A Contingent Water Banking Program to Support Shortnose Sturgeon Migration in the Savannah River Basin during Drought Periods

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Abstract

This study presents a model to investigate the costs of augmenting streamflows in drought years to support shortnose sturgeon spawning and migration. We demonstrate how the model can estimate the acre foot water payment necessary under alternative drought scenarios to induce water users to participate in a contingent water banking program to meet sturgeon seasonal flow requirements.

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Introduction

The Savannah River Basin (SRB) covers portions of the states of Georgia, North Carolina, and South Carolina. The darkest red lines in figure 1 indicate the boundaries of the SRB. The river is approximately 300 miles long with a drainage basin consisting of 10,577 square miles. The river has three major reservoirs that are administered by the Army Corp of Engineers: Hartwell, Russell, and Thurmond. Water uses in the SRB include consumptive uses such as agricultural irrigation, golf course irrigation, industrial uses, residential use, and cooling for thermoelectric power generation. Nonconsumptive or instream uses include hydroelectric power generation, recreation, ecosystem services, and wildlife habitat. One species that populates portions of the Savannah River are shortnose sturgeon.

Shortnose sturgeon have been listed as an endangered species since 1967. While they feed and winter in both fresh and saline waters, they spawn exclusively in freshwater. In the Savannah River, shortnose sturgeon spawning sites are located approximately 110 to 170 miles north of the river mouth, an area below Augusta, Georgia, which drains into the Atlantic Ocean. Nursery sites are located upstream 20 to 25 miles north of the river mouth in the vicinity of the Savannah National Wildlife Refuge (Hall et al, 1991 and Jenkins et al, 1993). Figure 2 identifies these major sturgeon migration and spawning sites. High seasonal streamflows are required to facilitate sturgeon migration to and from spawning grounds from January to May. Maintaining the required streamflows is especially difficult during droughts when declining water supplies are sought for out of stream consumptive uses by agriculture, industry, residential use and nuclear cooling. Previous research has shown that the marginal net benefit of water in irrigation is very low, meaning that a relatively low payment could induce agricultural users with low marginal net benefits of water rights to lease their rights for sturgeon migration purposes in drought periods.

The objective of this study is to estimate the economic cost, or minimal payment required for a water banking program to augment streamflows during droughts to promote shortnose sturgeon spawning and migration in the Savannah River Basin of Georgia and South Carolina. The next two sections outline the hydrologic-economic model and the methods utilized to estimate the net benefit functions for water uses. The following section discusses expected results and associated issues. The conclusion summarizes the paper and discusses some issues for future study.

Data and Methods

Hydro-Economic Model

A non-linear multi-period optimization model that incorporates the important economic, biological, and hydrologic linkages within the SRB is used to estimate the minimum cost of leasing water rights for several drought severity scenarios. The economic aspect of the hydro-economic model of basin surface water use consists of net benefit functions for all surface water uses (irrigation, industrial, energy, golf course, municipal, and nonconsumptive uses such as recreation and wildlife habitat) in the Savannah River Basin. Each water use activity is broken down into sub categories. Examples include irrigated crops such as corn and cotton, industries such as paper and cotton manufacturing or energy production technologies such as nuclear and natural gas combustion. These net benefit functions take the general form:

$$NB_{ijt} = p_{ijt}(X_{ijt}) - c_{ijt}(X_{ijt}) \qquad (1)$$

or

$$NB_{kjt} = p_{kjt}(X_{kjt}) - c_{kjt}(X_{kjt}) \qquad (2)$$

where,

i: consumptive water use, *i*= 1,…,N ;

k: nonconsumptive water use, *k*= 1,….K ;

j: reach, *j*= 1,…,M ;

t: time period, *t*= 1,…,T ;

NB_{ijt}: net benefit of consumptive water use *i*, in reach *j* during time period *t* ;

NB_{kjt}: net benefit of nonconsumptive water use *k*, in reach *j* during time period *t* ;

p_{ijt}: willingness to pay by consumptive water user *i,* in reach *j* during time period *t* ;

p_{kjt}: willingness to pay by nonconsumptive water user *k,* in reach *j* during time period *t* ;

c_{ijt}: acquisition and purification cost incurred by consumptive water user *i,* in reach *j* during time period *t* ;

c_{kjt}: acquisition and purification cost incurred by nonconsumptive water user *k,* in reach *j* during time period *t* ;

X_{ijt}: quantity of water demanded by consumptive user *i,* in reach *j* during time period *t* ;

X_{kjt}: quantity of water demanded by nonconsumptive user *k,* in reach *j* during time period *t*.

These net benefit functions will consist exclusively of the net benefit attributable to water used as opposed to water delivered. They will provide a measure for each consumptive and nonconsumptive use of the contribution of water to net social welfare. A unique feature of nonconsumptive water use is that it takes on the characteristics of a public good, namely that such use is nonrival and nonexcludable. This means that water devoted to one nonconsumptive use is available for other nonconsumptive uses. For instance, if streamflows are maintained for recreational purposes this same water is also used for ecosystem preservation and fish habitat. All nonconsumptive water uses will have the same quantity of water demand, X_{kjt}.

As implied by the subscripts in equations 1 and 2, the SRB is broken down into *J* reaches based on critical nodes. These critical nodes are chosen based upon the location of reservoirs, dams, and significant water users. Each reach faces a water use constraint. The constraint is specified as:

$$\sum_{k=1}^{K} X_{kj-1\,t} + F_{j-1,t} + P_{jt} + W_{jt}\left(X_{ij-1\,t}\right) - \sum_{i=1}^{N} X_{ijt} - \sum_{k=1}^{K} X_{kjt} - E_{jt} - G_{jt} \leq F_{jt} \ (3)$$

where,

$\sum X_{kjt}$: total nonconsumptive water use in reach *j* in time period *t ;*

$\sum X_{ijt}$: total consumptive water use in reach *j* in time period *t ;*

F_{jt}: stream outflow from reach *j* in time period *t* ;

P_{jt}: precipitation and runoff from reach *j* in time period *t* ;

$W_{jt}(X_{ij-1,t})$: return flow from consumptive water use in reach *j* in time period *t*, which is a function of consumptive water use in the previous reach;

E_{jt}: evapotranspiration from reach *j* in time period *t* ;

G_{jt}: groundwater seepage from reach *j* in time period *t*.

There are minimum and maximum streamflow constraints for each reach in each time period based on river capacity and basin managerial objectives. F_{jt}^{L} is the minimum streamflow in reach j during time period *t* and F_{jt}^{H} is the maximum streamflow in reach j during time period t.

Since nonconsumptive water uses are not extracted from the stream, they become part of the effective streamflow in each node. Thus, the minimum and maximum effective streamflow constraints that must be met in each node are:

$$F_{jt}^{L} + \sum_{k=1}^{K} X_{kjt} \leq F_{jt} \leq F_{jt}^{H} + \sum_{k=1}^{K} X_{kjt} \qquad (4).$$

There are also capacity constraints on the water use activities. For example, irrigation will be limited by the number of acres of irrigable land, industrial capacity will be limited by plant size, municipal water use will be limited by plant size, and energy production will be constrained by total generating capacity. Maximum streamflow constraints will be set such that under normal river flow and reservoir level conditions, the water levels for recreational water activities will not be exceeded. For example, under normal conditions reservoir levels will not be above boat ramps. These constraints will act as de facto constraints on $\sum_{k=1}^{K} X_{kjt}$ and $\sum_{i=1}^{N} X_{ijt}$.

Maximizing equations 1 and 2 subject to equations 3 and 4 will produce an optimal allocation of water across water uses. An optimal, or efficient, solution will result where the marginal net benefits (MNB) are equal to the shadow price for all *N* and *K* uses within each reach:

$$MNB_{ijt} = MNB_{kjt} = \lambda_t \qquad (5).$$

Assuming that the water constraint binds, the optimization will produce shadow prices that give the willingness to pay for water across uses.

Water Use Benefit Estimation

The following subsections illustrate the methods for calculating $p(X_i)$, the demand functions or willingness to pay for each water use. For the initial stages of this study, nonconsumptive water uses such as recreation and wildlife habitat will be ignored.

Industrial Water Use

Given the lack of firm specific data and the empirical requirements of accurately estimating industrial water demand functions, net benefit functions for industrial water users in the Savannah River basin are estimated with residual imputation and point expansion. Using production data for each county and knowledge of water using industries, total water use for each county will be apportioned out amongst the industries in that county. Using this water use level and a known production level for a given year, the residual is imputed to water. All production costs, including an allowance for returns to debt and owner's equity, returns to management, land and capital, are subtracted from the revenue generated by the output. The resulting residual is the benefit attributable to the water used in production (Griffin, 2006). Dividing this total by the production level provides the average benefit derived from water used in production for a given level of water use. This benefit is a willingness to pay or 'price' for water. This price-quantity point provides one point on the water demand curve for a specific industrial product. This single point is expanded to a complete demand curve using elasiticities and appropriate functional forms estimated in previous studies of water demand for that industry or sector (Young, 2005).

This method of benefit measurement can produce under or over estimates of net benefits very easily. An input can be omitted or mispriced, output can be mispriced, or the amount of water used per unit of output could be wrong. Residual imputation would tend to overestimate the value attributable to water use and is thus seen as an upper bound. The procedure works best when water is a major input and produces a considerable amount of value per unit. Conservative assumptions are used at each step of the calculation. Because any error will be magnified in the residual several times over, it is most appropriate to use when water is used in large quantities (Griffin, 2006; Young, 2005).

Water Use in Power Generation

Two categories of power are generated in the SRB: hydroelectric and thermoelectric. Hydroelectric power generation is a nonconsumptive, instream use of water while thermoelectric power generation (nuclear and natural gas or other fuel based combustion) is a partially consumptive use in that the majority of water used for cooling is recycled or returned to the stream while a portion is consumed as evaporation as the plant is cooled. Different techniques are required to value these two power sources.

In the case of thermoelectric generation, more water is required for production than is actually consumed. The amount of water required for power generation is valued while the amount consumed is subtracted from total available water. As in industrial uses, residual imputation and point expansion could be a useful approach to finding a demand curve for water in thermoelectric power generation. As previous studies that estimate the elasticity of demand for water in thermoelectric power generation are unavailable to the best of our knowledge, an alternative approach is used to estimate demand.

Multiple points along the demand function can be estimated by implementing residual imputation for different time periods and/or for different power plants. Each of these price points provides the input price of water for a given level of production. Combined with other input prices and output levels, a translog cost function for thermoelectric power generation can be generated. The derivative of the translog cost function with respect to the price of water gives the derived demand curve for water (Christensen and Greene, 1976).

More formally, the translog cost function for thermoelectric power generation is written as

$$\ln c = \beta_0 + \beta_y \ln Y + \frac{1}{2}\delta_{yy}(\ln Y)^2 + \sum_i \beta_i \ln P_i + \frac{1}{2}\sum_i \sum_j \delta_{ij} \ln P_i \ln P_j + \sum_i \delta_{yi} \ln Y \ln P_i \text{ (6)},$$

where *c* is total cost, *Y* is output, the *P_i's* are input prices (including water) and $\delta_{ij} = \delta_{ji}$. In order to obtain the properties of a standard production function, the following conditions must hold:

$$\sum_i \beta_i = 1 \text{ (7)},$$

$$\sum_i \delta_{yi} = 0 \text{ (8)},$$

$$\sum_i \delta_{ij} = \sum_j \delta_{ij} = \sum_i \sum_j \delta_{ij} = 0 \text{ (9)}.$$

Taking the directive of the cost of function with respect to the price of water, P_w, provides the derived demand for water (Greene, 2008):

$$X_w = \frac{\partial c}{\partial P_w} \text{ (10)}.$$

For hydroelectric power generation, a different method of valuation is required. This method is taken from Young (1996) and is based on Albery (1968). The maximum output of a hydroelectric plant in kilowatt (kW) is

$$Installed\ Capacity\ (kW) = 0.0848eqh \quad (11),$$

where

e: overall hydraulic, mechanical, and electrical efficiency;

q: flow in cubic feet per second (cfs) at maximum output; and

h: effective mean head in feet (pond elevation minus tailwater elevation).

Then total capital cost is

$$Total\ capital\ cost\ (\$) = 0.0848eqh(K) \quad (12),$$

where *K* is capital cost in dollars per installed kW capacity of the total project. The total annual cost *excluding* the value of water is

$$Annual\ accounting\ cost = 0.0848eqh(K)(\alpha + \beta) \quad (13),$$

where α is the capital recovery factor for the assumed planning period and interest rate and β is the factor for the annual operating and maintenance costs of the plant. The total annual cost *including* the value of water is then

$$Annual\ economic\ cost = 0.0848eqh(K)(\alpha + \beta) + xqf \quad (14),$$

where *x* is the value ($) of one cfs of water for one year and *f* is the annual capacity utilization factor (the ratio of average load on the plant to maximum generating capacity).

With 8,760 hours in a year, electricity generated per year in kWh is

$$Electricity\ generated\ (kWh\ per\ year) = 0.0848eqhf(8760) \quad (15).$$

Dividing equation 14 by equation 15 yields the cost of generating hydropower in $/kWh:

$$\frac{0.0848eqh(K)(\alpha+\beta)+xqf}{0.0848eqhf(8760)} \text{ (16).}$$

The value of water used in hydroelectric power generation, *x*, can be derived by setting equation 16 equal to the accounting price of electricity, *y* in cents per kWh, and solving for *x*.

$$\frac{0.0848eqh(K)(\alpha+\beta)+xqf}{0.0848eqhf(8760)} = \frac{y}{100} \text{ (17).}$$

Dividing *y* by 100 converts the right hand side to dollars per kWh. Inserting appropriate values into equation 17 allows for *x* to be solved for. The use of equation 18 allows x to be converted to the more conventional value per acre foot, *z*, by dividing by 721.1, the number of acre feet equivalent to one cfs flowing for one year.

$$z = \frac{x}{721.1} \text{ (18).}$$

Water Use in Agricultural Irrigation

Crop yield response functions for the irrigated crops in the SRB are taken from the DSSAT crop modeling software (Jones et al, 2003). Functions for dryland crops are included to estimate yields, costs, and revenues for crops under scenarios that result in reduced irrigation. A short run crop production function takes the form of:

$$Y_i = f(w_i \,|X_k) \quad (19)$$

Yield per acre for crop *i* is Y_i which is a function of applied water, w_i, and all other inputs, X_k. During the growing season, all other inputs and fixed and applied irrigation water is variable. The profit function, π_i, for crop *i* is

$$\pi_i = p_i Y_i - cw_i - C_k \text{ (20)}$$

The price per unit of crop *i* is p_i, the cost of water is *c*, and the total cost of all other inputs if C_k. The cost of water is the greater of the costs of capture, transportation, and application or the payment offered by the water authority.

Under conditions when the water constraint does not bind, the optimal application of water will be where

$$\frac{\partial \pi}{\partial w_i} = p_i \frac{\partial Y_i}{\partial w_i} - c = 0 \text{ (21)}$$

Or equivalently, where

$$p_i \frac{\partial Y_i}{\partial w_i} = c \quad \text{(22)}$$

Assuming a simple quadratic form, the crop yield response function for applied water becomes

$$Y_i = a + bw_i - dw_i^2 \text{ (23)}$$

where, *a*, *b*, and *d* are estimated coefficients. Taking the first derivative with respect to w_i yields

$$\frac{\partial Y_i}{\partial w_i} = b - 2dw_i \text{ (24)}$$

Inserting this derivative into equation 22 and solving for w_i produces the derived demand for water for crop *i*, w_i^*:

$$w_i^* = \frac{b}{2d} - \frac{c}{2dp_i} \text{(25)}$$

Irrigation water is supplied by both ground and surface water. For counties in the SRB with both groundwater and surface water irrigation, the percentage of surface water used in irrigation is assumed to be identical to the percentage of acreage irrigated with surface water. We assume in the short run that groundwater and surface water are not substitutes.

Water Use in Golf Course Irrigation

Of all consumptive water uses, golf course use is the least researched. While a few studies have analyzed the environmental impacts of golf course water use (Watson et al, 2004, for example), to the best of our knowledge no study has attempted to estimate demand for golf course irrigation water. Templeton et al (2002) found that revenues per acre foot of applied water on golf courses were 8.1 times higher on average than for traditional crops in California. This lends credence to the intuitive belief that water is more highly valued as an input in golf courses than in low valued agricultural crops, but doesn't assist us in determining the marginal value of water as an input in golf course production.

Water Use in Residential Consumption

This is the only category of water use in the SRB that is final consumption. As such, derived demand or residual imputation techniques will not be used here.

Residential water is drawn from two sources, ground and surface water. In terms of consumption, the two sources are perfect substitutes. As such, the demand must be estimated for residential water as a whole without regard to its source. Due to the lack of consumer level data, countywide residential demand is estimated. When the demand for surface water increases due to policy changes or when the supply decreases due to drought, in the short run the change in surface water demanded for the county is assumed to be in proportion to the percentage of surface water consumed of total water demand. This will tend to overestimate the impacts of surface water availability on residential consumers, but it allows the estimation of the maximum impacts on consumers.

County level water demand is estimated using a restricted regression model with a spline function and monthly data. The dependent variable is county monthly water use and independent variables are average water price in the county (P_w), population served (*Pop*) (which may include consumers in other counties for counties with large water utilities) average county income (*Inc*), and variable for time of year, summer or not summer.

The simple form of the function is as follows (Greene, 2008). For simplicity, we'll assume that there are two periods, summer and not summer. The expected county water demand given the period is

$$E[water|period] = \begin{cases} \beta_o^0 + \beta_1^0 P_w + \beta_2^0 Pop + \beta_3^0 Inc + \beta_4^0 Summer \\ \beta_o^1 + \beta_1^1 P_w + \beta_2^1 Pop + \beta_3^1 Inc + \beta_4^1 NotSummer \end{cases} \text{(26).}$$

Expected Results

As this study is still in the preliminary stages, results are not yet available. A few observations can be offered at this stage. Costs are incurred by out of stream right holders when out of stream diversions are reduced to maintain streamflows. Marginal per unit cost to water right-holders increases with drought severity as water must be taken away from increasingly more valuable uses to meet streamflow needs. The critical question is what level of payment is necessary under the different drought scenarios to bank a sufficient volume of water to maintain streamflows. A related issue when simulating the model for future scenarios with expected increases in out of stream diversions is the level of payment necessary to acquire water rights.

Conclusion and Discussion

This study is one of the first to address the cost of augmenting streamflow levels in the southeastern United States. With increased out of stream diversions and changing climatic conditions, maintaining adequate streamflows for environmental purposes is becoming a major environmental concern. A critical concern when trying to establish a contingent water right that involves the temporary use (lease) of water for in-stream uses in the southeastern United States is the legal status of the water committed to the market. Under the riparian doctrine, landowners with land adjoining a water source have the right to make beneficial use of the water, but are generally prohibited from taking ownership and transferring water to another user. As the law currently stands, if the riparian owner doesn’t make use of the water they lose the right to it, giving them little reason to conserve or consider the opportunity cost of their use. By demonstrating how riparian right holders can benefit economically by leasing their water rights for environmental uses, this study can help motivate efforts to reform the institutions governing water use in the southeastern United States while demonstrating how these institutional changes can assist in species and environmental preservation.

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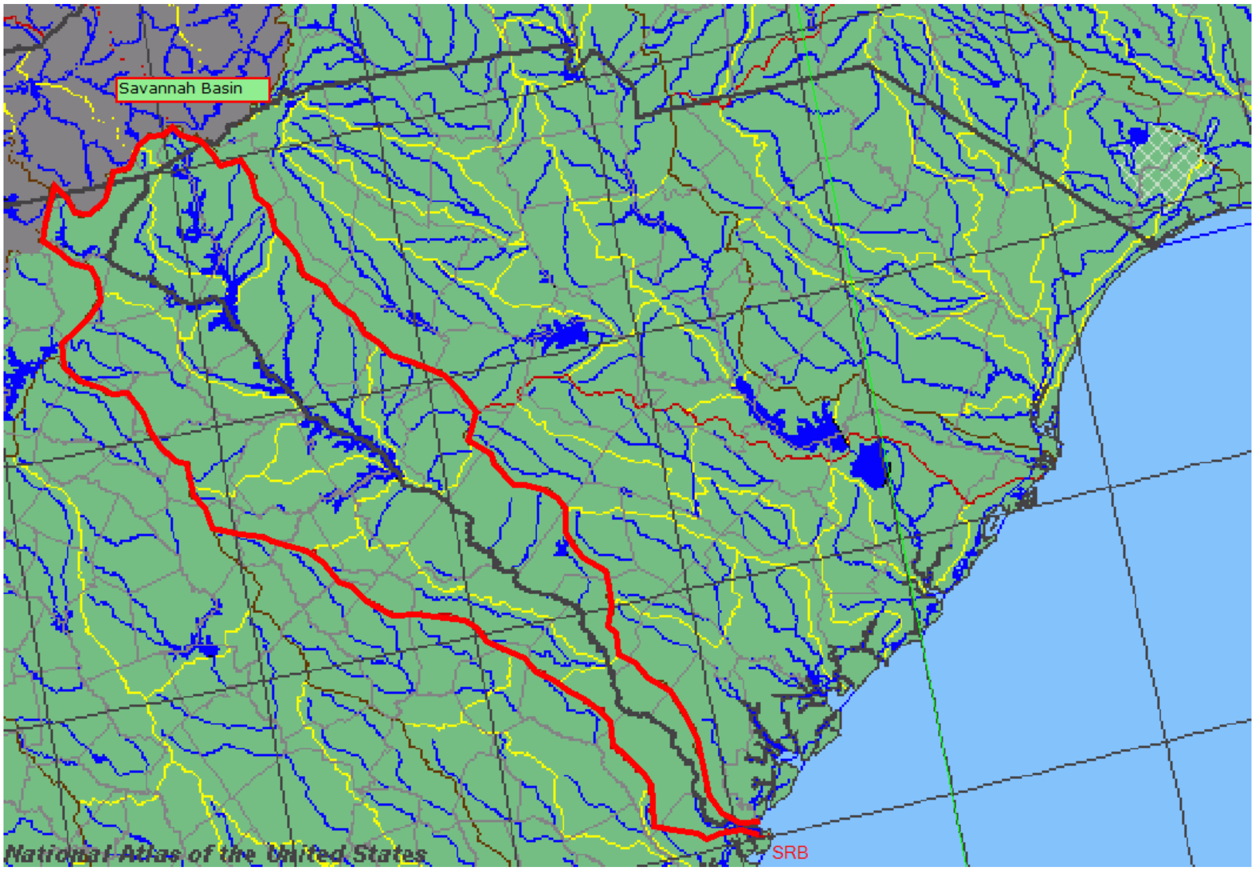

Figure 1. The Savannah River Basin boundaries

Figure 2. Map of Critical Sturgeon Habitat Sites and Landmarks on the Savannah River