Yikai Jing & Azura Liu John Fay

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**Analysis of water supplies and withdraws’ effects on water resources capacity in Durham, North Carolina**

**Abstract**

Future global water consumption rates will depend on the economic and environmental feasibility of extracting water from increasingly stressed aquifers. Affected by many factors, people are falling into a panic of water shortage. Here we analyze the effects of precipitation and water withdrawal on the water resources capacity, including surface water and groundwater, in Durham. We confirmed that municipal withdrawals of Durham are not related to river discharge of Cape Fear Lake, Flat River and Little River. We predict that water capacity of the Durham region can remain stable over a certain period of time and provide sufficient water for regional development and human activities.

**Introduction**

Water is an essential substance for human survival and development. As the world population increases, living standards improve, water trading patterns change, and industry, agriculture, and manufacturing expand, human society's demand for water resources is further expanded (Ercin et al., 2014).

During the last few decades, the scarcity of fresh water is evidently becoming a threat to the sustainable development of human societies due to the steady increase in demand. In addition to these pressures from humans, climate change, including global warming, significant decreases in precipitation in some areas, and increasingly frequent extreme weather events, may reduce water production. These conflicting trends raise further concerns about future water scarcity (Brown et al., 2013). The 2018 edition of the United Nations (UN) World Water Development Report (WWDR) presented concerns about water security that “the capacity of a population to safeguard sustainable access to adequate quantities of water with acceptable quality, is already at risk, and the situation will become worse in the next few decades.”

On the global scale, there is enough fresh water on an annual basis to meet the current needs of human society for survival and development (Vörösmarty, et al., 2000). However, there are great variations of water availability and water demands on space and time. that is, the distributions of water resources, population, agriculture, and industry are uneven, leading to existing water scarcity in several specific parts of the world during specific times of the year (Mekonnen et al., 2016). Therefore, the study of long-term water resources capacity for local areas is significant.

The water resources consumed by human society are generally blue water (fresh surface water and groundwater) (Wada et al., 2011). Groundwater supplies drinking water for billions of people and provides nearly half of the water used for agricultural irrigation (Siebert et al., 2010). It has a perennial distribution suitable for providing reliable drinking water and supporting efforts to adapt to extreme natural weather disasters and climate change (Taylor et al., 2013). In other words, the amount of groundwater is more stable in the long term compared to the amount of surface water. Surface water, because of its exposure to the surface, is susceptible to the influence of external substances. Its water volume also fluctuates greatly under natural conditions due to temperature, evaporation, sand content and other factors. And in recent years, influenced by the development of human activities, the aquifers’ shrinkage and salt intrusion in coastal areas have been increasing dramatically. (Boretti et al., 2019).

In this study, we focus on the Durham region in North Carolina, and hope to analyze the impact of regional water withdrawal and precipitation on regional water capacity, including surface water and groundwater, through data since complete records are available.

**Methods**

In order to better determine trends and the stability of the water resource capacity in Durham, it is important to identify the factors that affect water capacity. We are concerned in this study with the influence of natural factors and human activities, which are precipitation and water withdrawal. Data of precipitation in North Carolina published by National Oceanic and Atmospheric Administration (NOAA) and water resources depletion value related to human activities published by the North Carolina Department of Environmental Quality (NCDEQ) Division of Water Resources are used as the focused factors. Researching and predicting water depletion requires models of certain scale, and these models inevitably rely on a variety of simplifying assumptions. One assumption is that there are no feedbacks between water supply and water demand. Another assumption is that the flow is proportional to the river capacity if both the river width and the riverbed depth remain stable, in another word, the cross-sectional area of individual parts of the river remains constant.

According to the Local Water Supply Planning published annually by the North Carolina Department of Environmental Quality (NCDEQ) Division of Water Resources, the surface water sources of Durham area are mainly Cape Fear Lake, Flat River and Little River, with the Eno River used as a backup source in case of emergency. Among these rivers, Flat River, Little River and Eno River belong to the Neuse River basin, while Cape Fear Lake belongs to the Haw River basin. United States Geological Survey (USGS) provides complete flow data for these rivers. While total discharge and withdrawals are analyzed, we also look for differences in discharge variability and vulnerability to human activities among the rivers. The Local Water Supply Planning also describes the destination of treated sewage in Durham region. According to the report, the treated effluent flows into Ellerbee River and New Hope River, which belong to Neuse River basin and Haw River basin respectively. The design receiving capacity of both rivers is the same, 20 million gallon per day (MGD); the actual receiving capacity is also approximately the same, about 10 MGD, so it can be assumed that the treated effluent is equally distributed to the two rivers. From the report, it is clear that the water withdrawal and discharge points are located in different rivers, even if they are in the same watershed. Therefore, when considering the sources of river recharge, we only considered precipitation recharge without considering the volume of treated wastewater in Durham region.

The data captured from different data sources are firstly processed and unified into a unit of months to facilitate subsequent data analysis and comparison. Where the river flow data are daily flows, they are averaged by month.

The time-series analysis of river flow is performed to strip out the seasonal and trend information from the long-term river flow data. The surface water volume changes in the Durham area were determined from the trend information.

Analysis of variance (ANOVA) is performed to determine if precipitation and municipal water use had a significant effect on river flow. ANOVA is a collection of statistical models and their associated estimation procedures (such as the "variation" among and between groups) used to analyze the differences among means. We can determine the existence of certain relationship between two or more factors through analysis of variance. Based on the data, we develop three full models to test the following factors (Table 1).

* Model 1: the effect of precipitation on river discharge.
* Model 2: the effect of municipal withdraws on river discharge.
* Model 3: the effect of precipitation on groundwater table level.
* Model 4: the effect of municipal withdraws on groundwater table level.
* Model 5: the effect of groundwater table level on river discharge.

**Table 1** Full models constructed to determine factors that affect river discharge.

|  |  |
| --- | --- |
| **Model 1** | *Precipitation ~ Cape Fear River Discharge + Flat River Discharge + Little River Discharge* |
| **Model 2** | *Municipal Withdraws ~ Cape Fear River Discharge + Flat River Discharge + Little River Discharge* |
| **Model 3** | *Groundwater Table Level ~ Precipitation* |
| **Model 4** | *Groundwater Table Level ~ Municipal Withdraws* |
| **Model 5** | *Groundwater Table Level ~ Cape Fear River Discharge + Flat River Discharge + Little River Discharge* |

After separating unrelated factors, linear regression is used to determine the relationships between effective factors and build up the numeric model that is able to predict the streamflow within certain years.

**Results**

The time-series analysis on Cape Fear Lake (Figure 1.1a), Flat River (Figure 1.1b) and Little River (Figure 1.1c) do not show any obvious trend in long term. However, we can tell a great similarity between the trend patterns of Cape Fear Lake and Flat River. This raises our concern because they do not come from the same basin. Instead, Little River, which comes from the same watershed as Flat River, shows a more different pattern.

Histogram

Description automatically generated

**Figure 1.1** Time-series Analysis on Precipitation.

The time-series analysis on precipitation (Figure 1.2) in Durham shows a gradual rise since 2010 and a dynamic increase in recent years.

Histogram

Description automatically generated

**Figure 1.2** Time-series Analysis on Precipitation in Durham.

The time-series analysis on groundwater table level (Figure 1.3) in Durham shows a significant decrease since 2010.

Chart

Description automatically generated

**Figure 1.3** Time-series Analysis on Groundwater Table Level in Durham.

The time-series analysis on municipal withdrawals (Figure 1.3) in Durham shows an obvious increase since 2010. However, the drop in 2019 and 2021 needs more data and reports to explain.

Chart

Description automatically generated

**Figure 1.4** Time-series Analysis on Municipal Withdrawals in Durham.

The 3 full models used a backwards selection procedure to remove any insignificant interaction terms or variables. Akaike Information Criterion (AIC) was the indicator to confirm the model of best fit for the models. P-value was the indicator to confirm the factors’ effectiveness, which measured the probability that an observed difference could have occurred just by random chance. Though the backwards reduction, we can determine the final models that include the effective factors in Table 2.

**Table 2** Final models with effective factors that affect river discharge.

|  |  |
| --- | --- |
| **Model 1** | *Precipitation =* *1.041e-01 - 4.799e-05 \* Cape Fear River Discharge + 4.917e-04 \* Flat River Discharge -1.576e-04 \* Little River Discharge* |
| **Model 2** | *Municipal Withdraws = 28.61* |
| **Model 3** | *Groundwater Table Level =* *38.74* |
| **Model 4** | *Groundwater Table Level = 45.10 – 0.2261 \* Municipal Withdraws* |
| **Model 5** | *Groundwater Table Level =* *38.68 + 0.0008 \* Flat River Discharge - 0.0009 \* Little River Discharge* |

The results show that there is no significant correlation between the municipal withdrawals and river discharge. At the same time, there is no significant correlation between the precipitation and groundwater table level. For Cape Fear River, there is a negative correlation with precipitation. For Flat River, there are positive correlations with both precipitation and groundwater table level. For Little River, there are negative correlations with both precipitation and groundwater table level. For the groundwater table level in Durham, there is a negative correlation with municipal withdrawals.

From the time-series analysis, we conclude that the water capacity of the Durham region can remain stable over a certain period of time and provide sufficient water for regional development, human activities. And the analysis proves that the effect of urban water use on river discharge is not significant. It is the natural factors such as precipitation and groundwater table that impact on the river discharge most.

**Conclusion**

In order to assess the stability of the North Carolina water market and the scope for future development, we analyzed factors that may affect the capacity of surface water resources, including precipitation, water withdrawals. Through time-series analysis and regression analysis, we concluded that the impact of municipal withdrawals on river discharge is not significant, while precipitation and groundwater have a great impact on river flow. The rivers around Durham can maintain a stable amount of water for a certain period of time in the future.

The current analysis is deficient. One possible problem is that we could not obtain the accurate groundwater capacity and groundwater use in North Carolina. Recording changes in groundwater levels greatly reduces the magnitude of changes in groundwater volume. The neglect of this variable may lead to blind optimism about water resource capacity. Therefore, in the future, the accurate data on groundwater is expected to be available to improve this analysis. Another factor that biases the results is that although we do not consider the effect of sewage volume as a factor on river flow because the water withdrawal and discharge points for Durham are located in different rivers, we cannot guarantee that other cities are not discharging sewage to the studied rivers. Similarly, we cannot determine whether the studied river is used as a water source only in Durham. These could have some influence on the experimental results. Therefore, in further studies, we need to identify all withdrawal and discharge points in the studied rivers.

In the more than 60 years since the development of water resources management, the primary goal of water resources development has been to support the economy and to identify ways to increase freshwater supplies to meet anticipated demand (Gleick, 1998).With broadened consideration that includes issues of sustainability and equity, a new debate on water policy has now begun, as reflected by the statements coming from the 1992 Dublin statement, Agenda 21 from Rio, the World Bank, and the Global Water Partnership. The core arguments of the debate are that incorporating sustainability and equity features into water resources planning and policy goals has become a major policy priority, and this requires a high priority to maintain the integrity of water resources and the flora and fauna and human societies that develop around them. This argument is possible because there is already a consensus that economic and environmental constraints on resource development may shape future global groundwater depletion. Not only the volume of physically available water needs to be explored, but also the volume of water that is economically and environmentally exploitable. Then understand how these limitations affect the assessment of when aquifers become unsuitable for human applications (Turner et al., 2019).

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