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The Economics of Competing Water Uses under a FERC Licensing Agreement: Estimation of Property Value, Recreation, and Hydroelectric Impacts

Matthew Bingham, Jason Kinnell

Veritas Economics, Cary, USA
Email: matthew.bingham@veritaseconomics.com

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Abstract

Reservoirs provide a variety of services with economic values across multiple sectors. As demands for reservoir services continue to grow and precipitation patterns evolve, it becomes ever more important to consider the integrated suite of values and tradeoffs that attend changes in water uses and availability. Section 316 (b) of the Clean Water Act requires that owners of certain water cooled power plants evaluate technologies and operational measures that can reduce their impacts to aquatic organisms. The studies must discuss the social costs and benefits of alternative technologies including cooling towers (79 *Fed. Reg.* 158, 48300 - 48439). Cooling towers achieve their effect through evaporation. This manuscript estimates the property value, recreation, and hydroelectric generation impacts that could result from the evaporative water loss associated with installing cooling towers at the McGuire Nuclear Generating Station (McGuire) located on Lake Norman, North Carolina. Although this study specifically evaluates the effects of evaporative water loss from cooling towers, its methods are applicable to estimating the economic benefits and costs of a new water user or reduced water input in any complex reservoir system that supports steam electric generation, hydroelectric generation, residential properties, recreation, irrigation, and municipal water use.

Keywords

Property Value, FERC, Hydroelectric, Recreation, Water Levels

1. Introduction

Hydropower does not require fuel input. As such, it has no emissions and among the lowest operating costs of electricity generating technologies. Creating hydropower facilities typically requires constructing a reservoir. Although constructing reservoirs has negative impacts such as interrupting stream flows and flooding land, reservoirs that are constructed for hydropower often ultimately result in many beneficial uses. These include serving as drinking water sources, supporting industrial uses, providing places to boat and fish, and enhancing the quality of nearby residential and commercial properties [1]. As a result, reductions in water levels and availability in reservoirs may lead to social costs by negatively affecting hydroelectric generation, drinking water supplies, industrial use/output, recreation, and property values [2] [3]. This manuscript assesses the social costs of changes in water consumption that would result from implementing closed-cycle cooling at the McGuire Nuclear Generating Station (McGuire) on Lake Norman, North Carolina. Lake Norman is a reservoir that was created by impounding the Catawba River with construction of the Cowans Ford Dam in 1963. The lake serves as the water source for the Cowans Ford Dam hydroelectric station and is used by McGuire and the Marshall Steam Station (Marshall) for cooling purposes. Numerous homes line the shores of Lake Norman. It supplies municipal drinking water to the City of Charlotte, Town of Mooresville, and Lincoln County and irrigation water to nearby golf courses. It is also a popular recreation destination for boaters and fishermen and visitors to Lake Norman State Park [4].

Lake Norman is part of the Catawba-Wateree River Basin. Duke Energy operates 13 hydropower stations in this watershed in what is known as the Catawba-Wateree Hydro Project. Through operation of these plants, Duke Energy manages the water levels of 11 lakes (reservoirs) in the watershed, including Lake Norman. The Federal Energy Regulatory Commission (FERC) license that governs Catawba-Wateree Hydroelectric Project operations was approved on November 1, 2015, and extends for 40 years.

The FERC license includes the Catawba-Wateree Comprehensive Relicensing Agreement. The Comprehensive Relicensing Agreement reflects the inputs of 85 stakeholders who helped develop a collective vision for the region's needs. As part of this agreement, minimum, maximum, and target water levels were set for each lake to protect fish habitat, public water systems, industrial and power generation water intakes, recreation access, and aesthetics [4]. The minimum reservoir elevations stipulated in the operating license were based in part on thermal power generation needs at McGuire and Marshall and municipal water withdrawals. For Lake Norman, the target water level is seasonal, ranging from 94 to 98 feet with a normal maximum level of 100 feet. Minimum target levels are also seasonal and range from 91 to 95 feet. **Table 1** presents the mandated water levels for Lake Norman [5].

The FERC operating license also contains a drought management Low Inflow Protocol that establishes water-use restrictions during drought conditions. Restrictions apply to hydroelectric generation, public water systems, and flows for recreation and aquatic life [4].

Table 1. Lake Norman mandated water levels.

Month (s)	Minimum (feet)	Target (feet)	Maximum (feet)[a]
January	93	96	100
February	91	94	100
March	92.26	95.26	100
April	93.65	96.65	100
May-October	95	98	100
November	93.98	97	100
December	93	96	100

a. Full pond elevation is 760 feet above mean sea level, (ft msl).

Table 2. Net difference in water consumption.

Month (s)	Evaporative Water Loss from Cooling Towers		
	Millions of Gallons per Day (MGD)	Millions of Gallons per Month (MGM)	Cumulative Losses Millions of Gallons (MG)
January	8.9	276	276
February	8.9	249	525
March	8.9	276	801
April	9.1	273	1,074
May	9.8	294	1,368
June	9.6	288	1,656
July	9.5	295	1,951
August	9.9	307	2,257
September	10.4	312	2,569
October	9.8	304	2,873
November	9.1	273	3,146
December	8.7	270	3,416

Characterizing changes in Lake Norman's volume requires estimates of changes in evaporation due to cooling towers. The net difference in evaporation between baseline conditions and evaporation with cooling towers was calculated in millions of gallons per day (MGD) and by month (MGM). Baseline refers to the conditions that will exist on Lake Norman with McGuire continuing to operate without cooling towers. Table 2 presents the estimated results.

Evaluating the social costs of the daily losses in the first column of Table 2 requires considering the total changes in volume. To do this, the total evaporative effect of cooling towers is specified to accumulate over the course of a year. Meteorological conditions are specified to be identical under both Baseline and With Cooling Tower scenarios, meaning that increased evaporation does not change rainfall. To identify the cumulative evaporative effect, the difference in evaporation is identified at the monthly level by multiplying daily evaporation in each month by the number of days in each month, which produces output for the second column (MGM). In turn, the cumulative monthly difference is shown in column three, which is the total millions of gallons evaporated by the end of each month.

2. Level and Flow Effects

Hydropower relies on pressure from water to generate electricity. Evaporative loss on hydropower reservoirs can lead to social costs due to changes in reservoir level/area that change flow through turbines and downstream of the dam. For any given volume of water, these effects are mutually exclusive; there is either a level effect or a flow effect.

At one extreme, all the effects occur to water level and none to flow. This occurs when increased evaporation is not accompanied by a change in hydroelectric operations. In this case there is an effect to hydropower generation due to reduced water levels, but there is no effect to downstream activities such as paddling and fishing. Because there is less water in the impoundment, there is a level effect in the reservoir. This level effect can impact properties and recreation.

At the other extreme, all the effects occur to flow and none to level. In this case, hydroelectric operations are reduced to exactly offset losses due to evaporation. There is no change in levels or in social cost from level effects. However, the flow through the turbines and downstream are reduced, thereby leading to social costs from lost generation and from lost downstream flow.

Figure 1 depicts the organizing framework used to evaluate the effects of increased evaporation at Lake Norman. As this figure indicates, evaporation at Lake Norman directly impacts the volume of water in the lake. Changes in volume lead to changes in lake levels. Because Lake Norman's levels are governed by a FERC operating license, there is a feedback (double arrows) between the license conditions and lake levels. Changes in downstream releases are a primary mechanism for controlling lake level; therefore, there is a connection between the FERC license and downstream flow. Hydroelectric generation is related to flow and to lake level because lower lake levels result in reduced water pressure at dam turbines.

Lake Norman has a sloping shoreline. As a result, when the level of the lake goes down, its area shrinks. This relationship is indicated by the arrow between level and area. Recreation and property could be affected through reductions in waterbody surface acreage and levels. The number of visits to a lake is typically related to its size. Changes in reservoir elevations can affect shoreline attractiveness and the size of navigable areas. Lower reservoir elevations can lead directly to property damage (e.g., dock rotting) and indirectly to damage resulting from reduced aesthetics of the shoreline.

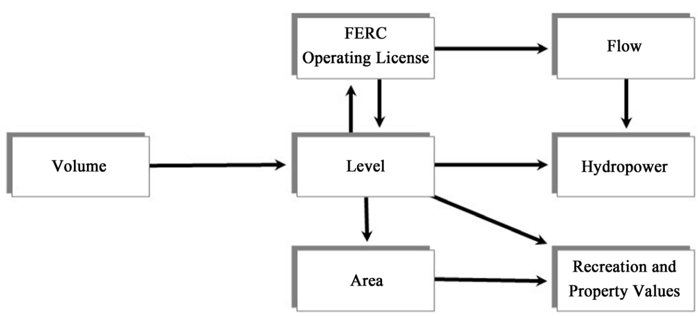

Figure 1. Effects of evaporation from Lake Norman.

There are currently no industrial water withdrawals from Lake Norman; therefore, no evaluation of these effects was conducted. There are three agricultural intakes for golf courses that are not considered critical and are therefore not protected by the Low Inflow Protocol of the FERC operating license. Although there could be impacts to water availability for these uses, social costs are expected to be minimal, and these are not depicted or evaluated as part of this study.

As described earlier, flow and level effects for any given volume of water are mutually exclusive. Therefore, the analysis considers these two effects under two distinctscenarios: Scenario 1—All Effects are Level Effects and Scenario 2—All Effects are Flow Effects.

3. Scenario 1—All Effects Are Level Effects

Under Scenario 1, impacts are evaluated for hydroelectric generation, property value, and recreation as a level effect. The analysis begins by considering the physical effect that the evaporation has on lake area and water level.

4. Physical Effects on Lake Area and Water Level

Closed-cycle cooling systems can either be dry cooling or wet cooling. Dry cooling systems do not result in evaporation. However, this approach is much more capital intensive than wet cooling and results in larger ongoing generation efficiency impacts. For these reasons, conversion of open-cycle plants to dry cooling has never been done. Wet cooling does rely on evaporation, and can have direct physical impacts on lake area and water level through evaporative effects. As water used for cooling is extracted from the lake, the water level drops. Because lakes have sloping shorelines, the area of the lake decreases as the water level drops. This level effect can cause negative economic impacts on recreation and shoreline property values.

The stage-area-volume curve for Lake Norman was used to determine the incremental volume (in acre-feet) associated with each foot of elevation change in Lake Norman for the upper 10 feet of the reservoir [6]. The upper 10 feet of the reservoir are roughly within the FERC-required reservoir operating range. As stated above, the evaporation rate is specified to be cumulative over a year. This means that the midpoint of evaporation would occur approximately in the middle of the year. Based on this, a reasonable expected value for the average annual effect would occur at the end of June. The cumulative amount of water evaporated at the end of June was subtracted from the stage-volume curve to determine the effect on stage (converted to inches). Sloped shorelines and the loss in lake level depend on the baseline water elevation and this can vary depending on baseline conditions. **Figure 2** illustrates these estimates for the upper 10 feet of water in Lake Norman (*i.e.*, between 750 - 760 ft msl).

As **Figure 2** illustrates, at normal full pond elevation (760 ft msl), the implied reduction from cooling tower operation in reservoir elevation is just under 1.9

inches. At a 10-foot drawdown (*i.e.*, 750 ft msl), the implied reduction in elevation is just under 2.4 inches.

There would also be an associated decrease in reservoir surface area due to cooling tower evaporation. Figure 3 presents the incremental surface area (in acres) for Lake Norman per reservoir elevation. As Figure 3 indicates, impacts to surface acreage depend upon the starting reservoir elevation. In the upper 10 feet of Lake Norman, incremental changes in surface area range between 395 and 1,000 acres, on a per-foot basis, as dictated by bathymetry.

The loss of wetted surface area due to increased evaporative losses was determined by converting the loss of lake elevation (in inches) from Figure 2 to a percentage of a foot (by dividing by 12). The resulting percentage was then multiplied by the incremental change in surface area (per each reservoir elevation) provided in Figure 3. The resulting loss of wetted surface area is depicted in Figure 4. The relatively large changes above 755 ft msl are consistent with the stage-volume curve and are believed to accurately reflect bathymetric features. For example, the large loss in acreage between 756 and 757 ft msl would result from a relatively more gradual shoreline slope over this range.

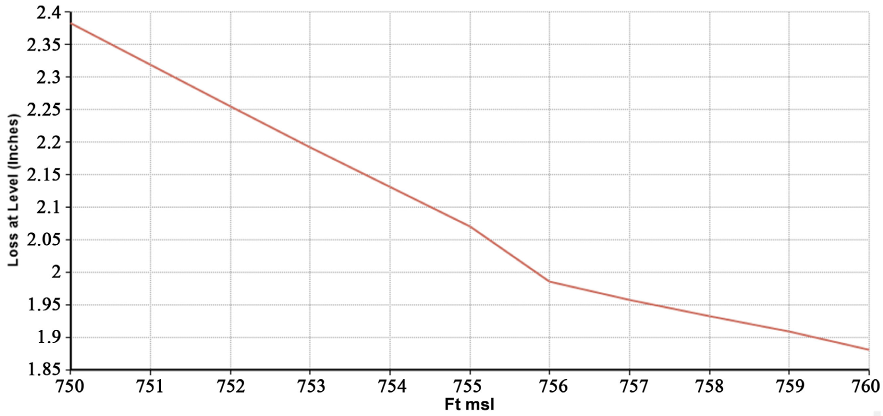

Figure 2. Water level reduction by reservoir elevation due to cooling towers for Lake Norman.

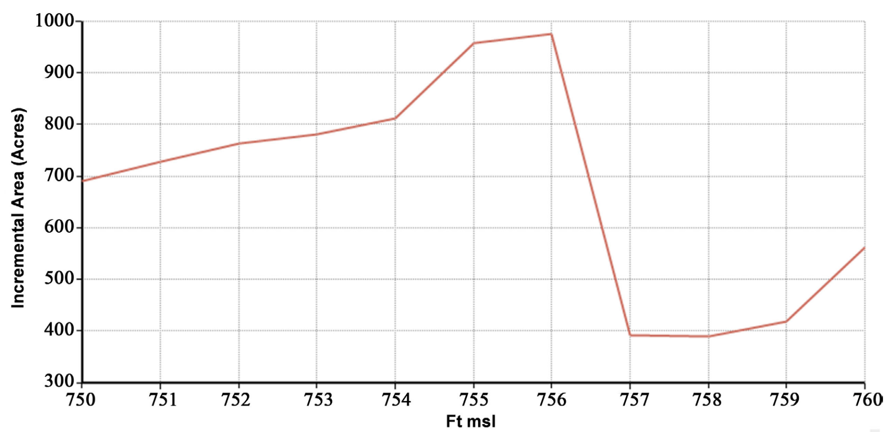

Figure 3. Incremental surface area per reservoir elevation for Lake Norman.

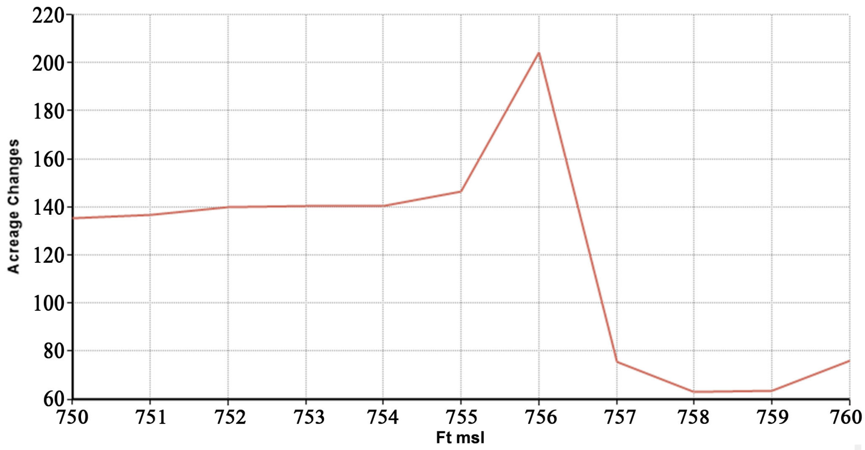

Figure 4. Wetted area reduction by reservoir elevation due to cooling towers for Lake Norman.

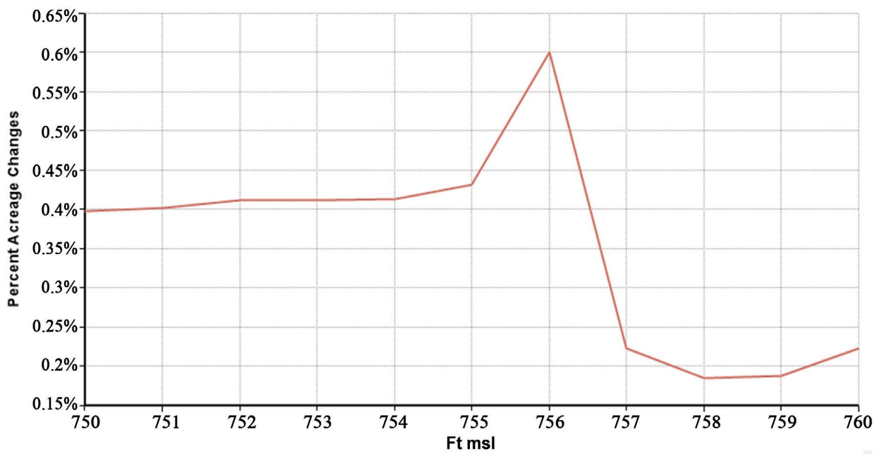

Figure 5. Percent surface area reduction by reservoir elevation due to cooling towers for Lake Norman.

Thereductions presented in **Figure 4** represent a small portion of Lake Norman's total surface area at full pond (**Figure 5**).

5. Recreation Impacts

Although these impacts are not particularly large percentagewise, they should be considered in the context of water uses at Lake Norman. Impacts to recreational fishing can be determined using recreation economics methodologies. The loss of wetted surface area can have a negative impact on the number of fishing trips. There are an estimated 80,692 fishing trips made to Lake Norman annually [7] [8]. The lake covers approximately 32,510 acres. This implies approximately 2.5 fishing trips per acre on Lake Norman. Multiplying this by the estimated reduction in acreage for each reservoir elevation results in an estimate of the reduced number of fishing trips resulting from operation of cooling towers on Lake Norman, as presented in **Figure 6**.

Within the upper 10 feet of Lake Norman's water column, impacts to fishing trips are the lowest at 758 ft msl (*i.e.*, approximately 150 trips lost) and the highest at 755 ft msl (410 trips lost). The value of these lost trips by reservoir elevation is presented in **Figure 7**. Per-trip values are specified to be $41.67 using results from Bingham *et al.* (2011) [9]. Social costs of recreation impacts from the decreased water levels range from approximately $6,500 per year to $17,100 per year at reservoir elevations of 758 ft msl and 755 ft msl, respectively.

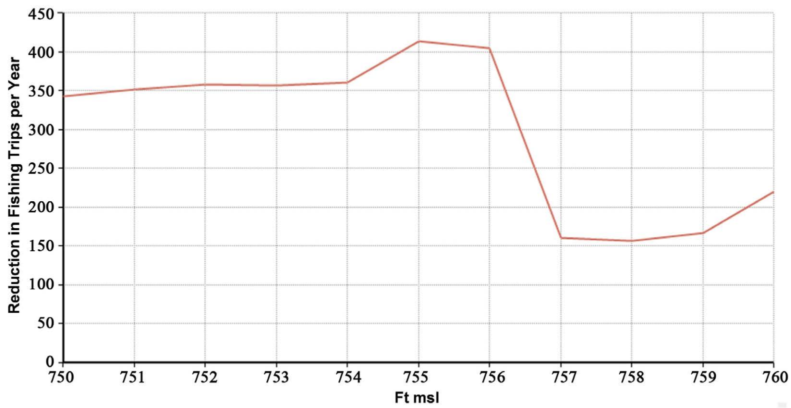

Figure 6. Reduction in fishing trips to Lake Norman due to cooling tower operation.

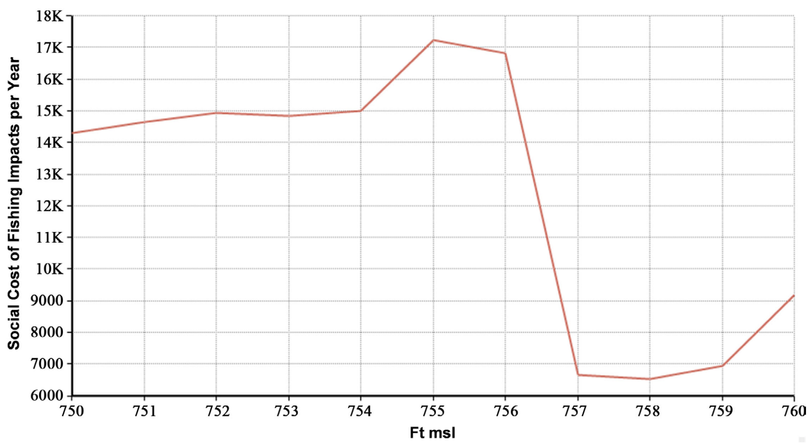

Figure 7. Social costs of fishing impacts due to cooling tower operation.

6. Hydroelectric Generation Impacts

Impacts to hydroelectric generation can be estimated using the hydropower equation, which characterizes generation as a function of head, flow, and turbine efficiency:

$$Generation = Head\ (ft)\ x\ Flow\ (GPM) / Efficiency\ factor \quad (1)$$

Head is directly related to reservoir elevation, which in turn is affected by increased evaporative losses. To calculate the effect, the distance between the turbines and the lake level for conditions of Baseline and With Cooling Towers are estimated. The Cowans Ford Dam turbines have two centerline elevations: the turbine distributor is at 647 ft msl and the turbine runner is 638.875 ft msl. The average of these elevations is 643 ft msl. Subtracting this figure from the midpoint of the operating range of 750 to 760 msl returns Baseline Head. Baseline generation is estimated using total generation of the Cowans Ford Hydroelectric plant for 2014, which was 148,025 megawatt hours (MWh) [10]. With Cooling Towers Head is the amount of water remaining after evaporative losses. Baseline Generation and With Cooling Towers Generation are then calculated and compared to estimate lost hydroelectric generation from the operation of cooling towers on Lake Norman. Figure 8 presents these estimates.

As expected, generation losses become larger as the reservoir elevation decreases. The cost of this lost generation was determined by multiplying the estimated MWh loss by the expected value of a MWh. For purposes of this evaluation, a value of $50 per MWh was used. This was specified to be higher than average generation costs because Cowans Ford turbines typically operate during times of peak demand and therefore offsets relatively expensive generation costs. Figure 9 presents the incremental cost of lost hydroelectric generation, per reservoir elevation, due to increased evaporative losses associated with cooling towers. Lost generation costs range from approximately $9,900 per year to $12,600 per year at lake elevations of 760 ft msl and 750 ft msl, respectively.

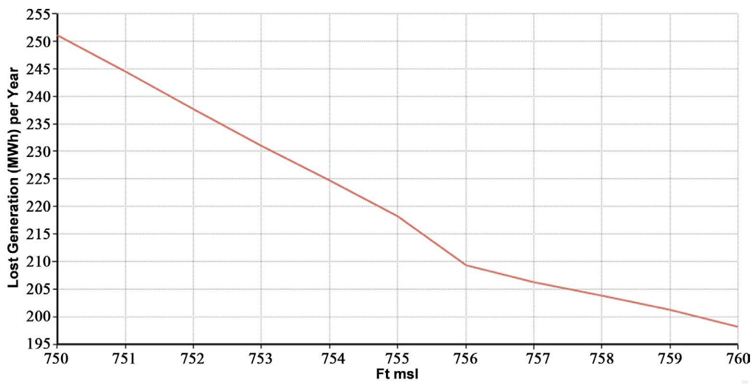

Figure 8. Lost hydroelectric generation from evaporation due to cooling tower operation.

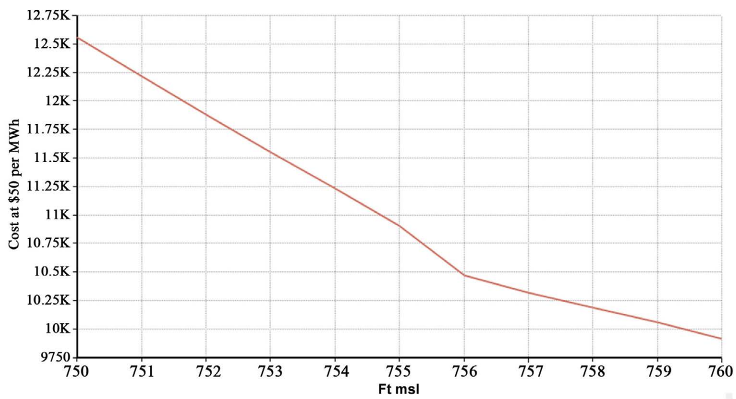

Figure 9. Costs of lost hydroelectric generation from evaporation due to cooling tower operation.

7. Property Impacts

Changes to water levels have the potential to affect the value of lakefront properties. There are no Lake Norman-specific studies that estimate the impacts of changing water levels on property values; however, several studies in the resource economics literature have modeled and estimated the relationship between water levels and lakeshore property values. Hatch and Hanson (2001) conducted a contingent valuation study of six reservoirs in Alabama [11]. They determined that a permanent, one-foot (12-inch) reduction in summer water levels resulted in a 4- to 15-percent decrease in lakefront property values. Lansford and Jones (1995a, 1995b) conducted a hedonic pricing study of the Lower Colorado River Authority's six reservoirs in the State of Texas known as the Highland Lakes System [2] [12]. The study compared the lake levels of Lake Austin and Lake Travis to estimate the relationship to shoreline property values. This study determined that a six-foot (72-inch) reduction from long-term historical water levels resulted in a $10,922 (2017 dollars) reduction in the sale price of waterfront properties. Kashian *et al.* (2016) conducted hedonic price modeling to estimate water-level impacts on the shoreline property values of Lake Koshkonong in Wisconsin [3]. They determined that a two-inch reduction in lake levels resulted in a $20,000 decrease in shoreline property values. Carey *et al.* (2011) studied the economic and property value impacts from changing water levels at Lake Keowee in South Carolina [13]. The authors developed a hedonic price model to determine the relationship between shoreline property values and lake levels. Results indicate that when lake levels are at the 25-percent quartile, a one-foot decline in lake water levels resulted in a 1.6 percent decline in property values. At the median, the 50-percent quartile, a one-foot decline in water levels resulted in property value declines of less than one-half of one percent.

Estimating the potential property value impact of reduced water levels requires an estimate of Baseline property values for properties along the Lake Norman shoreline. There is no available data file that specifically identifies the value of these properties. The website Zillow (https://www.zillow.com/) provides market value estimates that are publicly available; however, collecting values for each house is time intensive. Lake Norman has approximately 520 miles of shoreline and numerous shoreline properties. Given the extent of Lake Norman's shoreline and number of shoreline properties, the analysis sampled shoreline properties along Lake Norman and extrapolated property values to estimate the value of all properties along Lake Norman's 520 miles of shoreline.

The sampling and extrapolation approach used the Graphical Image Manipulation Program (GIMP), an image manipulating software, to trace the outline of Lake Norman. The traced outline of Lake Norman's shoreline resulted in 2,472 pixels. Four geographically distinct sections of 40 pixels each were selected as a sample. This sample represents approximately six percent of Lake Norman's shoreline. **Figure 10** shows Lake Norman's shoreline with the four sampled sections denoted in red and labeled Section A, B, C, and D.A database of shoreline property values for each of the properties in the 4-section sample was then developed using Zillow. The sum of the values of properties located along the shoreline within the 4-section sample was $451 million. The total property value of the sample sections was then extrapolated to estimate the total property value of the entire Lake Norman shoreline at $7.3 billion.

The estimated range of lake level reduction at normal full pond elevation and a 10-foot drawdown is between 1.88 and 2.38 inches (**Figure 2**). Since there are no current studies on the relationship between lake levels and Lake Norman shoreline property values, the analysis transferred the results from the existing property value studies in the literature. Because of the proximity of Lake Keowee to Lake Norman and the quality of the study, the analysis transfers the results from Carey *et al.* (2011) and estimates the decrease in property values resulting from a 2-inch loss to Lake Norman [13]. Based on the results from Carey *et al.* (2011), a 2-inch loss results in a 0.01 percent to 0.26 percent reduction in lakefront property values, which corresponds to a $730,000 decrease in shoreline property values using the 0.01 percent reduction [13].

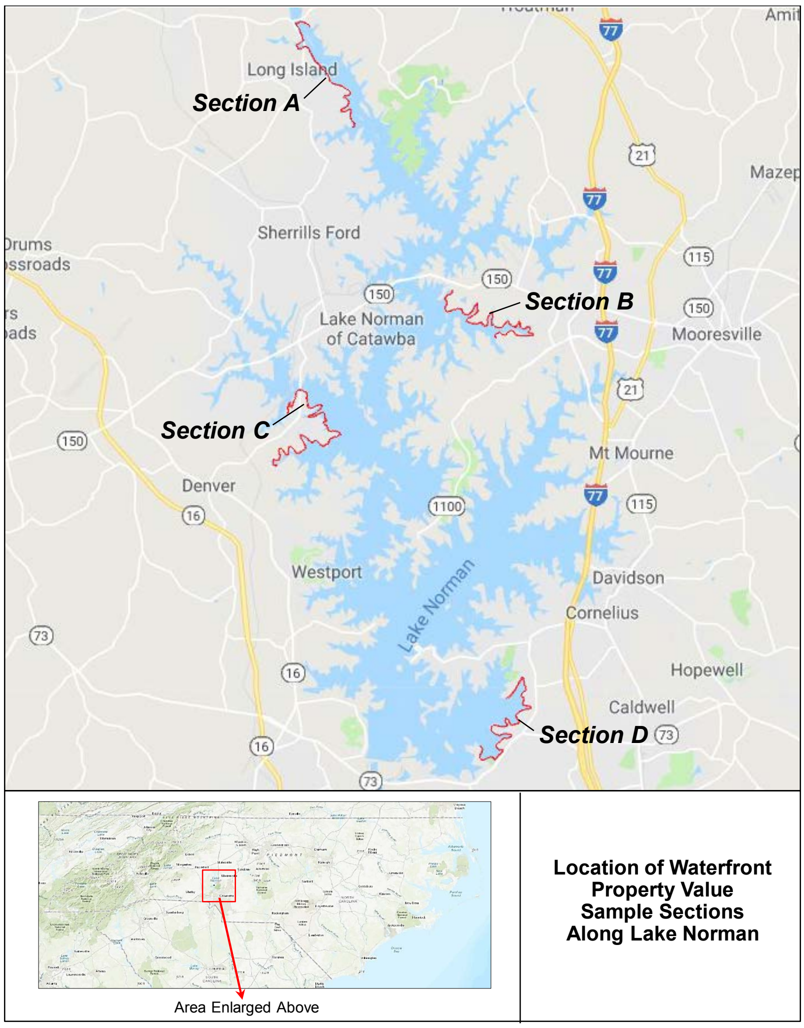

Figure 10. Property value sample sections along Lake Norman.

8. Scenario 2—All Effects Are Flow Effects

Under Scenario 2, impacts are evaluated for hydroelectric generation as a flow effect. Increased evaporation at Lake Norman due to cooling tower operation will reduce the available water for hydroelectric generation and will impact all downstream Catawba Wateree hydroelectric stations, beginning with the Cowans Ford Hydroelectric Station.

The average daily evaporative water loss from cooling towers summarized in Table 2 is 9.383 MGD or 14.52 cubic feet per second (cfs). The total energy lost for the entire river system is estimated by taking the average daily water consumption of 14.52 cfs and calculating the lost energy for this flow rate by station. Where two stations share a common dam (Great Falls/Dearborn and Rocky Creek/Cedar Creek), the newer, more efficient station was used in the analysis since it was the first dispatched.

The hydroelectric generating stations located downstream of Lake Norman include Cowans Ford, Mountain Island, Wylie, Fishing Creek, Great Falls/Dearborn (share a common dam), Rocky Creek/Cedar Creek (share a common dam), and Wateree. The total energy lost, calculated in megawatt hours (MWh), for the entire river system is estimated by taking the average daily water consumption and calculating the lost electricity for this flow rate by station as shown in the following equations:

$$\text{Turbine Power } (P_t) \text{ in kW} = e_t HQw/(737.6 \text{ Ft-lb /kW-sec}) \quad (2)$$

$$\text{Net Output Power } (P_{net}) \text{ in kW to Grid} = P_t e_g e_{st} \quad (3)$$

$$\text{Annual Lost MWh} = P_{net}(365.25 \text{ days/year})(24 \text{ hours/day})/(1000 \text{ kW/MW}) \quad (4)$$

where

Flowrate (Q) = 14.52 cfs;

Average Net Head (H) = Varies by plant as listed in Table 3;

Weight of Water (w) = 62.31 lb/ ft^3 @ 70F;

Turbine Efficiency (e_t) = Varies by plant as listed in Table 3;

Generator Efficiency (e_g) = Varies by plant as listed in Table 3;

Step-up Transformer Efficiency (e_{st}) = 0.99 for all plants.

Table 3. Estimated annual lost system hydroelectric generation and current value (2018 $) resulting from cooling tower addition at McGuire Nuclear Station.

Plant	Net Head Ft (N)	Turbine Best Efficiency (e_t)	Generation Efficiency (e_g)	Net Output kW	Annual Lost MWY	Annual Value ($50/MWh) 2018$
Cowans Ford	106	92.5%	97.5%	116.1	1,018	$50,881
Mountain Island	81	93.9%	96.5%	89.1	781	$39,065
Wylie	67	91.7%	97.3%	72.6	636	$31,817
Fishing Creek	59	92.6%	97.3%	64.5	566	$28,293

Continued

Deaborn	69	92.0%	97.0%	66.6	655	$32,773
Cedar Creek	60	92.5%	97.0%	57.0	573	$28,653
Wateree	77	96.3%	97.0%	87.3	766	$38,282

Incorporating the values from **Table 3** along with the values for flowrate, weight of water, and step-up transformer efficiency into equations 1, 2, and 3 produces the estimated annual lost hydroelectric generation in MWh that would result from the operating cooling towers at McGuire. Applying a $50 per MWh estimate to the lost megawatt hours produces the annual lost value presented in the last column of **Table 3**. Summing the total megawatt hours across all the plants results in an annual estimated loss of 4,995 megawatt hours valued at $249,765 (2018 $).

9. Summary

Reservoirs are often subject to multiple competing water uses and may be subject to complicated agreements. Within this context, determining the social implications of new uses and drought conditions requires careful consideration of the trade-offs across different uses and the economic values of different uses. This manuscript evaluates the implications of a new water user on Lake Norman with consideration of the Comprehensive Licensing Agreement which regulates Lake Norman water levels via proscriptions regarding the operation of the Cowan's Ford Dam hydroelectric facility. The evaluation considered potential impacts to steam electric generation, hydroelectric generation, residential properties, recreation, irrigation, and municipal water use. Identified impacts are primarily to recreation, hydroelectric generation, and residential property values which are summarized in **Table 4**.

A particularly important consideration is the trade-off between level effects and flow effects. This is determined by the proscribed relationship between the operation of Cowans Ford Station and lake levels. Under the FERC Operating Agreement, level effects over the allowed range would be offset by restricted flow through Cowans Ford Station. As a result, level effects would only occur when the Cowans Ford Station is prohibited from operating due to low lake levels that arise under drought conditions.

Because these conditions are relatively rare, social costs are expected to arise primarily from lost generation due to lost flow rather than from level effects. This lost generation, which is estimated to be 4,995 MWh per year, would be offset by dispatching fossil units. At an incremental cost of $50 per MWh, the estimated annual lost system hydroelectric generation for all stations downstream of Lake Norman is estimated to be $249,765. The lost hydroelectric generation would most likely be offset by fossil generation which would also lead to system-level changes in air emissions. Thus, the evaporation effects from the cooling towers would not only cause lost hydroelectric generation but would also lead to increased CO_2, SO_2, and NO_x emissions.

Table 4. Social costs of level effects from closed-cycle cooling.

Category Affected	Estimated Impact	Impact Type
Recreation	$17,100	Annual
Hydro-generation	$10,900	Annual
Property values	$730,000	One time

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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