Management of an Aquifer Threatened by Saltwater Intrusion: Borrowing from Pollution Control Strategies

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In a region that is surrounded by multiple bodies of water, inundated by seasonal rains, and threatened by floods, water is not a resource that South Louisianians often think much about over consuming. However, over-pumping threatens one of the state's largest groundwater reserves and sources of high-quality drinking water: the Southern Hills Aquifer System, which provides valuable freshwater supply to over 44,000 residents. This analysis assesses the relative effectiveness of three policy measures that could be implemented to limit saltwater intrusion into the aquifer: a cap-and-trade scheme for pumping permits, a tax on the water withdrawn, and a subsidy for industrial users not to withdraw. While each policy measure has both strengths and weaknesses in its ability to mitigate saltwater intrusion, a cap-and-trade scheme is the most feasible for the aquifer. The availability of data from the aquifer's regulatory body, the high costs of conducting further studies, and the difficulty of measuring the numerous and extensive social and environmental externalities associated with over-extraction from the aquifer make the cap-and-trade scheme the most feasible of the three policy measures in this analysis.

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INTRODUCTION

In a region that is surrounded by multiple bodies of water, inundated by seasonal rains, and continually threatened by floods, water is not a resource that South Louisianians often think much about over consuming. However, over-pumping threatens one of the state's largest groundwater reserves and sources of high-quality drinking water, the Southern Hills Aquifer System. The aquifer provides a valuable freshwater supply to over 44,000 residents of East Baton Rouge Parish, where the city of Baton Rouge lies roughly 80 miles northwest of New Orleans (Louisiana Department of Natural Resources 2020; U.S. Census Bureau 2019). It also supplies water to the petrochemical facilities and energy plants in Baton Rouge's industrial corridor. These users, who pump primarily from the 1,500ft- and 2,000 ft-deep sands, draw 5.5 percent more water from the aquifer each year than can naturally be restored (Capital Area Groundwater Conservation Commission 2020; Mitchell 2019). The resulting saltwater intrusion into these layers of the aquifer has not been adequately mitigated by the aquifer's regulatory body due to insufficient data collection and the challenges of measuring the costs of social and environmental externalities (Louisiana Legislative Auditor 2019). This analysis assesses the relative effectiveness of three policy measures on limiting saltwater intrusion into the aquifer: a cap-and-trade scheme for pumping permits, a tax on the water withdrawn, and a subsidy for industrial users not to withdraw. While each policy measure has both strengths and weaknesses in its ability to mitigate saltwater intrusion, a cap-and-trade scheme is the most feasible for the aquifer. The availability of data from the aquifer's regulatory body, the high costs of conducting further studies, and the difficulty of measuring the numerous and extensive social and environmental externalities associated with over-extraction from the aquifer make the cap-and-trade scheme the most feasible of the three policy measures in this analysis.

BACKGROUND

Louisiana's eleven aquifer systems provide high quality water at a low cost to both household consumers and industrial facilities across the state. The Southern Hills Aquifer System lies beneath six parishes (counties) in and around the city of Baton Rouge. The fresh water found within the aquifer system is predominantly "soft sodium-bicarbonate water with a dissolved solids concentration of about 200 mg/L" (Heywood and Griffith 2013). Though the aquifer system's ten earthen layers, called sands, are replenished by roughly 60 inches of rainfall per year, current rates of extraction annually exceed replenishment by roughly 5.5 percent (Louisiana Department of Natural Resources 2020; Mitchell 2019; U.S. Climate Data 2021). Experts estimate that over-pumping has caused the water table, or level at which the soil is saturated with water, beneath the greater Baton Rouge area to decrease by approximately 150 feet since the 1950s (Mitchell 2019).

As a result, saltwater has begun to seep across the aquifer's southern fault line and contaminate it (Town 2013). If groundwater withdrawals continue at current rates, salinity levels in the 1,500-ft and 2,000-ft sands, the layers most-used for drinking water, will certainly increase. A 2013 study projects an increase in salinity from 27 mg/L to 195 mg/L over the next 30 years, in parts of the aquifer immediately north of the fault line. The same study also projects a 25 percent increase in area within elevated concentration levels, in the 2,000-ft sand, by the year 2047 (Heywood and Griffith 2013). This saltwater encroachment jeopardizes the longevity of a valuable industrial and household resource (Runge et al. 2020). Should saltwater intrusion remain unmitigated and the Southern Hills Aquifer be rendered undrinkable, Baton Rouge's primary supplier, the Baton Rouge Water Company, may begin to source instead from the Mississippi River (Louisiana Public Service Commission 2013). The increased costs of treating river water, which would be passed directly onto consumers, could cause the cost of tap water to rise by roughly 300 percent (Joey Norman, Capital Area Groundwater Conservation Commission, in discussion with the author, March, 2021).

High consumption rates both by households in the rapidly growing metropolitan region and industrial facilities that use aquifer water for their operations are causing this over-pumping. The Baton Rouge Water Company, a private entity, is the sole municipal supplier for East Baton Rouge (EBR) Parish. Its subsidiary also supplies water to a neighboring parish (Louisiana Department of Natural Resources 2020). EBR Parish's 161,536 households consumed an average of 16 million gallons per day in 2020, or roughly 5.8 billion gallons per year (U.S. Census Bureau 2019; Capital Area Groundwater Conservation Commission 2020). A small group of industrial facilities, including ExxonMobil, Entergy, and Georgia Pacific, pump another 15.4 million gallons per day, nearly as much water per day as the entire public supply of EBR Parish (Capital Area Groundwater Conservation Commission 2020). According to the US Environmental Protection Agency, water is considered saline at a concentration greater than 250 mg/L chloride (Town 2013). Once the aquifer reaches excess levels of salinity, the municipal supplier and industrial facilities will face a difficult trade off: either invest in costly saltwater diversion technology, invest in a desalination facility, or replace groundwater with water taken from the nearby Mississippi River.

Excessive use of the aquifer has been partly due to limited regulatory action taken by the Capital Area Groundwater Conservation Commission (CAGWCC), the aquifer's primary management authority (Louisiana Legislative Auditor 2019). Though it was established in 1974 to prevent saltwater intrusion, a 2019 Louisiana Legislative Auditor Report found that the Commission "does not effectively regulate water withdrawals from the aquifer to reduce and manage saltwater encroachment and ensure the sustainability of fresh groundwater for the future" (Louisiana Legislative Auditor 2019). The CAGWCC has authority to set groundwater use priorities, approve well permits, establish withdrawal limits, and levy per-gallon withdrawal fees on all wells that pump over 50,000 gallons per day (Capital Area Groundwater Conservation Commission 2015). Under new leadership and pressure from environmental groups, the CAGWCC has recently begun taking steps to address the issue ("Solutions Summit" 2021; Wendland 2021). A two-year long study by The Water Institute of the Gulf promised to lay out a 50-year strategic management plan. Preliminary reports set forth several policy recommendations that the Commission will assess such as a fee schedule that includes flat and quantity-based rates, production caps, and monitoring through enhanced permitting, metering, and audits (Runge et al. 2020). After a review of the existing literature on groundwater management, the rest of this analysis will explore three policy options that were not suggested by the Water Institute: a production cap with tradable permits, a withdrawal tax that would be significantly higher than currently proposed pumping fees, and a subsidy to encourage industrial users to not withdraw from the aquifer, which would cover the cost of mitigation and abatement technology.

LITERATURE ON GROUNDWATER MANAGEMENT

Much of the literature on effective groundwater management regarding saltwater intrusion relies on geological modeling to optimize extraction rates (Cheng et. al 2000; Emch and Yeh 1998). Yet, private optimization does not always imply social efficiency across all users of the aquifer. Similar to the management of many renewable and nonrenewable resources, negative externalities are also a concern in groundwater management. As Hardin (1968) explains in his seminal piece The Tragedy of the Commons, in the instance of a rivalrous common good resource, individuals are incentivized to over exploit the resource. This imparts a cost, or externality, on all other users. For example, Rubio and Casino (2001), discuss how privately strategic behavior leads to the over-extraction of a common-property aquifer, by comparing the socially optimal and private extraction rates. Policies aimed at addressing many environmental issues work by forcing individuals or firms to internalize the social cost of an externality. The issue of externalities is particularly salient in the case of groundwater management. As discussed in Baniasadi et al. (2020), extraction of groundwater creates two distinct types of externalities: economic externalities and environmental externalities. As with other rivalrous public goods, such as fisheries and forests, depletion of the resource by one user increases production costs for all users causing the marginal social cost of extraction to exceed marginal private cost. This leads to over-extraction and possible destruction of the resource. In the case of a shared groundwater reserve, extraction by one user lowers the water table and increases pumping costs for all other users. In addition to this economic externality, consumption of a common good resource may also create environmental externalities. The environmental externalities of over-pumping from the aquifer include subsidence (when land sinks due to changes beneath the surface), increased salinity, and other forms of water pollution (Baniasadi 2020). Unlike with economic externalities, it is often more difficult to measure the marginal cost of environmental externalities and mitigate them with effective policy measures.

Existing research also largely addresses cases in which there are many users of the aquifer. For example, in rural areas where groundwater is primarily used for irrigation, tens of thousands of farmers might all pump from the same aquifer (Baniasadi 2020). However, in the case of the Southern Hills Aquifer, only a small group of companies extract the vast majority of water pumped. In addition to the handful of industrial facilities, individual use for household consumption is aggregated under the cost structure of a single private company: the Baton Rouge Water Company. Due to the unique conditions of the aquifer's use, this analysis will examine policy solutions that diverge from existing literature and explore the effectiveness of three models ubiquitous throughout the broader environmental policy literature on groundwater management.

ANALYSIS

BUSINESS AS USUAL

Policymakers must first consider the absence of a new policy before analyzing possible policy solutions. Under the current regulatory structure, the Southern Hills Aquifer is experiencing saltwater intrusion that could feasibly render the aquifer too salty to supply drinking water, within just a few decades. Though no study to date has determined an exact timeline, salinity levels could reach 195 mg/L chloride within 30 years; it would be considered saltwater at a concentration greater than 250 mg/L chloride (Haywood and Griffith 2013; Town 2013). A 2007 study by the

Water Institute of the Gulf found chloride levels as high as 266 mg/L in some parts of the aquifer. Once the water becomes salinated, both municipal supply and industrial users will be forced to either switch to the Mississippi River or invest in costly abatement technology, such as diversion wells or desalination facilities.

In a cost-benefit analysis, the aquifer users could compare the costs of abating saltwater intrusion today with the future costs of pumping water from a contaminated freshwater reserve. Abatement can be achieved through technology such as desalination facilities or scavenger wells, which are wells placed near the fault line to divert encroaching saltwater from contaminating the rest of the reserve (Kelson et al. 2016). Abatement could also be achieved by pumping less or using river water instead of groundwater. Without the respective marginal costs of both abatement technology and treating river water for use, assessing the incentives for conserving the resource is difficult. The cost of treating river water will vary significantly between firms, depending on their use and plant specific production function. Nonetheless, it is certainly more costly to treat highly polluted Mississippi River water for industrial use than pumping clean water straight from the aquifer. For the Baton Rouge Water Co., the processes for treating river water to drinking standards are even more extensive and the costs to treat water for drinking are higher than for industrial use. Therefore, the water company's incentives to abate are likely even higher than are industrial incentives to abate. A cost-benefit analysis would also account for the steep investment cost of retooling their wells to pumping systems to draw from the river rather than the aquifer. One of the largest industrial users, ExxonMobil, already owns property adjacent to the Mississippi River and already uses river water for roughly half of all the water they use (East Baton Rouge Parish Assessor "EXXONMOBIL", ExxonMobil 2019). This indicates that sourcing water from the Mississippi River is a feasible option for the company and may be the most cost-efficient alternative in the long run.

For Baton Rouge Water Co., this cost-benefit analysis would look somewhat different. While the industrial users will likely endeavor to pass increased production costs onto consumers, their goods are sold on a competitive market, perhaps limiting their ability to recoup all costs through higher prices. In contrast, the municipal supplier can pass increased production costs entirely onto household consumers. This is because household demand for tap water is generally inelastic across the US, and purchasing bottled water is hundreds of times more expensive (Bowman et al. 2019; Baton Rouge Water Company 2021). According to the company's website, bottled water costs 2,900 times more than tap water (Baton Rouge Water Company 2022). The Baton Rouge Water Company has a monopoly over provision of the utility and water demand in EBR Parish is expected to increase as Baton Rouge Water Co. continues to contract with the new developments populating the city's sprawling suburbia. Any or all of these three factors, price inelasticity of demand for water, monopolistic provision of the utility, and an almost-certain increase in demand, mean that the company's profit horizon may not be significantly impacted by even a sharp increase in production costs, should it be forced to switch to the Mississippi River.[1]

[1] Currently, Baton Rouge Water Co. enacts a diminishing fee schedule, incentivizing household users to consume higher quantities of water. The company charges $2.84 for the first 2,244 gallons used, $1.21 for the next 1,474 gallons used, and $0.74 for every additional 784 gallons after that. A fixed cost of $0.06 per month and an initial service fee of $300 covers the cost of metering and administrative costs, respectively.

For the water company, the marginal benefit of producing and supplying water from the aquifer could be determined by subtracting production costs from the above pricing information. Standard microeconomic theory suggests that marginal benefits of pumping will increase until the point in time at which extraction causes the aquifer to become too salinated for use in the municipal supply. When water in the aquifer becomes contaminated with salt, marginal production cost for the water company will shift upward. The magnitude of this marginal cost increase will depend on whether the company built a desalination facility to treat salt-contaminated groundwater or chose instead to pump from the river.

The costs of switching to river water from the aquifer are uncertain, but steep. For example, a new desalination facility in San Antonio could cost over $400 million to build (Water Technology Net 2020). In California, desalinated groundwater costs twice as much to produce as water sourced from nearby rivers (Robbins 2019). Baton Rouge Water Co. has already purchased property adjacent to the river (East Baton Rouge Parish Assessor, "BATON ROUGE WATER CO").

In a 2013 hearing before the Public Service Commission, the company stated that "obviously, the treatment plan is [to source] water from the Mississippi River," suggesting that this option yields higher profit than desalinating groundwater (Louisiana Public Service Commission 2013). In light of the social and private costs to be incurred if pumping continues as usual, alternative policies must be considered to mitigate saltwater intrusion into the aquifer.

CAP AND TRADE

The Water Institute of the Gulf has proposed implementing a production cap on the aquifer. However, this analysis will examine implementing a cap-and-trade model, in which tradable permits are allocated to all users. The command-and-control approach is a regulatory approach that has historically been used to address environmental externalities such as air or water pollution by setting "uniform, source-specific requirements" on abatement levels and technology (Schmalensee and Stavins 2019). However, when production permits are tradable, some of the deadweight loss that producers incur under such models can be avoided through tradable permits. Under a cap-and-trade system, polluting firms can compete for a certain number of permits, which allows them to buy and sell freely to one another. The regulatory body sets the desired quantity of abatement, and the firms set the price through bargaining among themselves depending upon abatement costs. Firms with lower abatement costs will buy permits from firms with higher abatement costs, and the per-unit price of the permit will fall somewhere between the per-unit cost of abatement for the firms. If production caps are set correctly the deadweight loss will be exceeded by the efficiency gains that come from firms internalizing the cost of the externality.

In order to ensure that the resource is preserved, a mitigation strategy should be used to prevent saltwater intrusion from increasing at any rate since the exact rate of saltwater intrusion across the aquifer is not currently known and because salinity levels vary between sands. The most recent data from the Capital Area Groundwater Conservation Commission shows that in the first two quarters of 2020, industrial users averaged a combined 15.39 million gallons per day for an estimated 5.61 billion gallons per year pumped from the 1,500-ft and 2,000-ft sands. Over the same period, the Baton Rouge Water Co. pumped an average of 16.0 million gallons per day for an estimated 5.84 billion gallons per year (Capital Area Groundwater Conservation Commission 2020, **Table 1**). All users combined pumped an estimated 11.45 billion gallons per year. Research shows that this current rate exceeds the natural recharge rate by 5.5 percent (Mitchell 2019). In order to prevent further saltwater intrusion, a cap should be set at 10.4 billion gallons per year (**Table 2**). Under one version of this policy, groundwater-use priority could be established for public-supply. This would allow Baton Rouge Water Co., which pumps roughly 5.83 billion gallons per year, to be exempt from the pumping cap altogether so that household consumers could continue to enjoy high-quality aquifer water (**Table 1**). Industrial users would then need to reduce their collective 5.61 billion gallons per year to 5.06 billion gallons per year to meet the pumping cap (**Table 2**). This reduction in pumping of about 0.55 billion gallons per year would be distributed evenly across all industrial users.

Abatement may be considered a full or partial switch to drawing from the Mississippi River, or simply limiting groundwater uses without compensating for it from another source. Of the three major users, ExxonMobil likely has the lowest abatement costs since it already draws part of its water supply from the river and would not have to make large capital investments to draw more. ExxonMobil could then sell its permits to other users that have higher abatement costs. It would sell as many permits as other users are willing to buy for a higher price than ExxonMobil's per-unit abatement cost. This trade will reduce the overall deadweight loss of limiting pumping, since those who can abate at a lower cost will abate more.

A cap-and-trade model allows the price mechanism to determine which firms abate more and which pump more than others, while also maintaining the desired maximum quantity of groundwater withdrawals. However, several issues may arise under the aquifer's current management structure. First, this policy relies on robust metering on all of the wells as well as enforcement of pumping limits. Currently, all pumping is self-reported so firms could easily exceed pumping permits. Second, while the CAGWCC can and does levy fees, it cannot tax, so this policy would require legislative backing. The 2021 Louisiana legislative session did not see progress on groundwater regulation; although a resolution was proposed to address the issue (HR 88, Marcelle 2021; Wendland and Ramsey "Aquifer" 2021). Nonetheless, a cap-and-trade system may be easier to pass through Louisiana's heavily Republican legislature than a purely command-and-control model, such as a uniform cap.

PIGOUVIAN TAXES

Another regulatory scheme that could be applied to groundwater extraction is a Pigouvian tax. A Pigouvian tax is a per-unit tax on any market activity that produces a negative externality. The marginal social cost of production exceeds the marginal private cost of production when negative externalities are present. Therefore, a Pigouvian tax is set at a rate that increases the marginal private cost to equal the marginal social cost. This type of tax causes the externality-producing activity to decrease since firms are forced to internalize marginal social cost. When applied to groundwater extraction the regulatory entity must know the marginal social cost of the externalities caused by pumping. Under a cap-and-trade scheme, the regulatory body would determine the maximum quantity of water pumped from the aquifer and allow the market to determine the price. In contrast, a Pigouvian tax sets the price of the aquifer's use while allowing the market to determine the exact quantity extracted. To ensure that pumping rates do not exceed the maximum rate at which saltwater intrusion will not continue to advance, the tax rate must capture the marginal cost of the advancing saltwater front. This creates several challenges for policymakers.

First, in groundwater extraction, the externality is one step farther removed from the source. Unlike air or other types of water pollution, firms do not actually emit the polluting substance. The use of the groundwater reserve pulls saltwater in across a geological fault making the impact of pumping on saltwater "pollution" indirect. The relationship between pumping and the resulting amount of saltwater intrusion depends upon the well's location relative to the fault line at which intrusion is occurring (Matthew Reonas, Louisiana Department of Natural Resources, in discussion with the author, January, 2021). A direct relationship between pumping rates at any particular well and the resulting saltwater encroachment would need to be established for a Pigouvian tax to be effective in limiting saltwater intrusion.

Second, each firm's extraction of groundwater incurs both an economic and an environmental externality as previously described. Pumping from one well not only increases the marginal cost of pumping for all other wells as the water table drops, but also accelerates all users toward the point at which the groundwater reserve is no longer fresh and cannot be used. At this point, production costs increase dramatically as users must either invest in costly abatement technology or invest in new infrastructure to pump from the Mississippi River. Therefore, a Pigouvian tax must equal the marginal increase in pumping cost for all other users, multiplied by the marginal cost of the advancing saltwater front. Ebert (1991) demonstrates the effectiveness of a Pigouvian tax to optimize production in the instance of an oligopoly. Ebert explains how choosing the correct magnitude of the Pigouvian tax "comes only with the knowledge of the actual technology for production and abatement" (Ebert 1991). Obtaining information regarding abatement costs may be difficult for the CAGWCC, without hiring a third-party consulting agency to determine a credible unit abatement cost curve. Currently, the agency relies on voluntary self-reporting. For the Baton Rouge Water Co., increased costs of treating river water would be passed directly onto the consumers causing the cost of tap water to increase by roughly 300 percent, according to CAGWCC member Joey Norman, in conversation with the author, March, 2021. The most recent data available on the water company's website indicates that rates begin at $2.84 per every 2,244 gallons consumed and decrease with higher rates of consumption (Baton Rouge Water Company 2013).

The situation is further complicated because the Baton Rouge Water Co. is a regulated monopoly, as a private company and sole utility provider. Under imperfectly competitive conditions, such as in the case of a monopoly, a Pigouvian tax will result in the underproduction of final products (Barnett 1980). In this case, Barnett (1980) proposes mitigating this consequence of the tax by adding a policy measure to increase production of final products. Yet, consumption of tap water likely has inelastic demand. Since household users may be unwilling to significantly reduce their consumption and the water company is continuing to increase its consumer base, a Pigouvian tax is unlikely to significantly reduce the quantity of water pumped by the water company. Instead, it will only increase deadweight loss for consumers, as they will pay a higher price to consume at the same level.

In order to determine the cost of allowing the aquifer system to become contaminated with saltwater, policymakers need to determine both the economic cost of switching to the river and the social and environmental health costs of consuming river water rather than aquifer water. While the infrastructure investments and treatment costs for river water are fairly consistent, the environmental health costs are complex. For example, researchers in Lutcher, Louisiana, a town just 50 miles south of Baton Rouge that sources its tap water from the Mississippi River, found that the water purification process left behind carcinogenic compounds. Preliminary studies suggest a correlation between water sourced near industrial discharge points, where industrial waste is disposed of into the river, and high rates of colon cancer (Katner 2020). The case of saltwater intrusion is more complicated because unlike air pollution or other types of water contamination, the externality is not felt at the margin. Instead, social and environmental costs only occur after pumping rates exceed recharge rates for an undetermined number of years. Thus, determining a Pigouvian tax rate that accurately captures the extent of the social costs of over-extraction may be impossible. As with a cap-and-trade scheme, setting an economically efficient Pigouvian tax relies on robust and accurate pumping data.

SUBSIDY

A third policy option that could be used to mitigate saltwater intrusion in the Southern Hills Aquifer is a subsidy for users to not withdraw water from the aquifer Subsidies are often utilized to incentivize abatement and avoid the creation of a negative externality. Subsidies are used to provide firms with the economic benefits they would otherwise reap from producing if they do not produce. As with Pigouvian taxes, the economically efficient level of a subsidy can only be found if both the cost of abatement and the value of the resource is known. The same mechanism used in the case of a Pigouvian tax to determine the economic value of not pumping from the aquifer would also be used to set the level of a subsidy.

Under this policy, the state of Louisiana could subsidize the transaction costs associated with mitigating saltwater intrusion. Transaction costs are varied, but primarily result from metering, monitoring, and research. As with the other policy options analyzed here, for a subsidy to be effectively enacted and enforced, sufficient metering must be conducted on all of the wells. The metering program currently proposed by the Capital Area Groundwater Conservation Commission has an investment cost of about $10.4 million. Under the proposed plan, this cost is to be paid out in fixed yearly installments of about $1.2 million in addition to over $400,000 in operation and maintenance, according to data presented at an April 2020 meeting of the commission. This brings the annual fixed cost to roughly$1.6 million. Furthermore, Louisiana has spent at least $5.3 million to conduct 12 studies on water resources and management strategies since 1956. The current study by the Water Institute of the Gulf alone costs $1.8 million in state tax dollars and federal grants (Wendland and Ramsey “Aquifer” 2021).

An EPA study on the effects of economic incentives for protecting the environment shows that subsidies may be more harmful than helpful. A subsidy may inadvertently incentivize the continuation or intensification of an environmentally destructive action that may otherwise not continue without the subsidy in place (Anderson 2004). However, if the subsidy is set at the appropriate level, industrial users will reduce pumping enough to halt saltwater intrusion even as they continue to utilize the aquifer at a lower level. Companies may opt to remain on the aquifer and pump less, if it is more efficient than undertaking the capital costs to switch their infrastructure to the Mississippi River. Alternatively, subsidies could be offered instead to cover the cost of retooling, and even a portion of the treatment cost of river water.

CONCLUSION

The issue of saltwater intrusion is well known by scientists and policymakers alike. However, Louisiana's water management plan is not comprehensive enough to ensure that the state's water resources are protected, conserved, and replenished for the health and welfare of its citizens (Louisiana Legislative Auditor 2019). As South Louisiana grapples with a variety of environmental and geological challenges, the State ought to prioritize the conservation of this increasingly valuable resource by establishing an effective management system.

Despite high transaction costs, each of the three policy measures analyzed have strengths and weaknesses. Both a Pigouvian tax and a no-withdraw subsidy would require extensive valuation of the aquifer resource; which may be cost-prohibitive in the short term. Nonetheless, if the value of the groundwater reserve were to be determined and the tax policy designed correctly, a Pigouvian tax would have the ability to force firms to internalize the economic and environmental costs of over exploiting the resource. Though it may not effectively decrease household water consumption, it would certainly decrease pumping from industrial wells. A cap-and-trade scheme avoids the need to conduct further studies, as it only requires the management entity to know the level at which to set a pumping limit. However, the management entity will also have to set up and operate the cap-and-trade system. Given the currently available data and the high costs of conducting further studies, the most effective way to reduce overall pumping of the Southern Hills Aquifer is to utilize a cap-and-trade scheme.

APPENDIX

Table 1: Daily Average and Yearly Estimate of Pumping Rates, by User by Category, from the "1,500-ft" and "2,000-ft" sands of the Southern Hills Aquifer.

USER	1st Q 2020, Mgal/day	2nd Q 2020, Mgal/day	Average Jan – June 2020 Mgal/day	Yearly Estimate Billion gal/year
Industry, 1500-ft	2.09	1.94	2.02	0.73
Industry, 1500-1700 ft	1.22	0.062	0.64	0.23
Other Industry, 2000 ft	4.755	4.85	4.80	1.75
Power Gen., 2000-ft	8.69	7.17	7.93	2.89
Industrial Subtotal	16.76	14.02	15.39	5.61
BR Water, 1500-ft	10.6	10.61	10.605	3.87
BR Water, 2000-ft	4.62	5.61	5.115	1.87
BR Water, 2000-2500-ft	0.2	0.37	0.285	0.1
Municipal Supply Subtotal	15.42	16.59	16.005	5.84
Total Withdrawal			31.39	11.45

Source: Prepared by the author; Data compiled from Capital Area Groundwater Conservation Commission, "Management Plan Pumpage Compliance Monitoring of Wells Impacting the '1,500-ft' Aquifer in EBR Parish. October 8, 2020.

Table 2: Withdrawal Reductions from the 1500-ft and 2000-ft sands, under a cap-and-trade policy.

Set withdrawal cap such that current pumping does not exceed recharge rate	
Current Total Withdrawal	11.45 Bgal/y
Recharge Rate	5.5%
Withdrawal Cap	11.45/1.05= 10.9 Bgal/y
Reductions Under Withdrawal Cap	
Baton Rouge Water Co. (no reduction)	5.84 Bgal/y
industrial Users Combined	5.61 Bgal/y
New Total	10.9 Bgal/y

Source: Prepared by the author; Calculations are my own, based on data from the Capital Area Groundwater Conservation Commission, "Management Plan Pumpage Compliance Monitoring of Wells Impacting the '1,500-ft' Aquifer in EBR Parish. October 8, 2020.

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