters

Throughout this exercise, we have solely focused on commuters' earnings as a measure of their economic impact. Yet, commuters also engage in economic activities other than their job. Commuters also purchase food, shop for goods, and utilize other services in the city they work in. Value is added to that city's economy with each transaction. Accounting for these additional impacts by commuters to an economy could be broadly accomplished by introducing

another factor to multiply earnings estimates by. However, this is also too broad a correction, and accurate analysis of added value traditionally requires painstaking, complex research.

Again, some comfort lies in the fact that the most valuable information from commute shed analysis is to glean the balance of water benefits traded and the proportional volume of benefits traded. If a standard factor was used to correct the water supply benefits of both sets of commuters to account for added value, the ratio or proportion traded of corrected benefits would be the same as the ratio or proportion traded of uncorrected benefits. A problem only arises if the added value correction factors are different from city to city.

### Other Regional Movements of People and Commerce

I have also neglected to account for the economic impact generated by recreation and tourism in the region. Day trips and tourist visits can also bring water supply benefits from one city to another. This type of analysis would truly require detailed tourism survey and research, which are conducted by convention and visitors bureaus and economic analysis consultants. Water managers who wish to consider the tourism-related economic benefits of water supply could consult these industry reports.

### Summary of Considerations

**The figures of water supply benefits calculated here are approximate and likely underestimates, and are intended as a relative measure to assess the balance of traded benefits within a region. The monetized figures are not intended as a precise value of Upper Neuse water supplies,** but serve as a conceptual tool to illustrate the connection between an economy and its dependence on water supply. However, this should not detract from the realization that our economy most certainly depends on water, and that commuters are one pathway through which water supply benefits are virtually transported between regions.

It should be noted that under the methods used here, ratios and other relative measures do not differ greatly between using raw commuter totals and using interpolated aggregate commuter earnings. If we attempted this entire exercise using just commuter flows (i.e., worker counts only, without interpolation of earnings), Hillsborough and SGWASA still contribute relatively low water supply benefits to Durham or Raleigh. Water supply benefits between Durham and Raleigh remain the most prominent exchanges of resources. Using worker counts, Raleigh commuters who work in Durham still outnumbered Durham commuters who work in Raleigh by a 1.23:1 ratio. After adjusting with earnings, this becomes 1.47:1 ratio. By this measure, when earnings are taken into consideration, there is some inflation of value to Raleigh's exports to Durham.

Whether this discrepancy has significant implications on the utility of commute sheds and *OnTheMap* as a decision tool requires further discussion. At the least, the method to calculate commute sheds and worker counts is concrete and systematic; the methods with which to interpolate economic impact in terms of earnings will need to be improved. But regardless of methodology, we can still glean the ratio or proportion of water supply benefits traded between two cities or water systems.

## DISCUSSION

To my knowledge, this report is the first known demonstration of applying *OnTheMap* to regional water resource planning and virtual water visualization. Depicting the intersection between water resource management and flows of economic activity – such as labor supplies – can educate watershed stakeholders in on how water resources could have such comprehensive impacts on human and economic activity. Virtual water and embedded water are difficult concepts to contextualize, but the commute shed approach could make them more relatable to the lay audience.

The illustration of the interdependence of Upper Neuse and regional water utilities alone can assist ongoing dialog on Basin-wide water supply management. As water and sewer utility managers begin to reach across city boundaries or even basin boundaries to discuss long-term collaboration, they should find commute shed analysis to be useful. City halls may be more likely to cooperate with a counterpart that is known to have both physical and virtual benefit ties. Commute shed analysis could facilitate cooperative decision making for several scenarios in particular:

### **Applications for Regional Planning: Water Allocation and Transfer Agreements**

Raleigh and Durham are actively looking outside of the Upper Neuse River Basin for long-term water supply; commute sheds can help decide whether water transfer agreements and pricing are fair. If it is determined that a proportion of water supply benefits from an intra-basin or inter-basin water purchase is being exported back to the buyer, there could be incentive for the two sides to negotiate more appropriate cost structure.

For example, Raleigh could be looking to Durham to secure emergency water supplies. My analysis above demonstrates that Durham is already a substantial virtual recipient of Raleigh's water supply and water infrastructure benefits. In negotiating a price for future emergency water transfers, Raleigh could demand a proportionately lower price for its water agreement purchase. Raleigh could use Durham's dependency on Raleigh's water supply benefits as a negotiation basis, stating that Durham depends on receiving virtual water supply benefits via Raleigh's commuters. Allowing Raleigh to access Durham water more cheaply could help Raleigh more efficiently provide water to Raleigh residents, many of whom will export those water supply benefits back to Durham anyway when they commute there for work.

### **Applications for Regional Planning: Joint Financing for Infrastructure Projects**

Constructing and renovating water infrastructure is tremendously expensive. Almost \$1 billion dollars of expansions and renovations on reservoirs, water treatment plants, and distribution systems has been proposed to ensure Raleigh's water demand for the next thirty years (City of Raleigh Public Utilities Department, various years). Smaller municipal water systems may project less spending, but their ability to finance those improvements will not be the same as Raleigh's. However, if the smaller utility is actually supporting the economy of the larger city, should the larger city help invest in the smaller utility's capital and operation projects?

Suppose a proposal is under consideration to increase water treatment plant capacity to meet growth demands in City A. If it is determined that residents living in this area of City A are mostly commuting to City B for work, and that it is really City B's development that is driving City A's water demand, there could be some negotiating basis for City A to seek some financial assistance from City B for this expansion project. Such collaborations do not have to be limited to capital investments; virtual connectivity can be used as basis for collaborations in financing facility operating costs as well as source water protection.

For example, my analysis above demonstrates that Durham is a substantial virtual recipient of Jordan Lake's water supply and water infrastructure benefits. Should Cary consider a major renovation or expansion project, it could demand that Durham finance an appropriate portion of the costs for these projects. Cary could use Durham's dependency on Cary's water supply benefits as a discussion point, stating that Durham is receiving virtual benefits of Cary's water supply and infrastructure, and that it is Durham's demand that is driving Cary's need for water infrastructure investment.

### **Applications for Regional Planning: Forecasting Supply and Demand of Water Benefits**

Commute sheds also help us visualize the sources for water supply benefit demands. Economic opportunity in City A may be driving housing demand in City B, if City B is supplying a steady stream of commuters to City A. Understanding where geospatially water demand will increase can help regional water managers forecast development trends and anticipate projects and needs.

*OnTheMap* allows you to visualize the density and distribution of residents, and analyze whether residents in one area are increasingly commuting elsewhere for work (in fact, *OnTheMap* can animate these trends for a visual display). Regional planners can use *OnTheMap* to generate commute sheds over a series of years, and prepare the data for time series analysis.

Socioeconomic observables provided by *OnTheMap* may even provide clues to anticipate water demands, if generalizations can be made on water usage for specific age or income groups.

Finally, commute shed analysis using *OnTheMap* can be performed in higher detail than the city unit. Traffic Analysis Zones (TAZ), ZIP codes, school districts, and other common regional planning units are all available in the software, commuter trends can be analyzed at these local units. City planners can determine which specific neighborhoods are responding to another city's labor demand, and in turn becoming prime exporters of residential water supply benefits.

### **Future Research**

There is still a lot of unexplored potential for *OnTheMap* with regards to applications to water management. The database from which *OnTheMap* draws is also publicly available (see Appendix 1). Academic researchers who would like to incorporate this unique geospatial and socioeconomic data with other datasets, and conduct more sophisticated statistical research without the confines of the *OnTheMap* interface will be able to do so.

A particular recommendation for *OnTheMap* designers: given the growing importance of water resource management across the United States, I suggest that the U.S. Census Bureau should add "municipal utility service area" as a layer of analysis within the software. Water resources and water infrastructure are integral components of regional development planning and economic growth. Compiling a database of service area boundaries should be easily achieved, and will greatly increase the utility of *OnTheMap* to its customers.

Lastly, should Upper Neuse River Basin managers invest in more sophisticated tools to analyze the flows of water and economic benefits in the region, there are solutions that can be explored. Simulation and forecasting models that attempt to optimize hydrologic networks and physical water transfers against economic functions and benefits of industry and agricultural water usage have been developed, particularly in the western United States where scarcity issues have a long history.

Most ambitiously, a University of California, Davis team of hydrologists, engineers, and economists modeled the water supply networks for the entire Sacramento-San Joaquin River Basin (Lund 2008). This immense watershed provides natural water supplies for the entire Central Valley agricultural region, as well as prominent economic centers such as San Francisco, San José, Stockton, and Sacramento. Additionally, via hundreds of miles of pipeline, the Sacramento-San Joaquin Basin also provides water services to the Los Angeles metropolis, effectively making this basin the primary source of water for the nation's most populous state

and among the world's most dominant economies. CALVIN, the study model, attempts to reconcile both the natural and engineered aspects of this watershed with the demands of its stakeholders.

While models alone are not a panacea for the difficulties of integrated watershed management, they can help stakeholders visualize and understand the entire scope of a watershed's resource flows, both tangible and virtual. Conceptualizing a system as complex as central California is a monumental task, but developing a similar tool for a small, well defined watershed such as the Upper Neuse River Basin should be relatively easier. The Upper Neuse has far fewer industry and political entities which control water resources and services, and its inter-basin infrastructure is far less complex. If developed, such an information system would allow regional managers to conduct comprehensive water accounting for the Upper Neuse and even its long-term inter-basin partners. Access to this framework would satisfy many of the usual failures of integrated watershed management efforts: poor understanding of stakeholder network, and poor information access for all negotiators.

## **Conclusions**

This study has shown that it is possible to use a commute shed analysis tool like *OnTheMap* to illustrate gradients of interconnectivity amongst municipalities within a watershed. Commute sheds appear to be useful for conceptualizing and estimating the virtual flows of water service benefits, in particular the balance of benefits traded between regions. However, a more concrete framework for translating commuter numbers to commuter economic productivity is needed if *OnTheMap* is to be used for any quantitative analysis other than relative comparisons.

Management of regional water supplies is a complex venture, and as Upper Neuse municipalities begin to sustainably plan for and share their water supplies and water infrastructure, a variety of approaches, conceptual frameworks, and tools will be necessary. Commute sheds, analyzed in the context of virtual water benefits, should provide municipal water managers with another approach to better understand how their water supply and water infrastructure benefits are being shared in the region. *OnTheMap*, in particular, looks to be a versatile, easily-accessible tool to compute commute sheds, and to complement more costly and time-intensive efforts such as water resources valuation or hydrologic and engineering modeling.

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Wu, Jeremy S., and Matthew Graham. "OnTheMap: An Innovative Mapping and Reporting Tool." *United Nations Seminar on Innovations in Official Statistics, February 20, 2009*. United Nations, New York, NY, 2009.

## **APPENDIX 1: LABOR DYNAMICS RESOURCES**

### **United States Census Bureau, Center for Economic Studies**

Longitudinal Employer-Household Dynamics (LEHD) Program Homepage

<http://lehd.did.census.gov/led/index.html>

*Overview of LEHD and LED partner projects and data resources*

LED *OnTheMap* Version 3 Information and Help Page

<http://lehd.did.census.gov/led/datatools/onthemap3.html>

*Introduction to the OnTheMap application and sample analyses*

LED *OnTheMap* Version 3 Entry Page

<http://lehdmap3.did.census.gov/themap3/>

*Starting point for the OnTheMap tool, beginning with location search*

*OnTheMap* United Nations Seminar Presentation

[http://unstats.un.org/unsd/statcom/statcom\\_09/seminars/innovation/Innovation%20Seminar/USA-OnTheMap.pdf](http://unstats.un.org/unsd/statcom/statcom_09/seminars/innovation/Innovation%20Seminar/USA-OnTheMap.pdf)

*Report introducing OnTheMap at the United Nations Seminar on Innovations in Official Statistics, New York, February 20, 2009*

### **Cornell University, Cornell Institute for Social and Economic Research (CISER)**

VirtualRDC Homepage

<http://www.vrdc.cornell.edu/news/>

*VirtualRDC is the sole institution hosting LED database used by OnTheMap, providing free access to researchers with registration. This database will allow researchers to analyze the LED data directly, without the limitations of the OnTheMap interface.*

*OnTheMap* Synthetic Data

[http://www.vrdc.cornell.edu/news/?page\\_id=205](http://www.vrdc.cornell.edu/news/?page_id=205)

*Background on the “synthetic data” concept*

*OnTheMap* Data Mini Site

<http://www.vrdc.cornell.edu/onthemap/doc/>

*Full instructions and technical requirements for accessing OnTheMap synthetic data*

## APPENDIX 2: COMMUTE SHED ANALYSIS STEPS

This is the methodology used to compile commute sheds, using Durham as an example.

The basic question in a commute shed analysis is: for all employed people residing in Town X, in which other towns are they commuting to for their primary work? Whereas a watershed traces the flow of water from its source to its sink, so too does a commute shed trace the source of a workforce from their place of residence to their place of employment.

1. Begin at the LED *OnTheMap* Entry Page (<http://lehmap3.did.census.gov/themap3/>)
2. In the “Place Name” query box, enter *Durham* and press “Enter”.
3. The view now switches to the analysis page, with a map view on the right, and a tabulated menu on the left. The tab active at this time should be “Search”, which should have provided a list of Name Search Results matching “Durham”.
  - a. Select *Durham, NC* by clicking on the name.
  - b. The map view will now zoom to and center on the City of Durham.
4. Click the “Map Key” tab on the left-side menu. This displays the legend for the map view to the right.
5. Click on the “Layers” tab. This allows the user to select which types of background geographic information should be displayed in the map view.
6. Click on the “Analysis” tab to begin selecting your analysis parameters. Note the drop-down menu at the top left of the screen, near the tabs. As indicated, four steps for parameter entry. Progress through each by clicking “Next”.
7. Data Settings (step 1)
  - a. Under “Live or Work”, select *Home/Residential Area* for a commute shed analysis. This will instruct the application to treat your map selection as a home/source area (rather than work/destination area).
  - b. Under “Job Type”, indicate the subset of worker jobs you wish to analyze. For this study, I chose *Primary Jobs* to focus on the highest paying job for an individual worker for the year, to glean the highest potential for economic productivity per individual worker. More importantly, the Primary Jobs count is equal to the total count of workers recorded in an area, capturing the full data set rather than a subset (*Private Primary Jobs*) or overlapping sets (*All Jobs*).
  - c. Under “Labor Market Segments”, indicate the subset of worker demographics you wish to analyze. For Table 1 and Figures 4-7, I selected *All Workers* as my parameter to capture the full data set.
  - d. Click “Next” at the top.
8. Study Area Selection (step 2)

- a. Now, mark the Home/Residential Area you wish to analyze. Right now, the map view on the right should still be centered on Durham. Go to the “Navigation” bar to your left. Click on “Layer”.
  - b. The “Layer” option allows you to select an area based on pre-defined geographic information, most of which is derived from the Census Bureau’s TIGER 2006 2<sup>nd</sup> Edition dataset. I selected *Cities/Towns* from the Layers drop-down menu.
  - c. Next, point your mouse cursor to Durham on the map; *click once* on any shaded area displayed as Durham. The application will then highlight Durham city boundaries in purple and pink outlines.
    - i. If you wish to include another city in this analysis, simply point and click on another shaded region. Your first selection will be retained, while adding the second selection.
    - ii. Analysis of areas using boundaries not stored in the *OnTheMap* database, such as municipal water and sewer service areas, should use the “Freehand” selection tool instead and draw in the selection boundary by mouse.
  - d. Click “Next” at the top.
9. Advanced Area Selection (step 3)
- a. For a general analysis of commute sheds, and not region-to-region specific commute sheds, this step can be skipped.
  - b. Click “Next” at the top to continue.
10. Map Overlay and Report (step 4)
- a. Under “Report Title”, type in a custom title if you wish.
  - b. Select *Commute Shed Analysis* (or *Paired Commute Shed Analysis*) to generate a commute shed report. “Home Area Profile Analysis” will instead report the demographic statistics for the home area selected.
  - c. Under “Map Precision”, select *Block*. This forces the application to focus at the Census Block level of detail, the most discriminate level possible in this data set.
  - d. Click “GO!” at the top to generate the commute shed report.
11. The report output will now be graphically depicted on the map viewer to the right, and the actual numbers will be available in one of four formats in the left menu bar: *HTML*, *Excel spreadsheet*, *Map and Report PDF*, or *Report-only PDF*.
- a. For a general analysis of commute sheds, the application will consider all possible locations within the database (all 46 states) when generating the commute shed tables. The application will tabulate the top 10 work area destinations for workers by number, and lump all other returns into “All Other Locations”.
  - b. The Map and Report PDF will only provide a partial map. To produce a map with your preferred scale and view, use the “Print Map” tab at the upper right hand side of the application.

## APPENDIX 3: ANNUAL EARNINGS COMPUTATION STEPS

This is the methodology used to interpolate aggregate annual earnings from commute shed data, using Durham and Greater Raleigh as an example.

### I. Commute Shed Profile

1. Begin at the LED *OnTheMap* Entry Page (<http://lehdmap3.did.census.gov/themap3/>)
2. Choose Durham as the Home/Residence Area again. All steps are the same as the commute shed steps described in Appendix 2, until **Part 9**, where you set **Advanced Area Selection** options.
3. Advanced Area Selection (step 3)
  - a. In the left menu bar, click *Create a Paired Work Area*. This will allow you to analyze how many of your home area workers are working at a specific destination.
  - b. Scroll down to the “Navigation” section of the menu bar. Directions here are identical to the Study Area Selection step. Go to “Layers” and choose *Cities/Towns* as the selection mode.
  - c. Now, use your mouse to choose the destination work area. For our example, highlight the shaded regions for Raleigh, Wake Forest, Rolesville, Knightdale, Zebulon, Wendell, and Garner.
  - d. Click “Next” at the top to continue.
4. Map Overlay and Report (step 4)
  - a. Under “Report Title”, type in a custom title if you wish.
  - b. Select *Paired Home Area Analysis* to generate a commute shed profile. This reports the demographic statistics only for workers who both reside in the Home/Residence Area selected **and** work in the Work Area selected.
  - c. Under “Map Precision”, select *Block*. This forces the application to focus at the Census Block level of detail, the most discriminate level possible in this data set.
  - d. Click “GO!” at the top to generate the commute shed report.
5. The report output will now be graphically depicted on the map viewer to the right, and the actual numbers will be available in one of four formats in the left menu bar: *HTML*, *Excel* spreadsheet, *Map and Report PDF*, or *Report-only PDF*.
  - a. With these steps, *OnTheMap* has generated the total number of workers who reside in Durham, but commute to Greater Raleigh for their primary jobs.
  - b. Additionally, we are showing how this group of workers is proportioned by Age, Earnings, and Industry. We will focus on Earnings.
  - c. See Appendix 5 for outputs generated for the Upper Neuse Basin.

### Estimated Annual Earnings Calculation

1. Begin with the output from the Paired Home Area Analysis we ran for Durham and Greater Raleigh:

<b>Paired Home Area Profile Report</b>		
<b><u>Total Primary Jobs</u></b>		
	<b>2006</b>	
	<b>Count</b>	<b>Share</b>
Total Primary Jobs	10,388	100.0%
<b><u>Jobs by Worker Age</u></b>		
	<b>2006</b>	
	<b>Count</b>	<b>Share</b>
Age 30 or younger	3,004	28.9%
Age 31 to 54	6,028	58.0%
Age 55 or older	1,356	13.1%
<b><u>Jobs by Earnings Paid</u></b>		
	<b>2006</b>	
	<b>Count</b>	<b>Share</b>
\$1,200 per month or less	2,545	24.5%
\$1,201 to \$3,400 per month	4,257	41.0%
More than \$3,400 per month	3,586	34.5%
<b><u>Jobs by Industry Type</u></b>		
	<b>2006</b>	
	<b>Count</b>	<b>Share</b>
Goods Producing	1,064	10.2%
Trade, Transportation, and Utilities	1,924	18.5%
All Other Services	7,400	71.2%

2. There is no way we can use these very general categories to back-track a fairly precise aggregate earnings figure. We are given age groups and industry groups, but we still know nothing about how wages are distributed within these categories.
  - a. For example, young workers in our subset may earn more than older workers if they happen to be in a high-paying industry. We also do not know what “All Other Services” comprises. Indeed, we have no idea what the true distribution of wages is in each category. “More than \$3,400/month” could well be skewed towards, say, \$10,000/month, or be closer to \$3,400.
  - b. As such, I have arbitrarily picked three representative earnings to serve as multipliers for each earnings group: **\$1,200, \$3,400, and \$6,800**. I chose the upper range of each earnings category (or twice the lower range in the case of the >\$3,400 category) as an approximation of actual earnings for two reasons: First, these figures already under-report each workers total earnings, since each worker may earn income from jobs other than their primary job. Second, the Triangle Region of North Carolina is heavily dominated by high-technology, government services, medical services, and higher education industries – all offering

traditionally high-salary professions. I thus chose a higher figure to approximate the aggregate totals.

- Multiply the worker counts in each earnings group with the respective multiplier.

DURHAM -> RALEIGH	Count	Multiplier	Product	Months	Est. Annual Earnings Per Year
\$1,200 per month or less	2,545	x 1,200 =	3,054,000	x 12 =	36,648,000
\$1,201 to \$3,400 per month	4,257	x 3,400 =	14,473,800	x 12 =	173,685,600
More than \$3,400 per month	3,586	x 6,800 =	24,384,800	x 12 =	292,617,600
<b>2006 Sum =</b>					<b>\$502,951,200</b>

- Multiply the product by 12 to compute an estimate of the aggregate annual earnings for each earnings group.
- Sum the earnings to compute an approximation of the aggregate benefits that Durham workers bring to Raleigh through their productive activity.
- Repeat using other Upper Neuse municipalities as the designated work area.
- Compare with flows of benefits from the reverse direction, i.e. Raleigh to Durham.

It can be argued that the highest earnings group could be assigned a higher multiplier figure, due to the abundance of high-paying occupations in the Triangle region. But again, the distribution of wages in this category could very well differ from city to city. The goal here is simply to produce an arbitrary but constant extrapolation index to compare these labor flows.

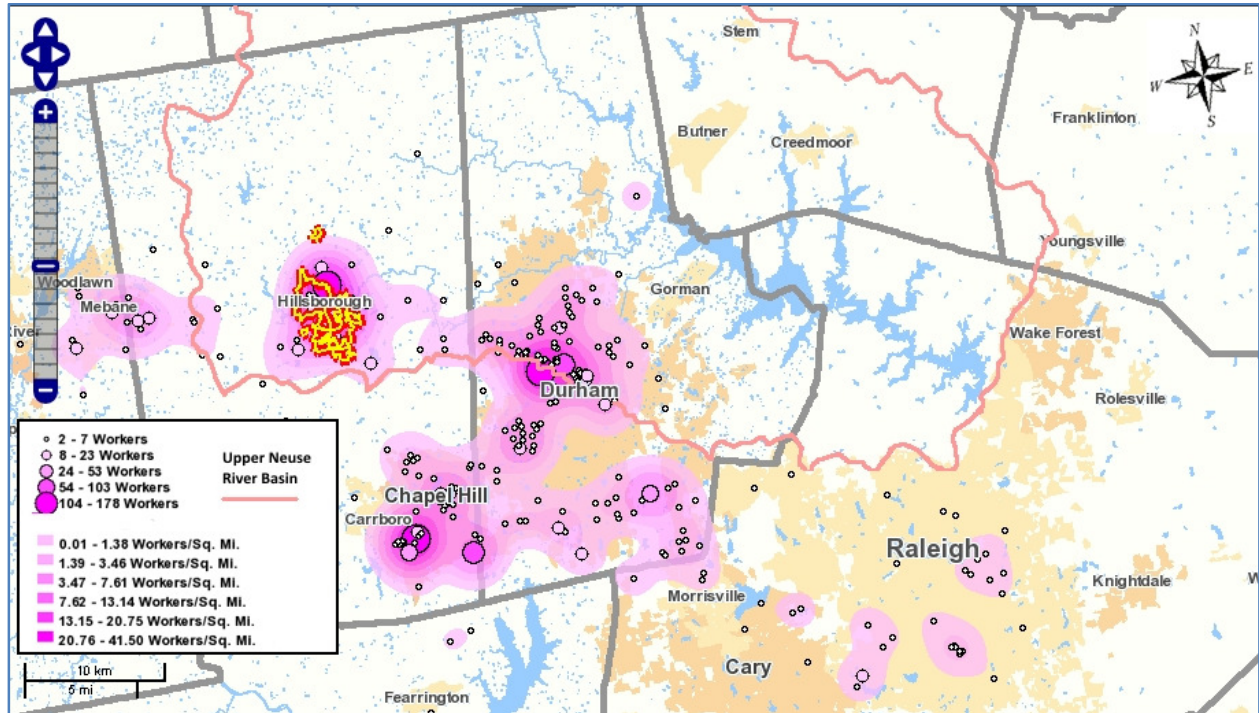
An **improvement** over this method would be to apply some standard wealth distribution function to these figures, and construct an aggregate earnings figure that way.

## **APPENDIX 4: COMMUTE SHED MAPS FOR UPPER NEUSE MUNICIPALITIES**

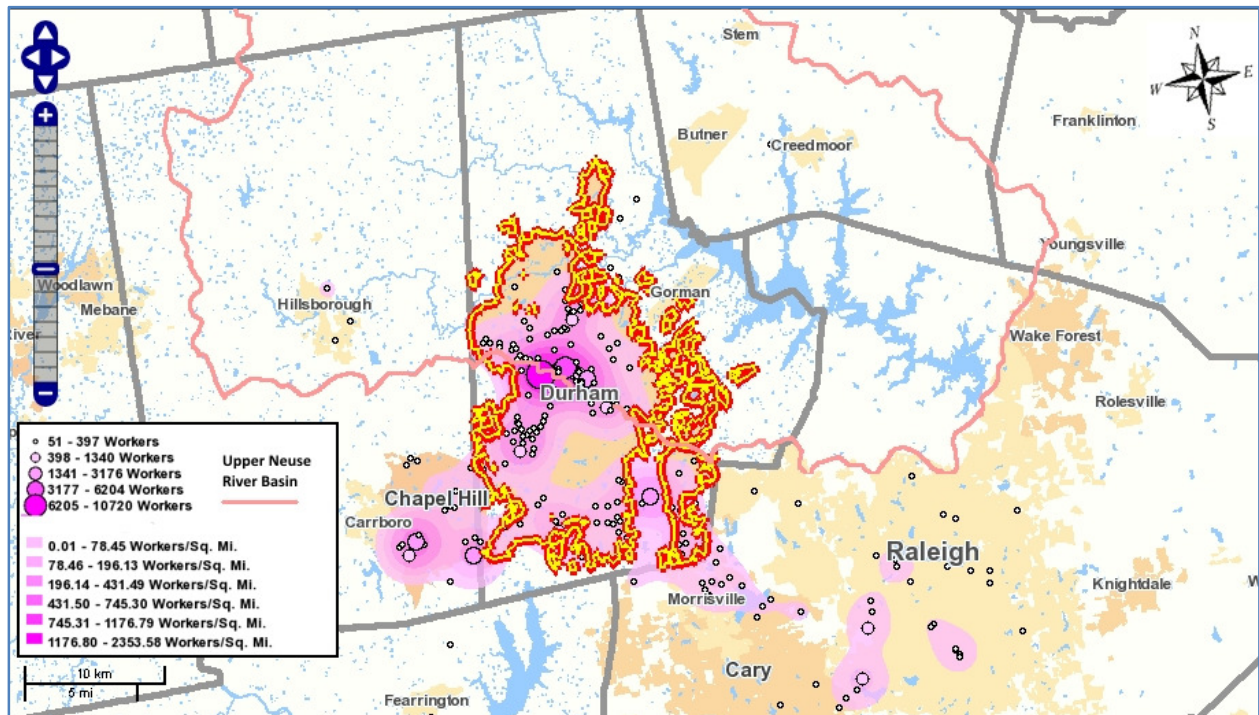
Figures by the author, edited from output generated using *OnTheMap*

These figures do not display the full set of commuter destinations for each city, but only the destinations within the region displayed by the figure.

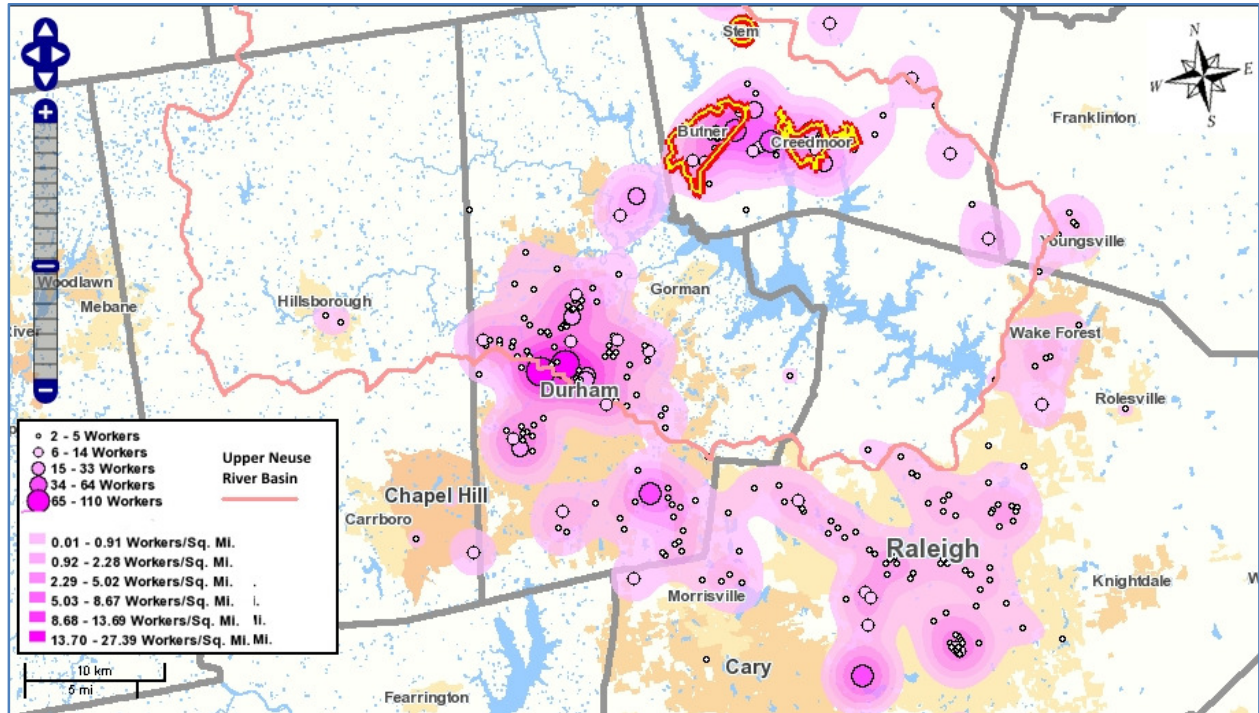
### Commute Shed of Hillsborough Residents, 2006



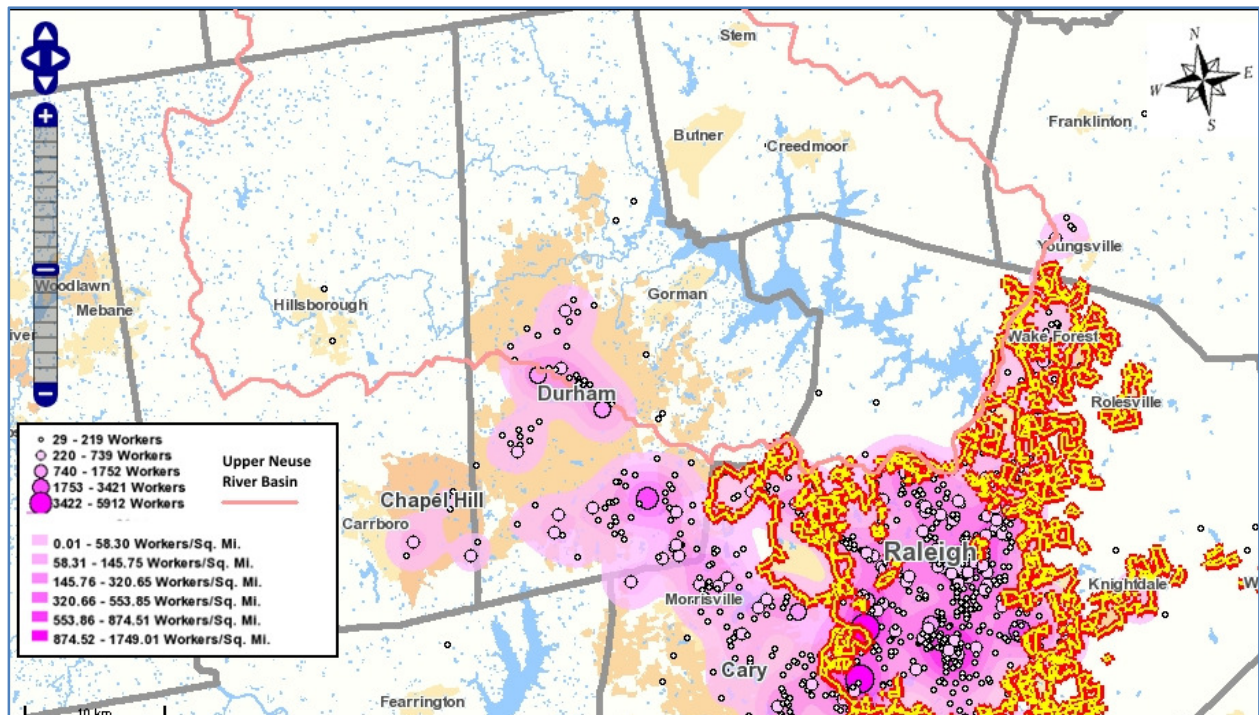
### Commute Shed of Durham Residents, 2006



### Commute Shed of Butner/Stem/Creedmoor Residents, 2006



### Commute Shed of Raleigh Residents, 2006



## **APPENDIX 5: COMMUTE SHEDS AND ANNUAL EARNINGS SUPPORTED AND EXPORTED**

Data source for all tables:

US Census Bureau, LED Origin-Destination Database, 2nd Quarter 2006

Primary Jobs only, using city boundaries defined by TIGER 2006 2<sup>nd</sup> Edition database

## City of Durham

Water and sewer provisions serving Durham  
 Infrastructure operated by the City of Durham  
 Analysis using only Durham boundaries

### Estimated Annual Earnings Calculations

Cities and Towns Where Workers are Employed	Job Count	Estimated Annual Earnings	Monthly Earnings Categories					
			< \$1,200 Multiplier: \$1,200		\$1,201-\$3,400 Multiplier: \$3,400		> \$3,400 Multiplier: \$6,800	
			Count	Est.	Count	Est.	Count	Est.
<b>Upper Neuse</b>								
Durham	45,352	\$2,303,606,400	8,837	\$10,604,400	19,688	\$66,939,200	16,827	\$114,423,600
Hillsborough	448	\$22,137,600	98	\$117,600	192	\$652,800	158	\$1,074,400
Raleigh	10,388	\$502,951,200	2,545	\$3,054,000	4,257	\$14,473,800	3,586	\$24,384,800
Butner/Stem/Creedmoor	144	\$7,228,800	26	\$31,200	68	\$231,200	50	\$340,000
<b>Cape Fear</b>								
Chapel Hill/Carrboro	8,548	\$499,795,200	1,167	\$1,400,400	2,924	\$9,941,600	4,457	\$30,307,600
Cary/Apex/Morrisville	4,202	\$205,312,800	995	\$1,194,000	1,733	\$5,892,200	1,474	\$10,023,200
<b>Roanoke</b>								
Oxford/Henderson	347	\$16,017,600	98	\$117,600	140	\$476,000	109	\$741,200
<b>Other</b>								
All Other Cities	21,251	\$1,032,792,000	5,399	\$6,478,800	8,296	\$28,206,400	7,556	\$51,380,800
<b>Total Supported by Durham Water and Sewer Provisions</b>	<b>90,680</b>	<b>\$4,589,841,600</b>	19,165	\$22,998,000	37,298	\$126,813,200	34,217	\$232,675,600

**Durham Commute Shed**

Cities and Towns Where Workers are Employed	Job Count	Share
<b>Upper Neuse</b>		
Durham	45,352	50.0%
Hillsborough	448	0.5%
Raleigh	10,388	11.5%
Butner/Stem/Creedmoor	144	0.2%
<b>Cape Fear</b>		
Chapel Hill/Carrboro	8,548	9.4%
Cary/Apex/Morrisville	4,202	4.6%
<b>Roanoke</b>		
Oxford/Henderson	347	0.4%
<b>Other</b>		
All Other Cities	21,251	23.4%
Total Primary Jobs	90,680	100.0%

**Durham Water Supply Benefits**

Cities and Towns Receiving Benefits	Estimated Annual Earnings	Share
<b>Upper Neuse</b>		
Durham	\$2,303,606,400	50.2%
Hillsborough	\$22,137,600	0.5%
Raleigh	\$502,951,200	11.0%
Butner/Stem/Creedmoor	\$7,228,800	0.2%
<b>Cape Fear</b>		
Chapel Hill/Carrboro	\$499,795,200	10.9%
Cary/Apex/Morrisville	\$205,312,800	4.5%
<b>Roanoke</b>		
Oxford/Henderson	\$16,017,600	0.3%
<b>Other</b>		
All Other Cities	\$1,032,792,000	22.5%
Total Benefits	\$4,589,841,600	100.0%

### Town of Hillsborough

Water and sewer provisions serving Hillsborough  
Infrastructure operated by the Town of Hillsborough  
Analysis using only Hillsborough boundaries

### Estimated Annual Earnings Calculations

Cities and Towns Where Workers are Employed	Job Count	Estimated Annual Earnings	Monthly Earnings Categories					
			< \$1,200 Multiplier: \$1,200		\$1,201-\$3,400 Multiplier: \$3,400		> \$3,400 Multiplier: \$6,800	
			Count	Est.	Count	Est.	Count	Est.
<b>Upper Neuse</b>								
Durham	805	\$45,369,600	119	\$142,800	302	\$1,026,800	384	\$2,611,200
<b>Hillsborough</b>	<b>250</b>	<b>\$10,816,800</b>	<b>74</b>	<b>\$88,800</b>	<b>113</b>	<b>\$384,200</b>	<b>63</b>	<b>\$428,400</b>
Raleigh	165	\$8,162,400	37	\$44,400	69	\$234,600	59	\$401,200
Butner/Stem/Creedmoor	2	\$28,800	2	\$2,400	0	\$0	0	\$0
<b>Cape Fear</b>								
Chapel Hill/Carrboro	429	\$23,541,600	68	\$81,600	169	\$574,600	192	\$1,305,600
Cary/Apex/Morrisville	48	\$2,671,200	7	\$8,400	19	\$64,600	22	\$149,600
<b>Roanoke</b>								
Oxford/Henderson	1	\$40,800	0	\$0	1	\$3,400	0	\$0
<b>Other</b>								
All Other Cities	1,205	\$58,243,200	299	\$358,800	490	\$1,666,000	416	\$2,828,800
<b>Total Supported by Hillsborough Water and Sewer Provisions</b>	<b>2,905</b>	<b>\$148,874,400</b>	<b>606</b>	<b>\$727,200</b>	<b>1163</b>	<b>\$3,954,200</b>	<b>1136</b>	<b>\$7,724,800</b>

### Hillsborough Commute Shed

Cities and Towns Where Workers are Employed	Job Count	Share
<b>Upper Neuse</b>		
Durham	805	27.7%
Hillsborough	250	8.6%
Raleigh	165	5.7%
Butner/Stem/Creedmoor	2	0.1%
<b>Cape Fear</b>		
Chapel Hill/Carrboro	429	14.8%
Cary/Apex/Morrisville	48	1.7%
<b>Roanoke</b>		
Oxford/Henderson	1	0.0%
<b>Other</b>		
All Other Cities	1,205	41.5%
<b>Total Primary Jobs</b>	<b>2,905</b>	<b>100.0%</b>

### Hillsborough Water Supply Benefits

Cities and Towns Receiving Benefits	Estimated Annual Earnings	Share
<b>Upper Neuse</b>		
Durham	\$45,369,600	30.5%
Hillsborough	\$10,816,800	7.3%
Raleigh	\$8,162,400	5.5%
Butner/Stem/Creedmoor	\$28,800	0.0%
<b>Cape Fear</b>		
Chapel Hill/Carrboro	\$23,541,600	15.8%
Cary/Apex/Morrisville	\$2,671,200	1.8%
<b>Roanoke</b>		
Oxford/Henderson	\$40,800	0.0%
<b>Other</b>		
All Other Cities	\$58,243,200	39.1%
<b>Total Benefits</b>	<b>\$148,874,400</b>	<b>100.0%</b>

### Greater Raleigh

Water and sewer provisions serving Raleigh, Wake Forest, Rolesville, Knightdale, Wendell, Zebulon, and Garner Infrastructure operated by the City of Raleigh

Analysis using only serving Raleigh, Wake Forest, Rolesville, Knightdale, Wendell, Zebulon, and Garner boundaries

### Estimated Annual Earnings Calculations

Cities and Towns Where Workers are Employed	Count	Estimated Annual Earnings	Monthly Earnings Categories					
			< \$1,200 Multiplier: \$1,200		\$1,201-\$3,400 Multiplier: \$3,400		> \$3,400 Multiplier: \$6,800	
			Count	Est.	Count	Est.	Count	Est.
<b>Upper Neuse</b>								
Durham	13,675	\$799,807,200	1,978	\$2,373,600	4,489	\$15,262,600	7,208	\$49,014,400
Hillsborough	130	\$6,172,800	32	\$38,400	56	\$190,400	42	\$285,600
<b>Raleigh</b>	<b>93,930</b>	<b>\$4,713,302,400</b>	<b>19,726</b>	<b>\$23,671,200</b>	<b>39,848</b>	<b>\$135,483,200</b>	<b>34,356</b>	<b>\$233,620,800</b>
Butner/Stem/Creedmoor	93	\$4,951,200	18	\$21,600	35	\$119,000	40	\$272,000
<b>Cape Fear</b>								
Chapel Hill/Carrboro	2,145	\$113,210,400	447	\$536,400	779	\$2,648,600	919	\$6,249,200
Cary/Apex/Morrisville	15,927	\$803,335,200	3,243	\$3,891,600	6,823	\$23,198,200	5,861	\$39,854,800
<b>Roanoke</b>								
Oxford/Henderson	607	\$31,814,400	141	\$169,200	202	\$686,800	264	\$1,795,200
<b>Other</b>								
All Other Locations	52,476	\$2,809,056,000	11,054	\$13,264,800	17,896	\$60,846,400	23,526	\$159,976,800
<b>Total Supported by Raleigh Water and Sewer Provisions</b>	<b>178,983</b>	<b>\$9,281,649,600</b>	<b>36,639</b>	<b>\$43,966,800</b>	<b>70,128</b>	<b>\$238,435,200</b>	<b>72,216</b>	<b>\$491,068,800</b>

**Raleigh Commute Shed**

Cities and Towns Where Workers are Employed	Count	Share
<b>Upper Neuse</b>		
Durham	13,675	7.6%
Hillsborough	130	0.1%
Raleigh	93,930	52.5%
Butner/Stem/Creedmoor	93	0.1%
<b>Cape Fear</b>		
Chapel Hill/Carrboro	2,145	1.2%
Cary/Apex/Morrisville	15,927	8.9%
<b>Roanoke</b>		
Oxford/Henderson	607	0.3%
<b>Other</b>		
All Other Locations	52,476	29.3%
Total Primary Jobs	178,983	100.0%

**Raleigh Water Supply Benefits**

Cities and Towns Receiving Benefits	Estimated Annual Earnings	Share
<b>Upper Neuse</b>		
Durham	\$799,807,200	8.6%
Hillsborough	\$6,172,800	0.1%
Raleigh	\$4,713,302,400	50.8%
Butner/Stem/Creedmoor	\$4,951,200	0.1%
<b>Cape Fear</b>		
Chapel Hill/Carrboro	\$113,210,400	1.2%
Cary/Apex/Morrisville	\$803,335,200	8.7%
<b>Roanoke</b>		
Oxford/Henderson	\$31,814,400	0.3%
<b>Other</b>		
All Other Locations	\$2,809,056,000	30.3%
Total Benefits	\$9,281,649,600	100.0%

**Butner, Stem, and Creedmoor (SGWASA)**

Water and sewer provisions serving Butner, Stem, Creedmoor, and unincorporated areas in southern Granville County Infrastructure operated by the South Granville Water and Sewer Authority (SGWASA)  
Analysis using only Butner, Stem, and Creedmoor boundaries

**Estimated Annual Earnings Calculations**

Cities and Towns Where Workers are Employed	Job Count	Estimated Annual Earnings	Monthly Earnings Categories					
			< \$1,200 Multiplier: \$1,200		\$1,201-\$3,400 Multiplier: \$3,400		> \$3,400 Multiplier: \$6,800	
			Count	Est.	Count	Est.	Count	Est.
<b>Upper Neuse</b>								
Durham	699	\$35,844,000	95	\$114,000	363	\$1,234,200	241	\$1,638,800
Hillsborough	6	\$259,200	1	\$1,200	4	\$13,600	1	\$6,800
Raleigh	482	\$22,240,800	91	\$109,200	269	\$914,600	122	\$829,600
<b>Butner/Stem/Creedmoor</b>	<b>174</b>	<b>\$7,192,800</b>	<b>49</b>	<b>\$58,800</b>	<b>91</b>	<b>\$309,400</b>	<b>34</b>	<b>\$231,200</b>
<b>Cape Fear</b>								
Chapel Hill/Carrboro	35	\$1,624,800	8	\$9,600	17	\$57,800	10	\$68,000
Cary/Apex/Morrisville	61	\$2,988,000	12	\$14,400	29	\$98,600	20	\$136,000
<b>Roanoke</b>								
Oxford/Henderson	191	\$8,793,600	44	\$52,800	94	\$319,600	53	\$360,400
<b>Other</b>								
All Other Cities	1,043	\$47,169,600	261	\$313,200	500	\$1,700,000	282	\$1,917,600
<b>Total Supported by SGWASA Water and Sewer Provisions</b>	<b>2,691</b>	<b>\$126,112,800</b>	<b>561</b>	<b>\$673,200</b>	<b>1,367</b>	<b>\$4,647,800</b>	<b>763</b>	<b>\$5,188,400</b>

**SGWASA Commute Shed**

Cities and Towns Where Workers are Employed	Job Count	Share
<b>Upper Neuse</b>		
Durham	699	26.0%
Hillsborough	6	0.2%
Raleigh	482	17.9%
Butner/Stem/Creedmoor	174	6.5%
<b>Cape Fear</b>		
Chapel Hill/Carrboro	35	1.3%
Cary/Apex/Morrisville	61	2.3%
<b>Roanoke</b>		
Oxford/Henderson	191	7.1%
<b>Other</b>		
All Other Locations	1,043	38.8%
Total Primary Jobs	2,691	100.0%

**SGWASA Water Supply Benefits**

Cities and Towns Receiving Benefits	Estimated Annual Earnings	Share
<b>Upper Neuse</b>		
Durham	\$35,844,000	28.4%
Hillsborough	\$259,200	0.2%
Raleigh	\$22,240,800	17.6%
Butner/Stem/Creedmoor	\$7,192,800	5.7%
<b>Cape Fear</b>		
Chapel Hill/Carrboro	\$1,624,800	1.3%
Cary/Apex/Morrisville	\$2,988,000	2.4%
<b>Roanoke</b>		
Oxford/Henderson	\$8,793,600	7.0%
<b>Other</b>		
All Other Locations	\$47,169,600	37.4%
Total Benefits	\$126,112,800	100.0%

### Chapel Hill and Carrboro (OWASA)

Water and sewer provisions serving Chapel Hill and Carrboro  
Infrastructure operated by the Orange Water and Sewer Authority (OWASA)  
Analysis using only Chapel Hill and Carrboro boundaries

### Estimated Annual Earnings Calculations

Cities and Towns Where Workers are Employed	Job Count	Estimated Annual Earnings	Monthly Earnings Categories					
			< \$1,200 Multiplier: \$1,200		\$1,201-\$3,400 Multiplier: \$3,400		> \$3,400 Multiplier: \$6,800	
			Count	Est.	Count	Est.	Count	Est.
<b>Upper Neuse</b>								
Durham	5,801	\$341,385,600	950	\$1,140,000	1,670	\$5,678,000	3,181	\$21,630,800
Hillsborough	214	\$9,756,000	57	\$68,400	95	\$323,000	62	\$421,600
Raleigh	1,869	\$95,536,800	472	\$566,400	619	\$2,104,600	778	\$5,290,400
Butner/Stem/Creedmoor	12	\$573,600	3	\$3,600	5	\$17,000	4	\$27,200
<b>Cape Fear</b>								
<b>Chapel Hill/Carrboro</b>	<b>11,962</b>	<b>\$660,787,200</b>	<b>2,317</b>	<b>\$2,780,400</b>	<b>3,912</b>	<b>\$13,300,800</b>	<b>5,733</b>	<b>\$38,984,400</b>
Cary/Apex/Morrisville	830	\$46,663,200	172	\$206,400	233	\$792,200	425	\$2,890,000
<b>Roanoke</b>								
Oxford/Henderson	40	\$1,965,600	9	\$10,800	17	\$57,800	14	\$95,200
<b>Other</b>								
All Other Cities	6,984	\$341,553,600	1,789	\$2,146,800	2,650	\$9,010,000	2,545	\$17,306,000
<b>Total Supported by OWASA Water and Sewer Provisions</b>	<b>27,712</b>	<b>\$1,498,221,600</b>	<b>5,769</b>	<b>\$6,922,800</b>	<b>9,201</b>	<b>\$31,283,400</b>	<b>12,742</b>	<b>\$86,645,600</b>

**OWASA Commute Shed**

Cities and Towns Where Workers are Employed	Job Count	Share
<b>Upper Neuse</b>		
Durham	5,801	20.9%
Hillsborough	214	0.8%
Raleigh	1,869	6.7%
Butner/Stem/Creedmoor	12	0.0%
<b>Cape Fear</b>		
Chapel Hill/Carrboro	11,962	43.2%
Cary/Apex/Morrisville	830	3.0%
<b>Roanoke</b>		
Oxford/Henderson	40	0.1%
<b>Other</b>		
All Other Cities	6,984	25.2%
Total Primary Jobs	27,712	100.0%

**OWASA Water Supply Benefits**

Cities and Towns Receiving Benefits	Estimated Annual Earnings	Share
<b>Upper Neuse</b>		
Durham	\$341,385,600	22.8%
Hillsborough	\$9,756,000	0.7%
Raleigh	\$95,536,800	6.4%
Butner/Stem/Creedmoor	\$573,600	0.0%
<b>Cape Fear</b>		
Chapel Hill/Carrboro	\$660,787,200	44.1%
Cary/Apex/Morrisville	\$46,663,200	3.1%
<b>Roanoke</b>		
Oxford/Henderson	\$1,965,600	0.1%
<b>Other</b>		
All Other Cities	\$341,553,600	22.8%
Total Benefits	\$1,498,221,600	100.0%

**Cary, Apex, and Morrisville (Jordan Lake)**

Water and sewer provisions serving Cary, Apex, and Morrisville  
Infrastructure operated by the Town of Cary  
Analysis using only Cary, Apex, and Morrisville boundaries

**Estimated Annual Earnings Calculations**

Cities and Towns Where Workers are Employed	Job Count	Estimated Annual Earnings	Monthly Earnings Categories					
			< \$1,200 Multiplier: \$1,200		\$1,201-\$3,400 Multiplier: \$3,400		> \$3,400 Multiplier: \$6,800	
			Count	Est.	Count	Est.	Count	Est.
<b>Upper Neuse</b>								
Durham	9,731	\$646,749,600	869	\$1,042,800	2,179	\$7,408,600	6,683	\$45,444,400
Hillsborough	48	\$2,724,000	5	\$6,000	21	\$71,400	22	\$149,600
Raleigh	21,316	\$1,205,006,400	3,509	\$4,210,800	7,318	\$24,881,200	10,489	\$71,325,200
Butner/Stem/Creedmoor	22	\$1,322,400	4	\$4,800	5	\$17,000	13	\$88,400
<b>Cape Fear</b>								
Chapel Hill/Carrboro	1,810	\$108,580,800	270	\$324,000	514	\$1,747,600	1,026	\$6,976,800
<b>Cary/Apex/Morrisville</b>	<b>17,813</b>	<b>\$928,708,800</b>	<b>4,155</b>	<b>\$4,986,000</b>	<b>6,020</b>	<b>\$20,468,000</b>	<b>7,638</b>	<b>\$51,938,400</b>
<b>Roanoke</b>								
Oxford/Henderson	111	\$5,448,000	27	\$32,400	44	\$149,600	40	\$272,000
<b>Other</b>								
All Other Cities	23,453	\$1,403,616,000	3,843	\$4,611,600	6,174	\$20,991,600	13,436	\$91,364,800
<b>Total Supported by Jordan Lake Water and Sewer Provisions</b>	<b>74,304</b>	<b>\$4,302,156,000</b>	<b>12,682</b>	<b>\$15,218,400</b>	<b>22,275</b>	<b>\$75,735,000</b>	<b>39,347</b>	<b>\$267,559,600</b>

**Jordan Lake Commute Shed**

Cities and Towns Where Workers are Employed	Job Count	Share
<b>Upper Neuse</b>		
Durham	9,731	13.1%
Hillsborough	48	0.1%
Raleigh	21,316	28.7%
Butner/Stem/Creedmoor	22	0.0%
<b>Cape Fear</b>		
Chapel Hill/Carrboro	1,810	2.4%
Cary/Apex/Morrisville	17,813	24.0%
<b>Roanoke</b>		
Oxford/Henderson	111	0.1%
<b>Other</b>		
All Other Cities	23,453	31.6%
Total Primary Jobs	74,304	100.0%

**Jordan Lake Water Supply Benefits**

Cities and Towns Receiving Benefits	Estimated Annual Earnings	Share
<b>Upper Neuse</b>		
Durham	\$646,749,600	15.0%
Hillsborough	\$2,724,000	0.1%
Raleigh	\$1,205,006,400	28.0%
Butner/Stem/Creedmoor	\$1,322,400	0.0%
<b>Cape Fear</b>		
Chapel Hill/Carrboro	\$108,580,800	2.5%
Cary/Apex/Morrisville	\$928,708,800	21.6%
<b>Roanoke</b>		
Oxford/Henderson	\$5,448,000	0.1%
<b>Other</b>		
All Other Cities	\$1,403,616,000	32.6%
Total Benefits	\$4,302,156,000	100.0%

**Oxford, Henderson, and South Henderson (Kerr Lake)**

Water and sewer provisions serving the Oxford, Henderson, and South Henderson  
Infrastructure operated by the City of Henderson and the Town of Oxford  
Analysis using only Oxford, Henderson, and South Henderson boundaries

**Estimated Annual Earnings Calculations**

Cities and Towns Where Workers are Employed	Job Count	Estimated Annual Earnings	Monthly Earnings Categories					
			< \$1,200 Multiplier: \$1,200		\$1,201-\$3,400 Multiplier: \$3,400		> \$3,400 Multiplier: \$6,800	
			Count	Est.	Count	Est.	Count	Est.
<b>Upper Neuse</b>								
Durham	578	\$24,441,600	173	\$207,600	272	\$924,800	133	\$904,400
Hillsborough	20	\$914,400	4	\$4,800	11	\$37,400	5	\$34,000
Raleigh	1,146	\$50,119,200	259	\$310,800	637	\$2,165,800	250	\$1,700,000
Butner/Stem/Creedmoor	164	\$7,425,600	34	\$40,800	90	\$306,000	40	\$272,000
<b>Cape Fear</b>								
Chapel Hill/Carrboro	92	\$4,485,600	14	\$16,800	51	\$173,400	27	\$183,600
Cary/Apex/Morrisville	139	\$5,824,800	39	\$46,800	71	\$241,400	29	\$197,200
<b>Roanoke</b>								
<b>Oxford/Henderson</b>	<b>4,394</b>	<b>\$176,644,800</b>	<b>1,421</b>	<b>\$1,705,200</b>	<b>2,118</b>	<b>\$7,201,200</b>	<b>855</b>	<b>\$5,814,000</b>
<b>Other</b>								
All Other Cities	4,008	\$174,753,600	1,046	\$1,255,200	2,010	\$6,834,000	952	\$6,473,600
<b>Total Supported by Kerr Lake Water and Sewer Provisions</b>	<b>10,541</b>	<b>\$444,609,600</b>	<b>2,990</b>	<b>\$3,588,000</b>	<b>5,260</b>	<b>\$17,884,000</b>	<b>2,291</b>	<b>\$15,578,800</b>

**Kerr Lake Commute Shed**

Cities and Towns Where Workers are Employed	Job Count	Share
<b>Upper Neuse</b>		
Durham	578	5.5%
Hillsborough	20	0.2%
Raleigh	1,146	10.9%
Butner/Stem/Creedmoor	164	1.6%
<b>Cape Fear</b>		
Chapel Hill/Carrboro	92	0.9%
Cary/Apex/Morrisville	139	1.3%
<b>Roanoke</b>		
Oxford/Henderson	4,394	41.7%
<b>Other</b>		
All Other Cities	4,008	38.0%
Total Primary Jobs	10,541	100.0%

**Kerr Lake Water Supply Benefits**

Cities and Towns Receiving Benefits	Estimated Annual Earnings	Share
<b>Upper Neuse</b>		
Durham	\$24,441,600	5.5%
Hillsborough	\$914,400	0.2%
Raleigh	\$50,119,200	11.3%
Butner/Stem/Creedmoor	\$7,425,600	1.7%
<b>Cape Fear</b>		
Chapel Hill/Carrboro	\$4,485,600	1.0%
Cary/Apex/Morrisville	\$5,824,800	1.3%
<b>Roanoke</b>		
Oxford/Henderson	\$176,644,800	39.7%
<b>Other</b>		
All Other Cities	\$174,753,600	39.3%
Total Benefits	\$444,609,600	100.0%

**APPENDIX 6: ANNUAL EARNINGS IMPORTED**

Data source:

US Census Bureau, LED Origin-Destination Database, 2nd Quarter 2006

Primary Jobs only, using city boundaries defined by TIGER 2006 2<sup>nd</sup> Edition database

**Water Supply Benefits = Estimated Annual Earnings**

Cities and Towns	Jobs Imported	Estimated Annual Earnings Imported	Monthly Earnings Categories					
			< \$1,200 Multiplier: \$1,200		\$1,201-\$3,400 Multiplier: \$3,400		> \$3,400 Multiplier: \$6,800	
Upper Neuse			Count	Est.	Count	Est.	Count	Est.
Durham	130,466	\$ 7,009,900,800	24,053	\$28,863,600	49,504	\$168,313,600	56,909	\$386,981,200
Hillsborough	3,657	\$ 163,276,800	980	\$1,176,000	1,698	\$5,773,200	979	\$6,657,200
Raleigh	276,697	\$ 13,960,632,000	56,254	\$67,504,800	118,568	\$403,131,200	101,875	\$692,750,000
Butner/Stem/Creedmoor	1,853	\$ 85,977,600	406	\$487,200	930	\$3,162,000	517	\$3,515,600
Cape Fear								
Chapel Hill/Carrboro	43,220	\$ 2,369,080,800	8,332	\$9,998,400	14,651	\$49,813,400	20,237	\$137,611,600
Cary/Apex/Morrisville	75,351	\$ 3,808,032,000	17,108	\$20,529,600	29,190	\$99,246,000	29,053	\$197,560,400
Roanoke								
Oxford/Henderson	17,728	\$ 751,128,000	5,032	\$6,038,400	8,758	\$29,777,200	3,938	\$26,778,400
<b>Total Benefits Imported</b>	<b>548,972</b>	<b>\$ 28,148,028,000</b>	36,639	\$43,966,800	70,128	\$238,435,200	72,216	\$491,068,800

These are the earnings of all workers who commute to a particular city to work.

E.g., All workers, from all 46 states within the *OnTheMap* database, who commute to Durham to work, including Durham residents who remain in Durham to work.

**APPENDIX 7: ANNUAL EARNINGS IMPORTED AS PERCENTAGES OF GROSS**

Data source: US Census Bureau, LED Origin-Destination Database, 2nd Quarter 2006  
Primary Jobs only, using city boundaries defined by TIGER 2006 2<sup>nd</sup> Edition database

**Water Supply Benefits = Estimated Annual Earnings**

Cities and Towns	Job Count	Estimated Gross Benefits Imported	Benefits Imported by City / Gross Benefits IMPORTED by City							
			Durham	Hillsborough	Raleigh	SGWASA	OWASA	Jordan	Kerr	Others
<b>Upper Neuse</b>										
Durham	130,466	\$ 7,009,900,800	32.9%	0.6%	11.4%	0.5%	4.9%	9.2%	0.3%	40.1%
Hillsborough	3,657	\$ 163,276,800	13.6%	6.6%	3.8%	0.2%	6.0%	1.7%	0.6%	67.7%
Raleigh	276,697	\$ 13,960,632,000	3.6%	0.1%	33.8%	0.2%	0.7%	8.6%	0.4%	52.7%
Butner/Stem/Creedmoor	1,853	\$ 85,977,600	8.4%	0.0%	5.8%	8.4%	0.7%	1.5%	8.6%	66.6%
<b>Cape Fear</b>										
Chapel Hill/Carrboro	43,220	\$ 2,369,080,800	7.1%	1.0%	4.8%	0.1%	27.9%	4.6%	0.2%	54.4%
Cary/Apex/Morrisville	75,351	\$ 3,808,032,000	2.9%	0.1%	21.1%	0.1%	1.2%	24.4%	0.2%	50.1%
<b>Roanoke</b>										
Oxford/Henderson	17,728	\$ 751,128,000	0.2%	0.0%	4.2%	1.2%	0.3%	0.7%	23.5%	69.9%
Total Primary Jobs	548,972	\$ 28,148,028,000								

Cities and Towns	Job Count	Estimated Gross Benefits Produced	Benefits Imported by City / Gross Benefits PRODUCED by City						
			Durham	Hillsborough	Raleigh	SGWASA	OWASA	Jordan	Kerr
<b>Upper Neuse</b>									
Durham	90,680	\$ 4,589,841,600	50.2%	1.0%	17.4%	0.8%	7.4%	14.1%	0.5%
Hillsborough	2,905	\$ 148,874,400	14.9%	7.3%	4.1%	0.2%	6.6%	1.8%	0.6%
Raleigh	178,983	\$ 9,281,649,600	5.4%	0.1%	50.8%	0.2%	1.0%	13.0%	0.5%
Butner/Stem/Creedmoor	2,691	\$ 126,112,800	5.7%	0.0%	3.9%	5.7%	0.5%	1.0%	5.9%
<b>Cape Fear</b>									
Chapel Hill/Carrboro	27,712	\$ 1,498,221,600	10.9%	1.6%	7.6%	0.1%	44.1%	7.2%	0.3%
Cary/Apex/Morrisville	74,304	\$ 4,302,156,000	4.5%	0.1%	18.7%	0.1%	1.1%	21.6%	0.1%
<b>Roanoke</b>									
Oxford/Henderson	10,541	\$ 444,609,600	0.3%	0.0%	7.2%	2.0%	0.4%	1.2%	39.7%

**APPENDIX 8: WATER SUPPLY BENEFITS IMPORT-EXPORT BALANCES**

Data source: US Census Bureau, LED Origin-Destination Database, 2nd Quarter 2006  
Primary Jobs only, using city boundaries defined by TIGER 2006 2<sup>nd</sup> Edition database

**Water Supply Benefits = Estimated Annual Earnings**

Producing Cities and Towns	Net Jobs Exported	Net Benefits Exported by Producer	Net Benefits Imported from within the Upper Neuse, and from neighboring basins			
			Durham	Hillsborough	Raleigh	But/St/Creed
<b>Upper Neuse</b>						
Durham	(39,786)	\$ (2,420,059,200)				
Hillsborough	(752)	\$ (14,402,400)	\$ (23,232,000)			
Raleigh	(97,714)	\$ (4,678,982,400)	\$ (296,856,000)	\$ 1,989,600		
Butner/Stem/Creedmoor	838	\$ 40,135,200	\$ (28,615,200)	\$ (230,400)	\$ (17,289,600)	
<b>Cape Fear</b>						
Chapel Hill/Carrboro	(15,508)	\$ (870,859,200)	\$ 158,409,600	\$ 13,785,600	\$ 17,673,600	\$ 1,051,200
Cary/Apex/Morrisville	(1,047)	\$ 494,124,000	\$ (441,436,800)	\$ (52,800)	\$ (401,671,200)	\$ 1,665,600
<b>Roanoke</b>						
Oxford/Henderson	(7,187)	\$ (306,518,400)	\$ (8,424,000)	\$ (873,600)	\$ (18,304,800)	\$ 1,368,000

Positive figures denote net imports

E.g., the net transaction between Raleigh and Hillsborough is an import of \$1.9 million into Raleigh from Hillsborough

Negative figures denote net exports.

E.g., the net transaction between Raleigh and Durham is an export of \$296 million from Raleigh into Durham

**APPENDIX 9: FLOWS OF WATER SUPPLY BENEFITS FROM THE UPPER NEUSE**

	<b>Durham</b>	<b>Hillsborough</b>	<b>Raleigh</b>	<b>But/St/Creed</b>	
<b>Water Provision Benefits Produced Per City</b>	\$4,589,841,600	\$148,874,400	\$9,281,649,600	\$126,112,800	
<b>Gross Exports to within the Upper Neuse</b>	<b>\$ 532,317,600</b>	<b>\$ 53,560,800</b>	<b>\$ 810,931,200</b>	<b>\$ 58,344,000</b>	
As Percentage of Production	11.6%	36.0%	8.7%	46.3%	
<b>Gross Imports from within the Upper Neuse</b>	<b>\$ 881,020,800</b>	<b>\$ 28,569,600</b>	<b>\$ 533,354,400</b>	<b>\$ 12,208,800</b>	
As Percentage of Production	19.2%	19.2%	5.7%	9.7%	
<b>Net Exports within the Upper Neuse</b>	<b>\$ (348,703,200)</b>	<b>\$ 24,991,200</b>	<b>\$ 277,576,800</b>	<b>\$ 46,135,200</b>	
As Percentage of Production	-7.6%	16.8%	3.0%	36.6%	
<b>Gross Leakage to OWASA</b>	<b>\$ 499,795,200</b>	<b>\$ 23,541,600</b>	<b>\$ 113,210,400</b>	<b>\$ 1,624,800</b>	
As Percentage of Production	10.9%	15.8%	1.2%	1.3%	
<b>Gross Imports from OWASA</b>	<b>\$ 341,385,600</b>	<b>\$ 9,756,000</b>	<b>\$ 95,536,800</b>	<b>\$ 573,600</b>	
As Percentage of Production	7.4%	6.6%	1.0%	0.5%	
<b>Net Exports to OWASA</b>	<b>\$ 158,409,600</b>	<b>\$ 13,785,600</b>	<b>\$ 17,673,600</b>	<b>\$ 1,051,200</b>	<b>\$ 190,920,000</b>
As Percentage of Production	3.5%	9.3%	0.2%	0.8%	<b>NET</b>
<b>Gross Leakage to Jordan Lake</b>	<b>\$ 205,312,800</b>	<b>\$ 2,671,200</b>	<b>\$ 803,335,200</b>	<b>\$ 2,988,000</b>	
As Percentage of Production	4.5%	1.8%	8.7%	2.4%	
<b>Gross Imports from Jordan Lake</b>	<b>\$ 646,749,600</b>	<b>\$ 2,724,000</b>	<b>\$ 1,205,006,400</b>	<b>\$ 1,322,400</b>	
As Percentage of Production	14.1%	1.8%	13.0%	1.0%	
<b>Net Exports to Jordan Lake</b>	<b>\$ (441,436,800)</b>	<b>\$ (52,800)</b>	<b>\$ (401,671,200)</b>	<b>\$ 1,665,600</b>	<b>\$ (841,495,200)</b>
As Percentage of Production	-9.6%	0.0%	-4.3%	1.3%	<b>NET</b>
<b>Gross Leakage to Kerr Lake</b>	<b>\$ 16,017,600</b>	<b>\$ 40,800</b>	<b>\$ 31,814,400</b>	<b>\$ 8,793,600</b>	
As Percentage of Production	0.3%	0.0%	0.3%	7.0%	
<b>Gross Imports from Kerr Lake</b>	<b>\$ 24,441,600</b>	<b>\$ 914,400</b>	<b>\$ 50,119,200</b>	<b>\$ 7,425,600</b>	
As Percentage of Production	0.5%	0.6%	0.5%	5.9%	
<b>Net Exports to Kerr Lake</b>	<b>\$ (8,424,000)</b>	<b>\$ (873,600)</b>	<b>\$ (18,304,800)</b>	<b>\$ 1,368,000</b>	<b>\$ (26,234,400)</b>
As Percentage of Production	-0.2%	-0.6%	-0.2%	1.1%	<b>NET</b>

## APPENDIX 10: LINKING WATER SUPPLY AND ECONOMIC OUTPUT

### Statement 1:

**If:** Clean water supply and associated infrastructure are essential to human health.

**And:** Health is essential for humans to generate economic output.

**Then:** Clean water supply and associated infrastructure are essential for human economic output

Debate arises on the suggestion that other factors are also essential for human well-being and economic output, such as housing, government, police and fire services, and markets. The latter three can be disregarded: government, security, and markets all are public institutions that inevitably depend on water and sewer provisions for proper function. Furthermore, if these goods are indeed fully independent of water services, then they should exist in both conditions with and without water services. These factors then cancel out, and the statement can still be used to determine the *specific* impact of water services, *ceteris paribus*.

Housing is slightly problematic: shelter is certainly essential for health, but a physical structure can exist independently of public institutions and water resources (the need for construction labor can be argued). We can use a legal condition to negate this quandary, however. North Carolina state code can lawfully require residences to connect to water and sewer lines, i.e. all houses must have water and sewer connections (North Carolina General Statutes §160A-317). We can support Statement 1 with the following:

### Statement 2:

**If:** Housing is built, it must have clean water supply and associated infrastructure.

**And:** Housing is essential for humans to generate economic output.

**Then:** Clean water supply and associated infrastructure are essential for human economic output.

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