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Agricultural Water Policy during Drought: A Strategy for Including Groundwater Permits in Future Irrigation Buyout Auctions in the Flint River Basin

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Abstract: Georgia's Flint River Basin has water management challenges from extensive groundwater pumping for agriculture and in-stream flow requirements. The state has experimented with buying out irrigation permits through auctions. Past auctions were relegated to surface water permits. Recently, the state has allowed groundwater permit holders to participate in future auctions. The Flow-Impact Offer (FIO) developed in this paper provides a way to reconcile the disparate impacts of groundwater and surface water withdrawals on in-stream flows when comparing offers in a buyout auction. The techniques suggested here to operationalize the FIO are applicable to other regions of the world as well.

Keywords: groundwater management; water auction; DSSAT; MODFLOW

1. Introduction

Georgia's Flint River Basin (FRB) has received particular attention regarding stream flow regulation because of its vast reaches, unique aquifer system, and varied uses. Stretching nearly 350 miles from the upper Piedmont region just south of Atlanta to the wetlands of the Coastal Plain in the southwest corner of the state, the FRB overlays the upper, lower, and middle boundary layers of the Floridan aquifer system. In its headwaters, the Flint River is a source of surface water for non-agricultural and industrial users while downstream users are largely agricultural producers of maize, cotton, peanuts, and soybeans, along with pecans and supplementary horticultural products. Approximately 80% of the water used for irrigation in the lower Flint River Basin is withdrawn from the Upper Floridan aquifer, the shallowest major groundwater reservoir and one of the most productive aquifers in the country [1–3]. The aquifer is characterized by high connectivity and permeability imparted by small, interconnected solution openings and a system of major groundwater conduits close to the Flint River [1]; within the aquifer system, there is such little permeability contrast that the Floridan is effectively one continuous aquifer in parts of north Florida and southwest Georgia [4]. Interchange between ground and surface water in this region can occur rapidly, frequently, and unexpectedly [5]. During the 1980s and 1990s, several studies suggested strong connectivity between groundwater withdrawal and reduced stream flow in southwest Georgia [6–8].

The FRB also provides a critical habitat to four federally endangered (E) and two federally threatened (T) mussel species: Fat threeridge (E; *Amblema neislerii*), Shinyrayed pocketbook (E; *Lampsilis subangulata*), Gulf moccasinshell (E; *Medionidus penicillatus*), Chipola slabshell (T; *Elliptio chipolaensis*), and Purple bankclimber (T; *Elliptoideus sloatianus*) [3]. The most commonly cited cause of mussel extinction, extirpation, or population decline is habitat degradation [9–11]; in the FRB, studies have shown low flow conditions and severe drought to adversely affect mussel distributions and assemblages [12].

Agriculture in South Georgia was revolutionized by the implementation of center pivot irrigation systems throughout the 1970s in an effort to combat the effects of drought on yields. Irrigation changed crop selection decisions, stabilized production and yields, and enabled the use of systems for the application of fertilizers, herbicides, and pesticides, decreasing the risk to agricultural producers [13]. A burgeoning population in the Northern part of the state has required more surface water withdrawals upstream; from 2000 to 2010, Georgia's population grew by 1.5 million, a change of over 18% [14]. The demand for water in the Southeastern United States has grown exponentially in the last four decades despite the increasing incidents of drought-induced water scarcity.

In response to the drought conditions of 1999 and 2000, the Flint River Drought Protection Act (the Act) was enacted in 2001 as a means of maintaining acceptable stream flow in the Flint River, defined as the quantity of stream flows at one or more specific locations which provides for aquatic life protection and other needs, as established by the director (of the Georgia Environmental Protection Division (GA EPD)), based on municipal, agricultural, industrial, and environmental needs [15] (Official Code of Georgia Annotated, O.C.G.A. 12-5-540). The Act provides a financial incentive program to ensure certain agricultural lands throughout the lower FRB are not irrigated during times of declared drought. If the director of the EPD declares a severe drought, a "drought protection auction" can be initiated whereby eligible permitted irrigators are paid on a per-acre basis to forgo irrigation on the permitted land. Initially, eligible auction participants were only those holding agricultural surface water withdrawal permits on perennial streams in the FRB because of the uncertainty surrounding ground and surface water interactions [16].

There have been two drought protection auctions since the inception of the Act: the first in 2001 and the second in 2002. The first auction proceeded by an "iterative and interactive process," with participants submitting blind offers of the per acre price they were willing to accept to not to exercise their irrigation permits that year. The Director of the EPD "either accepted or rejected an offer based on the total cost of all bids [offers] presented" ([16], p. 46). It is unclear exactly what this means. Nonetheless, farmers whose offers were rejected were allowed to re-submit during subsequent rounds until enough offers were accepted to remove the targeted amount of acreage from irrigation. The process was inefficient and time intensive; offers submitted over five auction rounds varied wildly, from \$75/acre to \$800/acre. The highest offers were rejected, leaving the average accepted offer at \$135/acre. The end result presumably took more than 33,000 acres out of irrigation for a total cost of approximately \$4.5 million [16].

The second auction in 2002 was held in response to the continued drought and attempted to improve efficiency while maintaining the acreage removed from irrigation by instituting a cap of \$150/acre on bids; all bids below this cap would be accepted "up to the point where sufficient acreage was taken out of irrigation" [16]. There was a single auction round with bids ranging from \$74/acre to \$145/acre and an average accepted bid of \$128/acre. The 2002 drought protection auction removed more than 41,000 acres from irrigation at a cost of \$5.3 million.

Though they succeeded in removing some acreage from irrigation, the auctions conducted under the Act were noticeably problematic. To be eligible in the 2001 auction, participants need only have had a surface water permit with no requirement of recent use. As a result, many participants were compensated "for very marginal or long-fallow land, or for land that is not typically irrigated (e.g., trees)", a loophole that was closed for the second auction by mandating participating permit holders to have irrigated in the previous three years [16]. Still, both auctions failed to remove the highest water use cropland from irrigation and excluded all holders of groundwater permits from participating; if a drought protection auction was held in 2019 under these rules, nearly 50% of permit holders and over 1,000,000 irrigated acres would be excluded from participation. In 2006, the rules were changed in order to grant eligibility to groundwater permit holders. The question that naturally arises from this policy change is how to prioritize groundwater and surface water offers in the event of a future auction. The objective of this paper is to propose a mechanism for comparing offers across irrigators that accounts for their respective impacts on in-stream flows. While data are not currently

available to parameterize the proposed mechanism, the framework presented here should facilitate a discussion on how to collect and compile relevant data to do so in the Flint River Basin and other watersheds around the world.

2. Incorporating Groundwater Permits into Future Auctions

The stated mechanism for prioritizing offers under the 2001 auction—i.e., accepting or rejecting an offer based on the “total cost” of all offers presented—is frustratingly vague. Fortunately, the 2002 auction appears to have prioritized offers on a dollar per acre basis, with the State clearly informing participants of its reservation price (the maximum offer (\$/acre) it would accept). That is, EPD appears to have received permit offers, converted the offers to \$/acre, and accepted offers from lowest to highest until the targeted acreage was reached and/or all offers below the reservation price had been accepted.

While one could argue that there should have been another condition to the prioritization—namely, that permits from streams/reaches with documented populations of endangered species should have been a top priority—there is an apples-to-apples quality to the \$/acre offers of the 2002 auction. Because the crop(s) a farmer would have irrigated if their offer was not accepted are unknowable, one is left to assume that each offer is associated with the same crop mix. In other words, the withdrawals (acre-inches) per acre that were prevented by accepting an offer were the same for all offers. Furthermore, because all of the participants in the auction were surface water permit holders, every acre-inch of water withdrawal prevented represented an exactly one acre-inch of water left in the stream. That is not the case with groundwater withdrawals.

The stream flow effects of a groundwater withdrawal from an individual well depends on its location vis-à-vis the stream, the connectivity of aquifer and the stream, and the timing, rate, and duration of pumping. The depression within the aquifer created by the groundwater withdrawal will initially be filled by groundwater, and may ultimately induce recharge from the stream to the aquifer. This recharge is often referred to as the stream-to-aquifer flux (hereafter, the flux). If the flux of a withdrawal can be estimated at a particular location, the proportion of the withdrawal that impacts stream flows—the flux-to-withdrawal ratio—can also be estimated for that location. Note that the flux-to-withdrawal ratio of a surface water withdrawal is one.

I propose utilizing the flux-to-withdrawal ratio associated with the location of a groundwater permit to inflate offers from groundwater permit holders in future auctions, creating a “flow-impact offer” that can be compared across groundwater and surface water permits. The proposed flow-impact offer (FIO) is represented by Equation (1).

$$\text{Flow-Impact Offer (\$/acre)} = (\text{Offer (\$/acre)} / \text{Flux-to-Withdrawal Ratio}) \times \text{Uncertainty Ratio} \quad (1)$$

Here, the original offer made by a groundwater permit holder is divided by the flux-to-withdrawal ratio. If, at a particular permit location, stream flows are expected to be reduced by only half the volume of a groundwater withdrawal, then, for a given offer (\$/acre-inch), the flow you are purchasing by preventing that withdrawal is twice as expensive as the flow purchased by preventing a surface water withdrawal. The uncertainty ratio is an additional inflationary variable that can be used to reflect the inherent uncertainty associated with the estimation of the flux-to-withdrawal ratio; this is analogous to the uncertainty ratio associated with water quality trading by non-point sources.

The State of Georgia could use the FIO to order offers in a future auction that includes both surface water and groundwater permit holders. By accepting FIOs from lowest to highest, the state could minimize the cost of meeting a particular flow, and/or maximize the flow purchased by a given amount of money.

3. A Strategy for Operationalizing the Flow-Impact Offer

Research into the relationship between groundwater and streams began in the 1980s and has increased ever since, due mainly to concerns about acid rain [17]. There is a significant amount

of literature dealing with ground and surface water connectivity, focusing both on the Flint River Basin and other regions. Many of these studies focus on the implementation and efficacy of flow system simulators such as the U.S. Geological Survey's three-dimensional MODFLOW-2000 model (US Geological Survey, <https://water.usgs.gov/ogw/modflow/MODFLOW.html>) and its predecessor, the MODular Finite-Element (MODFE), while others focus on groundwater pumpage and stream flows, their temporal variation, and their impacts on the ecology of the FRB [5,18–20]. As the stream flow effects of an individual well depend on its location vis-à-vis the stream, and the timing, rate and duration of pumping, there is a real need to estimate the impacts of ground and surface water interactions at an individual permit scale. Within the Flint River Basin, well locations and well depths could be mapped and flux-to-withdrawal ratios modeled in MODFLOW (or a similar program) at the individual permit level. This would, however, require information about the timing, rate, and duration of a withdrawal.

Crop simulation models such as the Decision Support System for Agrotechnology Transfer (DSSAT) have been developed to investigate the impact of management strategies (including irrigation), weather and soil conditions, and pest pressure on yields for a variety of crops. DSSAT models (free download at <https://dssat.net/>) have been calibrated for the soils and weather conditions of the Flint River Basin for all of the major irrigated crops—cotton, peanut, maize and soybean. Using DSSAT, a schedule of expected withdrawals (volume and timing) over a growing season could be simulated for each crop under drought conditions across the FRB. Using the United States Department of Agriculture (USDA) Census of Agriculture data, a “representative irrigated acre” could be used to establish the share of irrigated acres in the FRB for each of the major crops. This would facilitate the construction of a “representative” schedule of irrigation withdrawals to be modelled in MODFLOW.

4. A Simulation Exercise

In this section, the results of a simulation exercise are presented to illustrate the potential efficiency gains of utilizing the Flow-Impact Offer. The simulation model is developed using parameters for Spring Creek, a major tributary of the Flint River.

From 2008 to 2010, the Georgia Environmental Protection Division developed the state's first State Water Plan (<https://waterplanning.georgia.gov/>). This involved a series of resource assessments and sectoral projections of future water demand. I was the lead economist for the water demand projections for the agricultural sector. The parameters used in the simulation exercise reported here come directly from the analyses used to project agricultural water demand in the lower FRB for the State Water Plan.

Spring Creek runs through five counties (Calhoun, Decatur, Early, Miller, and Seminole) before joining the Flint River. In 2008, irrigation in those counties was used predominantly to grow corn, cotton, peanuts, and soybeans. Table 1 presents data from 2008 for each county regarding the number of irrigation systems, the proportion of systems that draw from groundwater and surface water sources, the acreage of each crop under irrigation, and the average acreage per irrigation system. These data were established by analyzing aerial photographs of the region.

DSSAT models for each crop in each county were run using fifty years (1958–2007) of weather daily data. DSSAT uses weather, soil, and management variables to calculate daily evapotranspiration levels for crops as well as soil moisture balances. The irrigation management strategy utilized in the DSSAT models was to apply 25 mm of water whenever the soil moisture content within the root zone dropped below 50%. Among the outputs generated by the DSSAT model is the amount of irrigation water applied over the course of the growing season. With 50 years of weather data, a distribution of irrigation applications was developed for each crop and county. Because the buyout auctions are only implemented under extreme drought conditions, the simulation exercise focuses on the 90th percentile of the cumulative distribution functions of the irrigation application distributions. Table 2 presents the seasonal amount of irrigation water (mm/ha) by crop and county associated with the 90th percentile of the distributions. In other words, 90% of the time, irrigators would apply that amount or less to their corn, cotton, peanut, and soybean fields.

Table 1. Irrigation system parameters used.

	Calhoun	Decatur	Early	Miller	Seminole
Irrigation Systems	366	704	640	771	522
Groundwater Source (%)	40	95	74	99	91
Surface Water Source (%)	60	5	26	1	9
Corn (ha)	2725	3789	4020	5506	4494
Cotton (ha)	4534	9109	8502	10,000	9798
Peanut (ha)	4534	8259	7004	7126	5830
Soybean (ha)	218	1721	1530	919	413
Average Field Size (ha)	29.4	37.4	25.7	28.8	40

Table 2. 90th percentile of irrigation water applied (mm/ha).

	Calhoun	Decatur	Early	Miller	Seminole
Corn	151.1	141.1	156.2	161.7	161.5
Cotton	141.3	113.6	138.6	136.1	143.5
Peanut	150.1	128.0	111.7	115.7	121.9
Soybean	113.7	95.8	70.6	62.8	83.1

For the simulation exercise, the irrigation systems in a county were divided between groundwater and surface water withdrawals based on the county-level share. For example, Calhoun County has 366 systems of which 40% draw from groundwater and 60% draw from surface water sources. Therefore, in Calhoun County, we assigned 145 of those systems to groundwater sources and the remaining 221 to surface water sources. For surface water systems, the flux was set to 1; for groundwater systems, the flux ratio was randomly assigned a value between 0 and 1 from a uniform distribution. For every simulation run, a new flux ratio was randomly generated for each groundwater system.

In total, there were 3132 irrigation systems across the five counties of interest. For every simulation run, a buyout offer was randomly generated from a uniform distribution between \$50/acre (\$123/ha) and \$180/acre (\$444/ha) for each system (groundwater and surface water). The random offers were then converted to a Flow-Impact Offer by dividing the offer by the flux ratio. In total, we ran 100 auction simulations.

The FIO developed in this paper is being proposed as an alternative institution (rule) for future buyout auctions. Recall that the 2002 buyout auction set a reservation price of \$150/acre (\$370/ha), i.e., bids up to that amount could be accepted while bids above could not. Also recall that the 2002 auction only allowed bids from systems drawing from surface water sources, but groundwater irrigators are allowed to participate in future auctions. As such, we compared the effects—in terms of both auction expenditures and flow impacts avoided—of applying the 2002 rules to all bids (surface water and groundwater) to a rule that accepts all FIOs up to the \$150/acre reservation price while rejecting all FIOs above it.

To calculate the expenditures for an accepted bid (b) in county (c) under auction institution (i), the offer (not the FIO) was multiplied by the county's average field size. The total expenditure for the auction was calculated as the sum of expenditures over all accepted bids, as in Equation (2):

$$\text{Expenditures}_i = \sum_B \sum_C \text{Offer}_b \times \text{Field Size}_c \quad (2)$$

To calculate the amount of water that remains in the stream due to accepting a bid in the auction, i.e., the amount of water purchased, an acreage-weighted average of the 90th percentile irrigation water applied (water) for each crop (r) was calculated for each county based on Equation (3). This was

then summed across all accepted bids (B) and counties (c) to find the total amount of in-stream water purchased by an auction institution (Water Purchased_i):

$$\text{Water Purchased}_i = \sum_R \sum_C B_c \times \text{Field Size}_c \times \text{Acreage}_{r,c} \times \text{Water}_{r,c} / \sum_R \text{Acreage}_{r,c} \quad (3)$$

where B_c is the total number of accepted bids in county c ; Field Size_c is the average field size per system in county c (ha); $\text{Acreage}_{r,c}$ is the hectares of crop r grown in county c ; and $\text{Water}_{r,c}$ is the 90th percentile of irrigation water applied to crop r in county c .

The average results for the two institutions—2002 rules versus FIO rules—across the 100 simulation runs are presented in Table 3, with standard deviations in parentheses, if all offers (2002 rules) or FIOs (FIO rules) at or below the reservation price are accepted. Table 4 presents the results when the state faces an auction budget constraint of \$4 million. That is, the state accepts, from lowest to highest, offers or FIOs (depending on the institution) up to the point where total expenditures equal \$4 million (the 2001 and 2002 FRB buyout auctions spent \$4.5 million and \$5.3 million, respectively).

Table 3. Simulation results with unconstrained auction budget.

	2002 Rules	FIO Rules
Bids Accepted	2413 (25.21)	1102 (25.36)
Acreage Purchased (ha)	77,348 (822.26)	34,437 (815.12)
Total Expenditures	\$19,103,214 (234,962)	\$7,600,455 (176,672)
Water Purchased (ha-mm)	14,823,264 (234,307)	9,773,348 (220,036)
Average Water Price (\$/ha-mm)	\$1.29 (0.02)	\$0.78 (0.01)

Table 4. Simulation results with auction budget constrained to \$4 million.

	2002 Rules	FIO Rules
Bids Accepted	767 (7.84)	669 (5.12)
Acreage Purchased (ha)	24,665 (622.89)	20,969 (531.25)
Total Expenditures	\$3,996,333 (0.00)	\$3,996,762 (0.00)
Water Purchased (ha-mm)	4,684,725 (22,318)	6,156,327 (16,242)
Average Water Price (\$/ha-mm)	\$0.85 (0.01)	\$0.65 (0.01)

5. Discussion and Conclusions

Georgia's Flint River Basin has water management challenges that are exacerbated by extensive groundwater pumping for agriculture. These challenges are further complicated by in-stream flow requirements associated with federally protected aquatic species. The state has experimented with buying out irrigation permits through auctions in the past. Those auctions were, however, relegated to surface water permits. Recently, the state has allowed groundwater permit holders to participate in future auctions. The Flow-Impact Offer developed in this paper provides a way to reconcile the disparate impacts of groundwater and surface water withdrawals on in-stream flows when comparing offers in a buyout auction.

The results of the simulation exercise presented in Section 5 demonstrate the potential efficiency gains from employing the FIO compared to treating groundwater bids the same as surface water bids. Under the agricultural production and auction parameters considered, if the state has an unlimited budget to purchase all offers at or below the state's reservation price, the state would take 2.24 times

as many hectares out of irrigation, thereby preventing about 1.5 times as many flow impacts under the 2002 rules compared to the FIO rules. To accomplish that, however, the state would spend about 2.5 times as much money in absolute terms, and about 1.7 times as much per ha-mm of flow impact prevented. In other words, under the FIO rules, the agricultural production impacts of the buyout are significantly reduced, as is the state's financial outlay, but the reduction in flow impacts is also considerably lower. From the perspective of \$/ha-mm of flow impact saved, the FIO rule outperforms the 2002 rule by a wide margin.

When the state faces a budget constraint for the auction, the efficiency gains of instituting the FIO rule are considerable. Under the \$4 million budget used in our simulation exercise, the FIO rule accepts fewer bids, takes less acreage out of irrigated production, and reduces flow impacts by an additional 31% compared to the 2002 rules. In other words, for the same amount of money, the state could significantly reduce flow impacts while minimizing agricultural production effects by adopting the FIO rule.

Around the world, there are many aquatic ecosystems whose sustainability depends on some minimum threshold for in-stream flows. Many of these ecosystems are in areas where groundwater withdrawals can affect surface water flows, for example, several watersheds throughout the Southern part of Africa [21], Australia [22], India [23], among others. The groundwater-surface water hydrology of some of these systems have been studied extensively [24,25] by spatially designating fluxes due to groundwater withdrawals. A buyout auction administered under the FIO proposed in this paper can serve as a starting point for new opportunities to efficiently manage low flows in these valuable yet vulnerable watersheds.

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