Mitigating a Commons Dilemma: Agricultural Water Use in the Mississippi Delta

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1.0 Introduction

Unsustainable exploitation of aquifers is an important issue for producers and government agencies with the responsibility to regulate and monitor the sustainable usage of this natural resource. The increased adoption of irrigation and advancements in irrigation technology have led to increased crop yields required to meet the ever increasing consumer demand. However, increased irrigation has led to the depletion of important aquifers in the United States. For instance, one of the most recognized aquifers facing overexploitation is the Ogallala aquifer. The Ogallala is a very deep aquifer that has an extremely slow recharge rate lying beneath a vast area of the central United States (the ‘corn belt’ in the Midwest covering parts of seven states ranging from parts of Wyoming, Nebraska, Kansas, and Texas). Although this aquifer has been subjected to increasing agricultural use and observed depletion for nearly a century, there are other aquifers in the United States that are just as susceptible to overexploitation.

This study analyzes the potential for overexploitation of the Mississippi River Valley Alluvial Aquifer (MRVAA). The MRVAA is a shallow aquifer that ranges from parts of southwestern Arkansas, northeastern part of Louisiana, western border of Tennessee, and the northwestern part of Mississippi. The region in Mississippi is known as ‘the Delta’ where the streams flow north to south with slight undulation (Coupe et al. 2012). Depending on the landscape characteristics, precipitation can contribute to the replenishment of the aquifer, but Arthur (2001) concludes that the Delta’s impermeable soil content allows little seepage into the aquifer but rather runoff into streams and rivers. Due to the generally low permeable soil types, recharge of the MRVAA is primarily from waterways (e.g. the Mississippi, Sunflower, and Tallahatchie Rivers) and other aquifers.

Irrigation is not new to the Delta region. Since the mid 1900's, extraction from the MRVAA has increased in part because of the poor quality (e.g. chemicals and sediments) and reliability of the surface water. More recently, government policies have affected the crop selection in the Delta. The Renewable Fuel Standard Program was designed to help combat pollution through the usage of gasoline and reduce foreign energy dependence.[1] Where cotton was once King, this policy contributed to rising corn prices which led many cotton producers to switch to corn. As opposed to cotton, the production of corn requires significantly higher levels of water.

The increasing use of ground water for agriculture in the Delta has led to declining water table levels, which in turn have lowered the base flows of the streams and rivers (Coupe et al. 2012). Even though the Delta region receives significant annual precipitation, as compared to the Midwest and West, precipitation is the least during the growing seasons for most row crops, especially corn. As such, Delta producers utilize irrigation to combat the uneven seasonal distributions of precipitation (Coupe et al. 2012). Though stochastic rain events during the growing season helps buffer ground water extraction, the rainfall has not proven dependable enough for stable crop production.

Though the Delta region now produces crops that require larger amounts of irrigation water, the underlying cause of over extraction is that the MRVAA is essentially a common pool resource (CPR). The characteristics of a common pool resource is subtractability and non-excludability (Ostrom et al. 1994). Non-excludability means that it is difficult, but not impossible, to exclude potential users from benefiting from the resource. Extraction of groundwater at unsustainable rates over time will lead to over exploitation, or more common

[1] The RFS was enacted under the 2005 Energy Policy Act and expanded within the 2007 Energy Independence and Security Act (Renewable Fuel Standard Program, 2016).

called the "Tragedy of the Commons" (Hardin, 1968). This is due to the individual user's incentives to maximize personal profit without concern for their impacts on others, and hence negatively impacts social welfare. Hardin (1968) suggested government regulation was required to avoid unsustainable over exploitation of CPRs. Other researchers however, notably Noble Laureate Elinor Ostrom (1999), have proposed that self-governance on a localized level can yield more efficient and sustainable management of the CPR.

To manage depleting water resources, the state of Mississippi instituted the Riparian Rights Doctrine in 1985 (Whittington, 2014). The adoption of the law gave ownership of all public waterbodies to the State.[2] The Mississippi Department of Environmental Quality (MDEQ) was formed and charged with the responsibility to regulate the usage of all surface and groundwater in order to ensure maximum sustainable use of the water in the state. By §51-3-1, "It is hereby declared that the general welfare of the people of the State of Mississippi requires that the water resources of the state be put to beneficial use to the fullest extent of which they are capable, ….".

Acquisition of permits to use the 'State' water could be purchased through the Environmental Quality Permit Board (EQPB). Since then, permits have risen from 2,823 in 1987 to 17,656 in 2013 in the Delta alone. A permit costs $10 and lasts for 10 years, until 2016 where the permits have been reduced to 5 years. The special terms and conditions of the permit sets a water use limit per permit up to 1.5 acre-feet per acre per year for row crops, up to 3.0 acre-feet per acre per year for rice, and up to 5.0 acre-feet per acre per year for all types of aqua culture except fingerlings which can extract up to 7.0 acre-feet per acre per year when raising fingerlings (MDEQ, April, 2016). However, these permit levels are roughly twice that of

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[2] Mississippi Code Annotated §§51-3-1 through §§51-3-55 (2004).

estimated usage by normal agricultural practices for any crop in the region and thus are not considered binding (YMD, 2010). Therefore, the MRVAA has essentially been an unregulated common property to date.

Regulation of water in general has long been opposed by the major farm groups in the state. For example, MDEQ threatened to mandate metering of all wells in the Delta. This resulted in an agreement with farm groups of a voluntary sampling of wells by 2015.[3] Therefore, there exists a tension in the Delta between water sustainability and economic prosperity as would be expected in a CPR dilemma. State officials appear to be reluctant to force highly unfavorable regulation and has thus impeded progress toward reaching a sustainable water management solution in the Delta. Decreasing the water extraction allocation below the profit-maximizing required level of water may induce significant political 'push back' from the historically politically powerful producers in the Delta. Current regulatory policies on water use amounts and/or any localized self-governance have not stemmed the reduction in the water levels observed in the MRVAA.

The main objective of this study is to investigate producer water extraction behavior in a non-cooperative game under various regulatory policies. To achieve the objective, a game is constructed that incorporates the major features of a CPR similar to the MRVAA. The game is then tested in a laboratory experiment under various regulatory policies. Three policies are tested. The first is a policy of no regulation. The second and third represent a credible threat of future *limited use* and a *moratorium* if "critical" water levels are reached. Credibility is established when the majority of the producers are out of water and support regulation. The threat of credible future regulation may facilitate early cooperation, which not only delays the

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3 http://deltafarmpress.com/blog/time-growing-short-voluntary-metering-delta-irrigation-wells

enforcement of the regulation but also extends the time in which water levels reach critical levels.

The main contributions of the research are both academic and policy relevant. For instance, this is the first game developed applicable to shallow aquifers, as well address heterogeneously endowed producers. Also, the research provides the first analysis of the relevant strategic issues in the Mississippi Delta region, as well as informs policy makers of the impacts of potential regulations.

Preliminary results indicate that without regulation, the decline in water was slower than would be expected under a pure strategy of myopic static profit maximization. Interestingly, water extraction with no regulation was comparable and slightly slower to a threatened future limited use regulation. Only under the threat of extreme moratorium did water extraction decline as compared to no regulation, but still resulted in water levels reaching a critical level prior the end of the planning horizon.

2.0 Literature Review

There exists a plethora of CPR literature regarding irrigation systems. The inefficient management of water resources occurring in the Delta is not new nor surprising when reviewing prior research conducted within this arena. Many different academic disciplines, different branches of ’hard sciences’ (e.g., ecology and hydrology), political science, and multiple focuses within the field of economics to name a few, have all provided insights to better inform future policies. The literature within this section has been gathered from different research disciplines and those contributing the most relevance toward the scope of this study has been divided into two main subsections: common pool resources and game theoretic applications to common pool resources.

2.1 Common Pool Resources

Sustainable management of CPRs has been debated by researchers for over a century. Garrett Hardin (1968) brought attention to a potential outcome, which is better known as the "Tragedy of the Commons," resulting from inefficient management practices by economically rational individuals concerning renewable natural CPRs without government intervention or establishing and enforcing private property rights. Since Hardin's essay, a plethora of research has been conducted either supporting or contradicting his conclusions. Nobel Laureate Elinor Ostrom and others have concluded that while Hardin's conclusions are a possibility, that such extreme pessimistic outcome may not be the likely outcome in certain situations. Ostrom et al. (1999) and Walker and Gardner (1992) have published work stating that regulation from central government is not needed because cooperation through informal arrangements and/or traditional customs already established are viable alternatives in a localized level.

Sustainable management of groundwater systems has become a focal point of common pool resource research. Research on groundwater commons has increased dramatically beginning in the latter part of the 20th century with the rapid depletion of several deep aquifers west of the Mississippi River. Ostrom and Gardner (1993) state that appropriation and provision problems transpire in irrigation system CPRs where the allocation of extracted water applied toward agricultural production constitutes the appropriation problem, while sustainable maintenance of the irrigation system makes up the provision problem. Some main characteristics of CPRs, subtractability and excludability, complicate and increase difficulty when attempting to manage a large watershed within a local, regional (state), and national level in addition to the problems of establishing self-governance regimes (Ostrom et al., (1999). Producers in the Delta extracting water from the MRVAA are currently facing these problems. A high concentration of myopic producers within a limited area have hindered the potential for self-governance in order to increase the social welfare and extend the life of the MRVAA to avoid external government regulations.

2.2.1 Game Theoretic Application to Common Pool Resources

The application of game theory when conducting economic research is relatively new when compared to traditionally accepted methodology. Many researchers analyzing strategic decision-making behaviors of producers exploiting aquifers have led to the utilization of game theoretic frameworks modeling either a cooperative or non-cooperative environment. When employing a cooperative game theoretic framework, occurrences of cheating or defecting will result in rapid disintegration shifting from the cooperative equilibrium toward a Nash or non-cooperative equilibrium (Loáiciga, 2004).

Loáiciga (2004) acknowledges that water laws implemented by some states, court adjudication of water rights, policy prescriptions encouraging beneficial uses of groundwater among rivals, and establishment of "water districts" regionally have not curbed the overexploitation of aquifers. Rephrasing Hardin's 1993 work, the author states that "privatized profits" incentivizes rational individuals to acquire maximized profits for themselves without concern for the "commonized costs," cost associated from extraction and loss of utility shared by all rivals, implying the best decision strategy for individuals is to continue extracting contributing toward groundwater storage depletion. The research presents a model depicting groundwater extraction within both cooperative and non-cooperative scenarios. The author concludes that non-cooperative settings facilitates over extraction due to the CC-PP paradox, but by employing credible and effective enforcement within a cooperative setting enables the possibility that sustainable extraction may be attained.

Archetti (2009) utilized a static game framework, where individuals choose whether to contribute to a public good by volunteering or not, which was replicated without time dynamics. This study also stated the use of mixed strategies, where the optimal decision for individuals differs from the optimal decision for the group, which presents a major issue for potential coordination. The author concluded that other strategy mechanisms (e.g. concept of brinkmanship when the public good is not produced and establishment of an optimal value equivalent to the number of required individuals to volunteer) should induce cooperation for the provision of a public good or prevention of overexploitation to ensure sustainability of the resource.

Madani (2010) stated that game theory is essentially the mathematical study of competition and cooperation that can be utilized to predict self-interested people's behavior in conflicts. Conventional optimization methods used by economists may not give insight about the reasoning behind why individuals make certain strategic decisions which may not result in the optimal equilibrium. Although game theory has not been widely accepted for use of water resource analysis, Madani (2010) indicates that a framework that studies an individual's strategic behavior, obtaining particular insights within groundwater extraction problems, and results that more accurately reflects actual behaviors of affected producers are a few benefits of applying game theory in CPR dilemmas.

2.2.2 Experimental CPR Dilemmas

Different research disciplines have contributed alternative viewpoints and strategies to solve CPR dilemmas. Most of the growing research applying game theory in CPR dilemmas have been collaborative studies between disciplines in order to produce well-formulated potential policy solutions from experimental results. Some form of cooperation among the users of groundwater

CPRs have been the most widely used and accepted solution, but without a definitive analysis technique or solution that may be applied universally. The MRVAA exhibits certain geological characteristics that differs from the majority of the relevant literature found, but certain aspects from previous research will be applied to this study in order to present a model that closely reflects the current situation in the Delta.

Other conflicts not subject to just the MRVAA but all groundwater systems has been addressed by researchers in the past. James M. Walker and Gardner (1992) focused on behavioral responses of rational decision makers when choosing between the trade-off of potentially destroying the resource and gaining profits from resource use. The natural replenish dynamics of the MRVAA is comparable to Walker and Gardner's (1992) acknowledgment that the presence of a natural regeneration process within CPRs indicates a range of "safe yield" of sustainable exploitation, and implies that probabilistic destruction of the resource will occur when the max threshold is exceeded. According to Walker & Gardner (1992), no institutions fostering cooperation and uncertainty adds difficulty when selecting the best policy to improve the lowest efficiencies because of the inability to understand potential future payoffs ultimately inducing CPR destruction. Currently in the Delta, there are no such institutions advocating cooperation, but MDEQ recently have implemented the usage of metering on wells to curb the amount of uncertainty. They, however, suggest the need for careful development of institutional revisions that stabilize resource extraction taking into account natural regeneration or development of environmental bonds which would offer enough of a deterrence of destroying the resource as potential policy prescriptions to deter complete resource destruction. Even a Nash equilibrium derived from a focal point in a theory does not guarantee participating subjects will stabilize at this equilibrium (Walker & Gardner, 1992; Keser & Gardner, 1999).

Keser and Gardner (1999) focused on rent dissipation (similar to Walker & Gardner, (1992)) and conducted CPR experiments utilizing game theoretic applications to discover whether experimental subjects played a Nash equilibrium. If experimental subjects do not play a Nash equilibrium in a theoretical non-cooperative commons dilemma, then the expected results from policy prescriptions, influenced by relevant research results, will not be achieved. Binmore (1992) earlier had specified these two main reasons why researchers presume participants will likely play the Nash equilibrium strategy: (1) participants will reach the equilibrium point through reason, and (2) participants will reach the equilibrium point through an adaptive process. Contradictory of Binmore, the results from the CPR experiment ran by Keser and Gardner (1999) showed that participants did not arrive at the predicted game Nash equilibrium.

Gardner et al., (1997) investigated individual's strategic groundwater extraction decisions, in accordance with state governance, to analyze how property rights (stock quotas that limit individual pumping levels) and regulations (limiting entry) affect profit appropriation. Within this setting, the research develops a dynamic programming model which is then empirically tested in a laboratory setting. A fixed stock of groundwater and fixed planning period was assumed. The research finds that the employment of regulatory mechanisms improves the efficiency, but still considerably below the optimal performance level.

Madani & Dinar (2012) presented and compared various types of non-cooperative institutions with a purpose to select the optimal available CPR management mechanism. The authors incorporate heterogeneous levels of groundwater drawdown and decision-making by an individual attributed to his location which directly affects accessibility of the resource. Their research controls for a heuristic management plan and takes into consideration future outcomes, externalities caused by individuals experienced by rivals sharing the resource, and may make sustainable contributions all while trying to maximize individual benefits. Different types of heuristic management plans can be grouped into two main categories, myopic and non-myopic management in relation to the long-run sustainability of the resource. The authors concluded that the “Tragedy of the Commons” outcome in a non-cooperative setting could be avoided and resource sustainability could be achieved, but requires a sufficient planning horizon, trust among users to deter deviating from optimal strategy, and choosing a smart non-myopic management institution.

Most recently, experimental research has considered asymmetric producers in relation to their position on a water canal. Holt et al., (2012) evaluate a special case of a groundwater CPR problem they call a sequential extraction commons. In this setting, there exists an external cost experienced by “downstream” producers when faced with a unidirectional flow. The unidirectional groundwater flow in the canal results in an *ordered effect*, but the inability to accurately measure the water extracted in groundwater diminish the ability for localized self-governance. The authors suggest establishing a water market which allows possible solution mechanisms, for example, non-binding communication, binding bilateral bargaining, auctions, and imposition of an optimal appropriation fee, to mitigate continual overexploitation. Initiating informal social arrangements among producers *may* efficiently mitigate a potential tragedy without external regulatory forces (e.g. bargaining and chat). These mechanisms tend to produce lower average efficiencies and are susceptible to free-riders. But other alternative cooperative mechanisms, external implementation of an optimal fee and an auction mechanism, yielded results almost reaching 100% efficiency. Therefore, to achieve the highest efficiency required an external source of control and management.

In summary, Ostrom et al., (1999) acknowledges that there is no universal solution that can be applied to every CPR dilemma because of the differences in resource characteristics. The dilemma facing producers in the Delta cannot be solved by utilizing the policy prescriptions suggested by a non-specific research study. This research will incorporate aspects from previous work that is relative to the current situation in the Delta in order to find the most efficient mechanism to save the MRVAA from resulting in a 'tragedy.'

3.0 Conceptual Theoretic Model

Past game theoretic research by Archetti (2009), Gardner et al. (1997), and Loáiciga (2004) assume increasing marginal costs and symmetric recharge rates for individual users of the aquifer. This modeling framework assumes the firm initially drills a shallow well and continually drills deeper as water levels decline, hence experiencing increasing marginal costs of extraction. This modeling approach is appropriate for analyzing deep aquifers such as the Ogallala aquifer.

However, the Mississippi River Valley alluvial aquifer is a shallow aquifer and producers initially drill their wells to the maximum depth. Since all users of the aquifer are at a symmetric depth, extraction costs are assumed symmetric and constant. In regards to aquifer recharge, deep aquifers, such as the Ogallala, may take thousands of years to replenish water levels even if extraction ceased (Ponce, 2006). However, shallow aquifers located close to surface water sources, such as the MRVAA, has the capability to recharge in a short time frame, possibly years (Ponce, 2006).

Additionally, recharge rates are not necessarily symmetric due to underground hydraulic conductivity and the location of a well in relation to recharge sources and rival extraction (Ponce, 2006; YMD, 2006; Coupe et al., 2012). Given the focus of the research is on aquifers such as the MRVAA, the following modeling framework assumes constant marginal costs of extraction and takes into account asymmetric recharge rates across firms and the externalities on recharge due to extraction and location of rivals.

3.1 Generalized Model Development

To begin, let *n* producers have symmetric water extraction technology and a numeraire number of wells. The i^{th} producer's *t* period production function can be generally defined as

(1) $$q_{it} = f\left(e_{it}, \mathbf{I}\right),$$

where e_{it} represents the individual's current period's water extraction applied to crops and a vector of numeraire inputs $\mathbf{I}$. It is assumed that (1) is a smooth and continuous function whereby $q' > 0$ and $q'' < 0$ with respect to water extraction. The water extraction possibilities in the current period *t* is conditional on the initial water level in the current period $L_{it} \in [\underline{L}, \overline{L}]$ which is the last period's ending stock, and current period's recharge r_{it}, such that

(2) $$\begin{cases} e_{it} > 0 \text{ if } L_{it-1} + r_{it} > \underline{L}_{it} \\ e_{it} = 0 \text{ if } L_{it-1} + r_{it} \le \underline{L}_{it} \end{cases}.$$

To include negative externalities from rivalry, let the producer's *t* period water level dynamics be generally represented as

(3) $$L_{it+1} = L_{it-1} + r_{it}(e_{jt}) - e_{it}.$$

In (3), L_{it+1} is the i^{th} producer's next period beginning water level. The period recharge, $r_{it}(e_{jt})$, represents the negative "congestion" externalities caused by *j* other individuals' current period extractions (Gardner et al., 1997). Congestion externalities exists from loss of extraction quantity or efficiency due to closely spaced wells (Gardner et al., 1997). For instance, in the MRVAA the congestion externality is caused by a large and growing number of well permits resulting in individual water table levels that are spatially heterogeneous (Figures 1 and 2).[4] Extending (3) allows for possible water level asymmetries based on location relative to competitors in the aquifer. For instance, assuming asymmetric recharge rates conditional on the i^{th} producer's l^{th} location, then it could be that

(4) $$r_{ilt}(e_{jkt}) \neq r_{jkt}(e_{ilt}) \ \forall \ l \neq k \ .$$

More specifically, it would be the case that $r_{ilt}(e_{jkt}) < r_{jkt}(e_{ilt})$ if i is further from the initial point of recharge than j and j's extraction impedes i's recharge (YMD, 2006). Therefore, individual recharge rates are a function of their *respective* rival user's extraction rates.

Equations 2-4 establish the individual's localized water level dynamics. Specific underground water conductivity identifies the order effect of location on recharge rates (YMD, 2006; Ponce, 2006). For instance, assuming $r_{it}(e_{jt}) < e_{it}$, then $L_{it+1} < L_{it-1}$ and $\Delta L_{it} < 0$. Given $r_{ilt}(e_{jkt}) < r_{jkt}(e_{ilt})$, then it is conceivable that the i^{th} producer in the l^{th} location could run out of water before the j^{th} producer in the k^{th} location if $|\Delta L_{it}| > |\Delta L_{jt}|$ for sufficiently long periods of time. It is possible the order effect is one directional such that

(5) $$L_{jt} = L_{jt-1} + r_{jt} - e_{jt} \ .$$

As long as $r_{jt} \geq e_{jt}$, then $\Delta L_{jt} \geq 0$ and the j^{th} producer never runs out of water. The time period in which any given individual may run out of water, t_{il}^{*} hence $e_{ilt^{*}} = 0$, can thus be generally defined as

(6) $$\overline{L} + \sum_{t_{il}=1}^{t_{il}^{*}-1} (r_{ilt}(e_{jkt}) - e_{ilt}) = L_{t_{il}^{*}-1} + r_{ilt}(e_{jkt}) \leq \underline{L} \quad ,$$

[4] Another externality is a stock. Stock externalities occur when individual extraction reduces the aquifer's aggregate water table level forcing producers to continually drill deeper wells at increasing costs. In the instant case, wells are initially drilled to maximum depth.

where $\sum_{t_{il}=1}^{t_{il}^*-1}(r_{ilt}(e_{jkt})-e_{ilt})<0$ is the aggregate change in the water level up to the current time period if extraction continues to exceed recharge. Therefore, the time it takes for a producer to run out of water is determined by the history *h* of all producer extraction decisions

(7) $t_{il}^*(h(e_{ilt}),h(e_{jkt}))$, where $\frac{\partial t_{il}^*}{\partial e_{ilt}}<0$ and $\frac{\partial t_{il}^*}{\partial e_{jkt}}<0$.

In regards to the MRVAA, figures 1 and 2 depict the historical spatial water table levels. As can be seen, it appears that it is likely that the producers in the southern portion of the MRVAA are impacted by a greater extent from water extraction from northern producers and those closer to the river sources than vice versa.

The resulting aggregate profit function for the i^{th} producer over a fixed time horizon $t\in[0,T]$ is defined as

(8) $$\Pi_{ilt}=\int_0^{t_{il}^*} pq_{ilt}\left(e_{ilt}\right)-c\left(e_{ilt}\right)dt+\int_{t_{il}^*+1}^{T} pq_{ilt}\left(0\right)-c\left(0\right)dt,$$

where $t_{il}^*(h(e_{jkt}),h(e_{ilt}))$. The integrands consist of a fixed output price of the crop assuming producers are perfectly competitive in the output market. Extraction costs are symmetric given symmetric pumping depths conditional on each individual's water availability. Intuitively, the first integral depicts the aggregate profits from a period of *irrigation* production and the second integral depicts the aggregate profits derived from *dry land* production, thus $0=c(0)<c(e_i)$. Also, production is higher with irrigation, hence $0<q_{ilt}(0)<q_{ilt}(e_i)$. Assuming positive extraction, e_{ilt}^*, is optimal in the short run, then any given irrigation period's profits before running out of water are greater than any given period's profits with dry land, hence $\Pi_{ilt},\ t\in[0,\ t_{il}^*]\ >\ \Pi_{ilt},\ t\in[t_{il}^*+1,\ T]$. Whether the aggregate irrigation profits are greater than the aggregate dryland profits depends on the length of t_{il}^{*} relative to T, which is determined by conditions (3) through (7), and the relative magnitudes of per period profits within each regime. It is only in the case when the aggregate planning period extraction $\sum_{t_{il}=1}^{t_{il}^{*}-1}(r_{ilt}(e_{jkt})-e_{ilt})<0$ is *sufficiently* small or zero that no producer will run out of water by *T*.

For positive extraction, rationality requires that a higher valued dryland crop is not available during the planning period *T*. If a producer runs out water before *T*, rationality requires the producer chooses the highest valued crop under dry land production. If there exists an equally profitable dryland crop per period, the producer will necessarily be indifferent between crop selection and to irrigate or not.

Finally, there may exist a set of extraction paths that satisfies

(9) $$\arg\max_{e\in[0,\bar{e}]} \Pi_{ilt} = \int_{0}^{t_{il}^{*}} pq_{ilt}\left(e_{ilt}\right)-c\left(e_{ilt},s_{ilt}\right)dt + \int_{t_{il}^{*}+1}^{T} pq_{ilt}\left(0\right)-c\left(0\right)dt .$$

The interesting result(s) from (9) are how long it takes for a producer in a location to run out of water, given the decisions of all users. The difficulty with deriving a unique set of individual path extractions is due to the various impacts the decision variables have on the limits of the first and second integrals according to equations (6) and (7), as well as mixed strategies. The first is that water levels are interrelated, and hence strategic. Secondly, the producers are heterogeneous in their respective externalities.

3.2 Hamiltonian Function

In context toward the MRVAA, a Hamiltonian function is needed to map out an optimal extraction path over a finite time horizon. To begin solving a Hamiltonian function, designation of variables within the function should be given. The Hamiltonian function can be generally defined as

(10) $$\max H = \int_0^T \left(R_t\left(e_t\right) - C_t\left(e_t, s_t\right)\right) dt$$

subject to $$\dot{s}_t = -e_t + g\left(e_{jt}\right)$$

$$s\left(0\right) = s_0 \qquad \mathrm{s}\left(T\right) \quad \text{free} \quad ,$$

where $R_t\left(e_t\right)$ represents the revenue accrued from extracting water and $C_t\left(e_t, s_t\right)$ represents the costs accrued from usage of energy in order to extract water from the aquifer. These costs are associated from the amount of energy needed to lift the water which varies depending on the stock level of the resource. This function is subject to the equation of motion where the value is determined by the changes in the water level as a result of extraction and amount of recharge. The boundary conditions, $s\left(0\right) = s_0$ and $s\left(T\right)$ free, represent the lower limit of integration and the upper limit of integration which is 'free' to vary depending on whether there exists any remaining stock or the increasing costs have resulted in economic infeasibility for any rational individual. If the value of *s* is free to vary, then the shadow price evaluated at *T* must equal zero. When assuming an interior solution, both maximum principle conditions and boundary conditions need to be satisfied. Two maximum principle conditions, first order condition with respect to extraction and two equations of motion, must first be satisfied, which are

(11.1) $$\frac{\partial H}{\partial e} = 0$$

(11.20) $$\frac{\partial \lambda}{\partial t} = \dot{\lambda} = -\frac{\partial H}{\partial s}$$

(11.21) $$\frac{\partial s}{\partial t} = \dot{s} = \frac{\partial H}{\partial \lambda}$$

In (11.20), $\dot{\lambda}$ is the change in the shadow price of groundwater which is derived by taking the first order condition with respect to the remaining stock. In (11.21), $\dot{s}$ is the change in stock, water level, within the aquifer which is derived by taking the derivative of the Hamiltonian with respect to the shadow price.

After establishing the different conditions needed to be satisfied, the present value Hamiltonian function can be explicitly written as

(12) $$H_i = x + be_{ilt} - ae_{ilt}^2 - P_e e_{ilt}\left[1 + L_0 - S_t\right]^\beta + FC + \lambda\left(-e_{lt} + g\left(e_{jt}\right)\right)$$

where $x + be_{ilt} - ae_{ilt}^2$ the revenue accrued for the i^{th} producer in the l^{th} location in time t, $P_e e_{ilt}\left[1 + L_0 - S_t\right]^\beta + FC$ represents total costs accrued for the i^{th} producer in the l^{th} location in time t, and $\lambda\left(-e_{lt} + g\left(e_{jt}\right)\right)$ represents the shadow price of groundwater for the i^{th} producer in the l^{th} location in time t. For simplicity, assume $\beta = 1$, but knowing that if $\beta > 1$ then the result is increasing costs at an increasing rate where economic infeasibility occurs within a few time periods.

The next step in solving the Hamiltonian involves satisfying the maximum principle conditions by taking first order derivatives of the Hamiltonian. These are

$$\frac{\partial H_i}{\partial e} = b - 2ae_t - P_e - P_e L_0 + P_e S_t - \lambda_t = 0$$

(13) $$e_t = \frac{b - 2ae_t - P_e - P_e L_0 + P_e S_t - \lambda_t}{2a}$$

(14) $$\dot{\lambda} = -\frac{\partial H}{\partial S} = -P_e e_t$$

(15) $$\dot{S} = \frac{\partial H}{\partial \lambda} = -e_t + g\left(e_{jt}\right)$$

Once these conditions have been derived, substituting e_t from (13) into (15) will result in

(16) $$\dot{S} = \frac{\partial H}{\partial \lambda} = -\left(\frac{b - 2ae_t - P_e - P_e L_0 + P_e S_t - \lambda_t}{2a}\right) + g\left(e_{jt}\right)$$

In order to derive the shadow price in time *t*, $\lambda(t)$, integration of (14) is required which yields

$$\lambda_t = \int \dot{\lambda} dt = \int -P_e e_t dt$$

(17) $$\lambda_t = -P_e e_t t + c_1$$

where c_1 is a constant of integration. The next step in the process requires (17) to be substituted in (16) which results in

(18) $$\dot{S} = \left(\frac{-b + P_e + P_e L_0 - P_e S_t + \lambda_t}{2a} \right) + g\left(e_{jt}\right)$$

which then needs to be integrated in order to get the function for S_t. Integration of (18) yields

(19) $$S_t = \left(\frac{L_0 - b + P_e + P_e L_0 - P_e S_t - 0.5 P_e e_t t^2 + c_1 t}{2a} \right) + g\left(e_{jt}\right) + c_2$$

where c_2 is the second constant of integration. Upon completion of each integration and deriving the two constants of integration, the boundary conditions are needed to specify both constants. Starting with the upper limit of integration, will be referred to as the transversality condition, and substituting the value into (19) results in

(20) $$\lambda(50) = -P_e e_t (50) + c_1 \rightarrow c_1 = 50 P_e e_t$$

After deriving the two constants through the substitution of each boundary condition, the control variable must be derived which is

(23) $$e_t = \frac{b - P_e - P_e L_0 + P_e S_t + P_e e_t t - 50 P_e e_t}{2a}$$

The optimal value of λ derived is represented as

(26) $$\lambda(t) = -P_e e_t t + 50 P_e e_t$$

$$S(0) = \frac{b - P_e - P_e L_0 + P_e S_t - 50 P_e e_t}{2a}$$

(27) $$S(T) = S(50) = \frac{b - P_e - P_e L_0 + P_e S_t}{2a}$$

3.3 Pure Strategies

To provide a simplified solution concept to (9), the decision set of the producers can be restricted to myopic pure strategies that are fixed throughout the extraction time frame. This solution concept provides boundaries for interesting welfare results, primarily extremes. These are especially useful when evaluating symmetric decisions either employed by producers or imposed by a social planner. The extreme strategies of interest are those which result in maximum time independent extraction and non-depletion of the aquifer. In turn, the resulting welfares can be used as bench marks for comparing laboratory experimental results.

4.0 Experimental Design

The experimental design examines three treatments to determine how individual decision-making behaviors change across different regulatory policies. The first treatment provides a baseline of observed decisions where no regulatory policies exist and producers are free to choose their extraction rate, unless they run out of water. If they run out of water, they revert to dryland practices.

The second treatment the politician has a credible commitment to enact a *limited use* regulation if over 50 percent of the farmers run out of water. This assumes that all farmers out of water would vote for or support the regulation. Implementation of the regulation will force all remaining producers to decrease pumping rates equivalent to the replenish rate of the aquifer if *all* producers had originally restricted their water use. Those without water revert to dryland practices. This results in the aquifer replenishing itself over time.

The third treatment establishes a *moratorium* on pumping under the same credible commitment. However, under a moratorium, all remaining individuals must revert to dryland practices. Therefore, the aquifer will replenish itself at a faster rate than under *limited* regulation.

All three treatments will be conducted in the Department of Agricultural Economics Experimental Teaching Lab. The majority of the subjects to be recruited will be undergraduate and graduate students from the Department of Agricultural Economics. Subjects will interact with a computer program when making decisions. The program will be written using z-Tree game development software (Fischbacher, 2007).

Each treatment will be replicated six times. Each session will consist of ten subjects. From the literature, this number of subjects is indicative of a 'large' cohort who will find it difficult to maintain cooperation, overt or tacit. No subject will be allowed to repeat a session. Therefore, 180 subjects will be recruited. Subjects will be recruited using email lists and personal invitation. Sessions are expected to last no more than one hour. Average payoffs are expected to equal $20, with an expected total cost of $3,600.

Each session will consist of a 50 period planning horizon. Each time period represents a production cycle. Subjects are called producers. Within each time period, all ten producers make simultaneous decisions to either *wait* to volunteer or *volunteer* to pump at a more conserved rate. If a producer chooses to wait, the producer's water extraction is assumed to equal that of a one shot (static) profit maximization decision. If all, or a large enough cohort of, producers choose to wait, the aggregate extraction exceeds the replenishment of the aquifer. If the aggregate extraction is greater than the natural replenishment, the water table level decreases. If, however, all producers choose to volunteer then the aggregate extraction equals the natural replenishment of the aquifer and the aquifer's water table remains static. Therefore, enough permits have been given out that continued static profit maximization decisions result in depletion of the aquifer, a situation not unlike the MRVAA.

Following the model development section, producers are heterogeneously endowed in regards to their expected water longevity. Water level variability for each producer depends on his/her location of the wells in relation to other producers and the strategic choices of rivals. For example, a producer whose wells are in close proximity to the recharge source is unaffected by rivals' decisions. If, however, a producer is located downstream of other rivals, then the upstream producer's extraction has a negative impact on the water available for every rival downstream. As such, it is plausible that some producers will run out of water prior to the end of the planning period. To maintain consistency across treatments, each session will end when the majority of the producers have ran out of water. Finally, each producer's planning period payoff in the experiment will be determined by parameterizing equations (1) through (9) in the model development section and provided after each period decisions are observed. This will allow for producers to update their planning horizon payoffs.

5.0 Preliminary Experimental Results

In a preliminary set of experiments in April 2016, data were collected as part of a group research project for AEC 8403: Game Theory. Two separate experimental sessions, each consisting of three rounds, was administered to gather enough observations to acquire preliminary results. The first session yielded data to be used as a baseline set of observations because the lack of a regulatory policy. Obtaining baseline observations allows for comparing results to other treatments where a threat of different degrees of regulation may be triggered.

The recharge rate of the aquifer was set to 0.025 per producer. To mimic asymmetries of recharge, producers were given heterogeneous water availability as depicted in table 1, assuming all producers decide to wait for all time periods. If an individual decides to wait, then the period extraction will be 0.1. If an individual decides to volunteer, then the extraction will be 0.025. Therefore, if producers chose a symmetric pure strategy wait, then table 1 depicts when each producer expects to run out of water before the end of the planning horizon and their respective per period payoffs. If producers choose a pure strategy wait, then table 2 depicts that no producer runs out of water during the planning horizon and the per period payoffs.

If all producers choose a pure strategy volunteer, the aquifer water table level remains static throughout the planning horizon. If all producers choose a pure strategy wait, over 50% of producers will run out of water at the 15th time period. The preliminary results from a 3-round average of the baseline set of observations, where there was no regulatory policy, showed that over 50% of producers ran out of water in the 21st time period. The preliminary results from a 3-round average with a credible commitment to implement a *limited use* regulatory policy showed that over 50% of producers ran out of water in the 19th time period. This implies that a limited use regulation does not improve sustainability nor efficiency in water extraction. One round of observations enforcing a moratorium regulatory policy showed that producers increased frequency to volunteer to avoid the implementation of the moratorium. This change in producer extraction decisions extended the time period to the 37th time period before the implementation of a moratorium. Therefore, a credible commitment to implementing a *moratorium* will significantly increase the length of time before the majority of the producers will run out of water resulting from a positive change in producer water extraction behavior.

Some comparative statics in figure 4 depict the percentage of volunteering by each producer depending on their respective location on the aquifer. The highest frequency of volunteering occurred in the presence of a credible commitment to implementing a *moratorium*.

Lower frequency of volunteering occurs when no regulatory policy exist and the lowest frequency of volunteering occurs when the possibility of a credible threat of implementing a *limited use* regulation exist.

6.0 Expected Outcomes and Implications of Research

The expected outcomes are likely to be similar to those observed in the preliminary experiments. However, results are likely to change under more robust replication. Regardless of the findings, the research should provide useful insights as to what may occur in the near term as regulators and farm groups wrestle over the degree and timing of future regulation. For instance, if policy makers value 'log rolling' over immediate action, they would be best served to threaten drastic regulation over soft regulation. Also, threatening extreme measures may avoid expediting the water table levels from reaching critical levels and allow time for producers in finding a more localized self-governance or potentially the formation of water markets.

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Tables

Table 1: Pure Strategy Wait to Volunteer

Water Level	period		1	2	3	4	5	6	7	8	9	10
1	0											
0.925	1		$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.85	2		$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.785	3		$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.73	4		$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.675	5		$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.63	6		$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.585	7		$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.55	8		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.515	9		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.48	10		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.455	11		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.43	12		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.405	13		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.38	14		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.365	15		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.35	16		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.335	17		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.32	18		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.305	19		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.29	20		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00	$ 5.00
0.285	21		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.28	22		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.275	23		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.27	24		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.265	25		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.26	26		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.255	27		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.25	28		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.245	29		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.24	30		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.235	31		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.23	32		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.225	33		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.22	34		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.215	35		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.21	36		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.205	37		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.2	38		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.195	39		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.2	40		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00
0.195	41		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.2	42		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00
0.195	43		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.2	44		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00
0.195	45		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.2	46		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00
0.195	47		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.2	48		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00
0.195	49		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
0.2	50		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00
0.195	51		$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 5.00	$ 5.00	$ 5.00
			1	2	3	4	5	6	7	8	9	10
			$ 157.00	$ 159.00	$ 163.00	$ 167.00	$ 173.00	$ 181.00	$ 193.00	$ 243.00	$ 255.00	$ 255.00

Table 2: Pure Strategy “Volunteer Payoffs

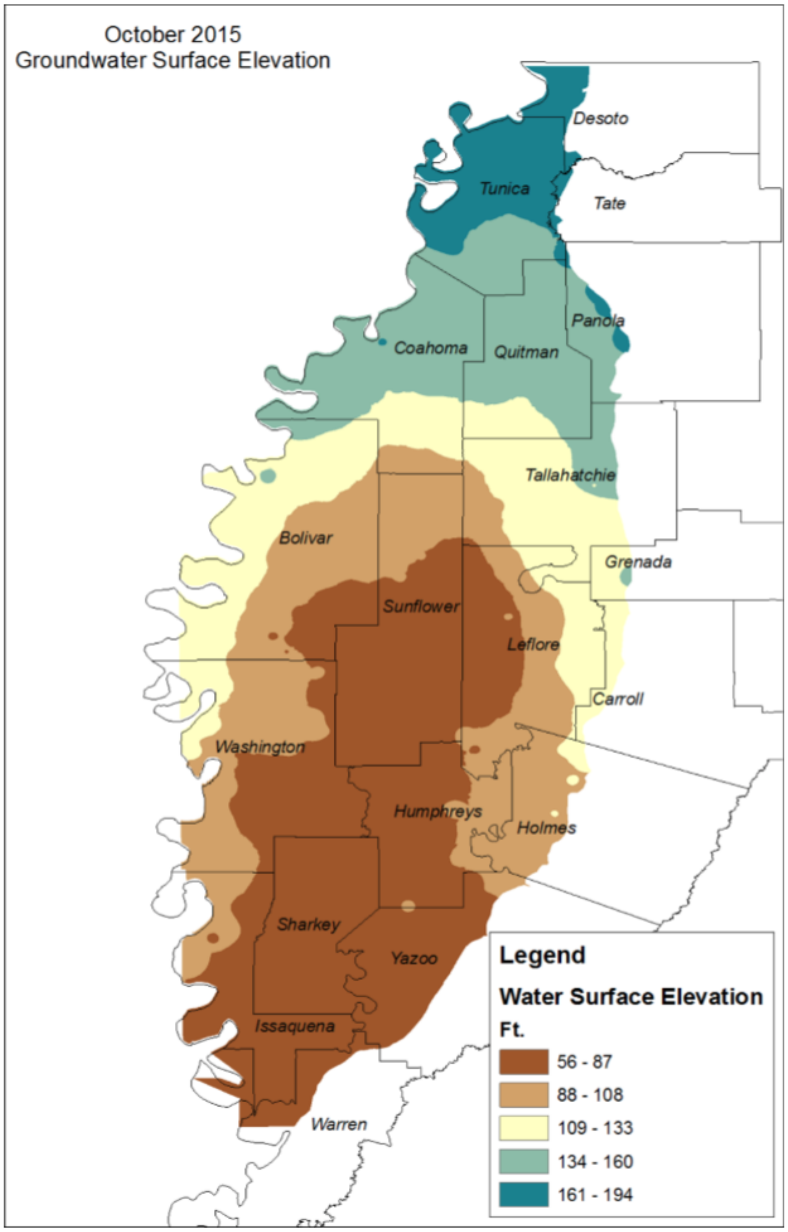
Water Level	period		1	2	3	4	5	6	7	8	9	10
1	0											
1	1		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	2		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	3		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	4		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	5		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	6		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	7		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	8		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	9		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	10		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	11		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	12		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	13		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	14		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	15		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	16		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	17		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	18		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	19		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	20		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	21		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	22		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	23		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	24		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	25		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	26		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	27		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	28		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	29		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	30		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	31		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	32		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	33		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	34		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	35		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	36		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	37		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	38		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	39		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	40		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	41		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	42		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	43		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	44		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	45		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	46		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	47		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	48		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	49		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	50		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
1	51		$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00	$ 4.00
			1	2	3	4	5	6	7	8	9	10
			$ 204.00	$ 204.00	$ 204.00	$ 204.00	$ 204.00	$ 204.00	$ 204.00	$ 204.00	$ 204.00	$ 204.00

Table 3: Experimental Participant's Decision Spreadsheet

Player Number:	6	Seat number: A1
Time Period	*Your Choice*	*Your projected payoff*
1	*1*	*180*
2	*0*	*180*
3	*0*	*180*
4	*1*	*181*
5	*1*	*180*
6	*1*	*181*
7	*1*	*180*
8	*1*	*181*
9	*1*	*180*
10	*0*	*180*
11	*1*	*179*
12	*0*	*179*
13	*0*	*181*
14	*0*	*181*
15	*0*	*181*
16	*0*	*181*
17	*0*	*181*
18	*0*	*181*

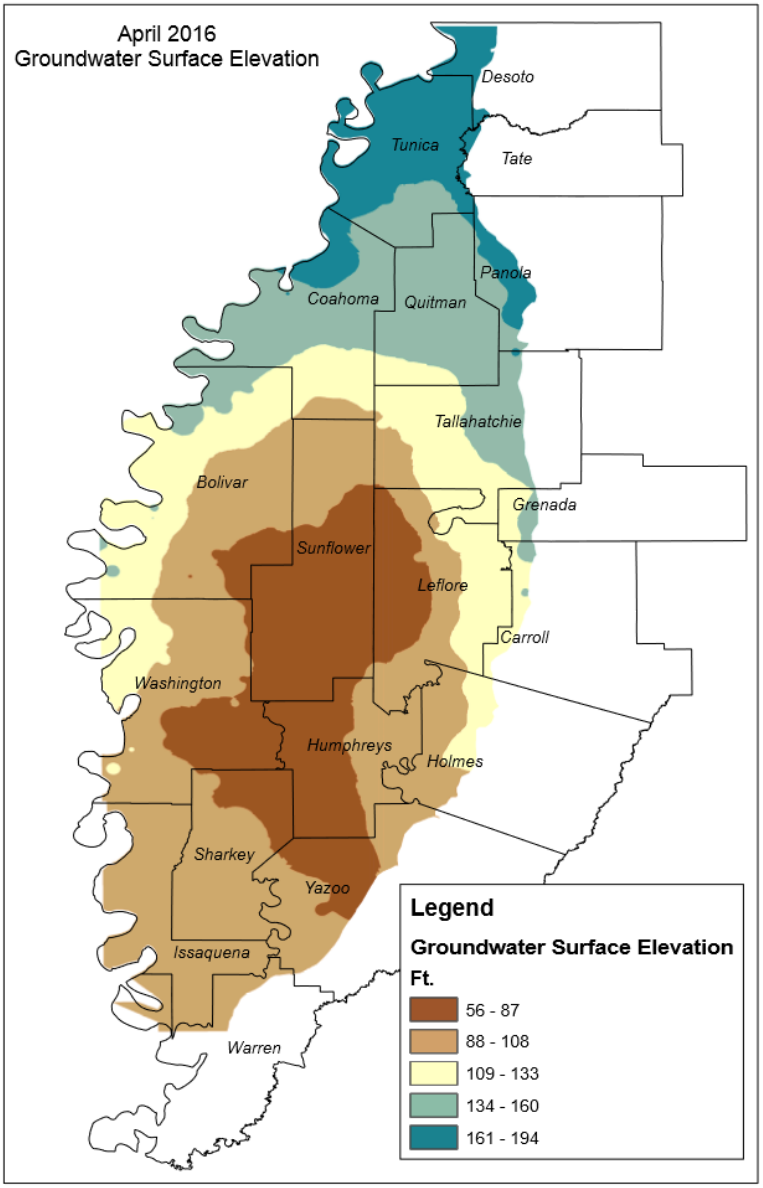
Figures

Figure 1. MRVAA Water Levels During Growing Season



Courtesy of: YMD.org

Figure 2. Recharge of MRVAA Before the Start of the Growing Season



Courtesy of: YMD.org

Figure 3: Water Level Dynamics Based on Extraction Decisions under Different Policies

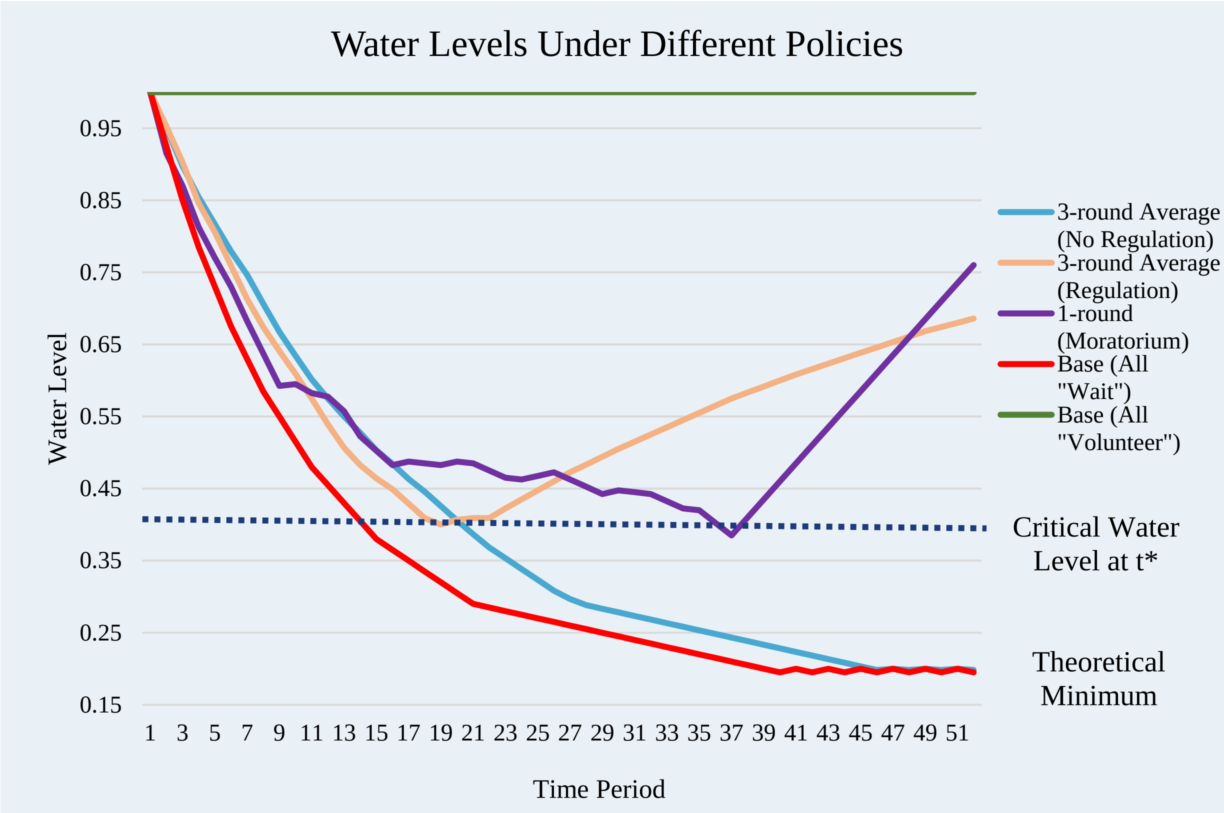


Figure 4: Percentage of Volunteering Relative to Extraction Opportunities within each Treatment

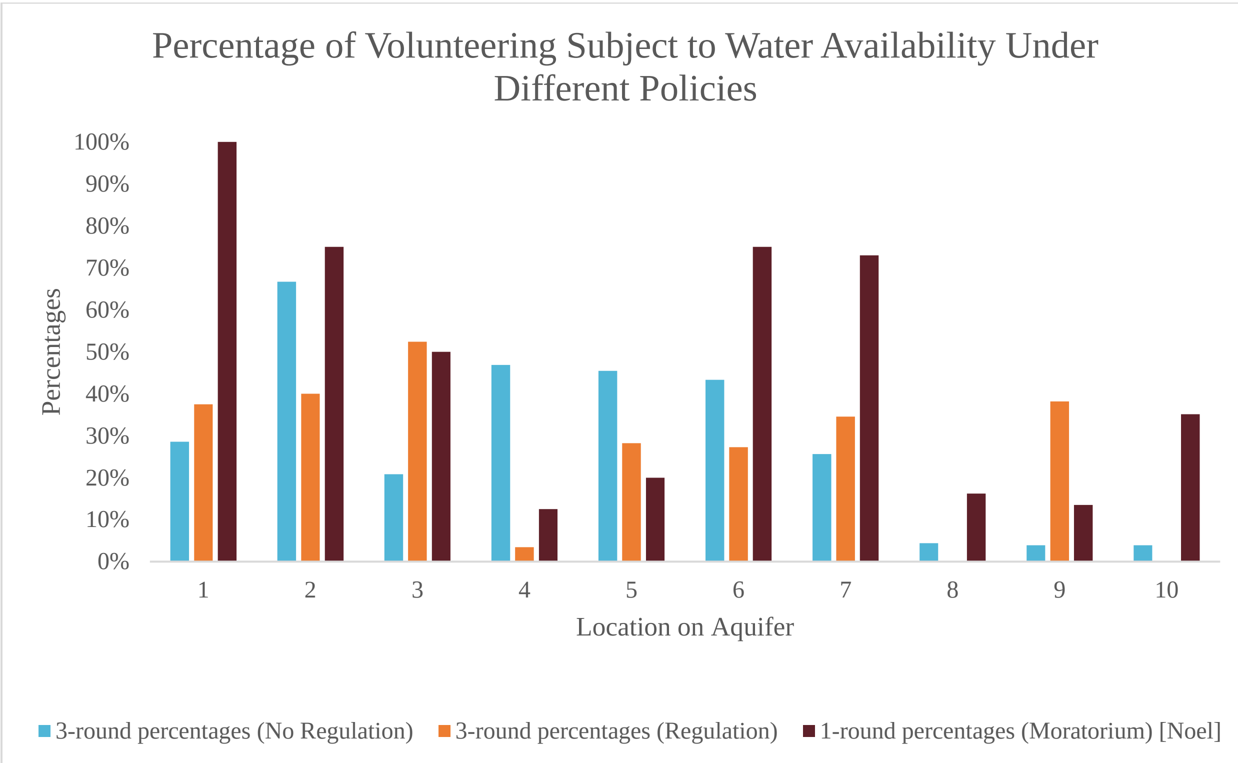
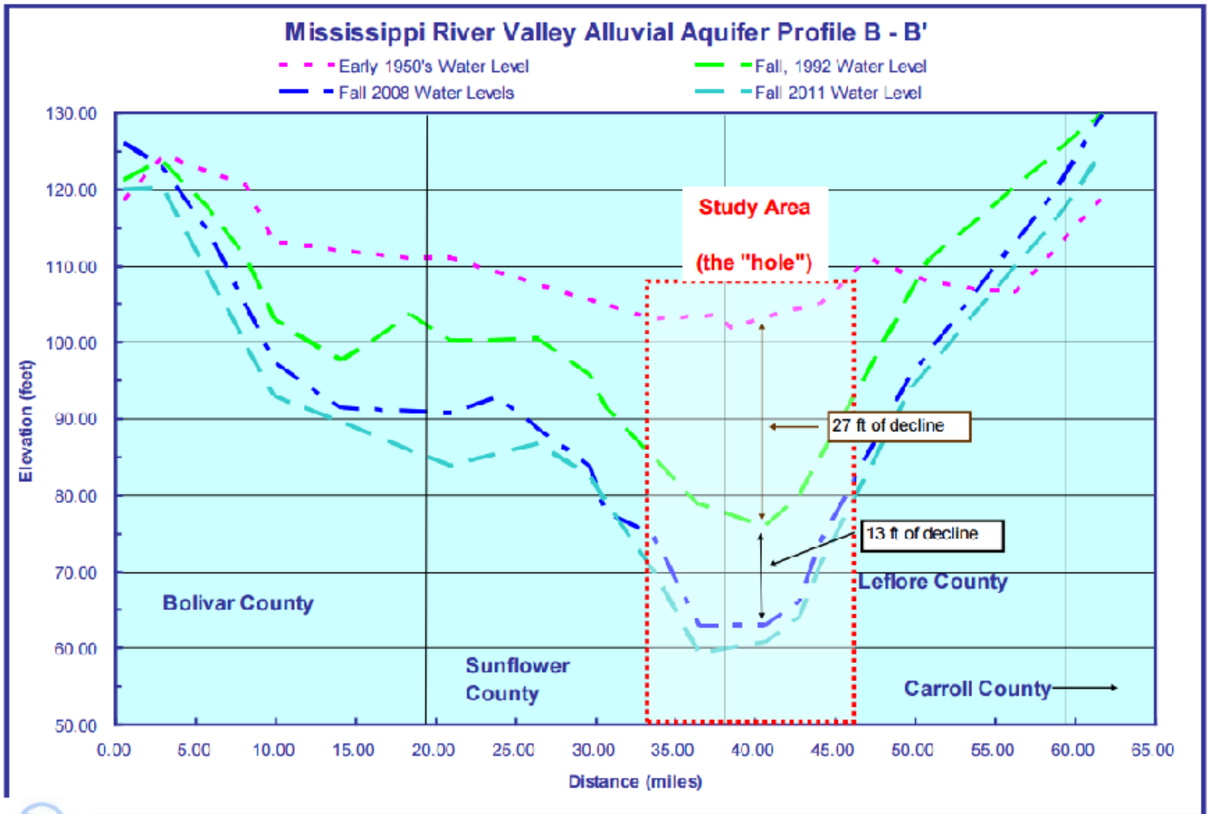


Figure 5: Heterogeneous Water Levels of MRVAA in Mississippi Delta



Courtesy of:
http://www.ymd.org/pdfs/deltawatermeetingsept2011/TuesdaySept13/10amsession/CharlotteByrdDEQ.pdf