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Economic Implications of Biological Control of *Arundo donax* in the Texas Rio Grande Basin

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Economic Implications of Biological Control of *Arundo donax* in the Texas Rio Grande Basin

ABSTRACT

Arundo donax, or giant reed, is a large, bamboo-like plant that is native to Spain and has invaded several thousand acres of the Rio Grande riparian zone in Texas and Mexico. The plant grows to over 26 feet tall, and consumes large quantities of water, estimated as an amount equivalent to about 11% of irrigation water diverted by Valley irrigation districts (i.e., some estimates are more than 5.5 acre-feet per acre). With concern of increased water demands in the Texas Lower Rio Grande Valley region, the United States Department of Agriculture, Agricultural Research Service (USDA–ARS) is investigating four herbivorous insects as potential biological control agents for *Arundo donax* to facilitate increased water supply.

This study examines selected economic implications for agricultural water users in the United States of applying these biological control agents along the Rio Grande. The research includes (a) estimating the value of the water saved due to the reduction of *Arundo donax*, (b) a benefit -cost analyses, (c) regional economic impact analyses, and (d) an estimate of the per-unit cost of water saved over a 50-year planning horizon (2009 through 2058). The model *Arundo*Econ© is used to perform a baseline deterministic analyses using low- and high-value irrigated composite acre values. That is, the saved water is initially valued based on being applied to agriculture as irrigation. Since the actual crop mix irrigated with the saved water is unknown, a range is provided by assuming all irrigated crops are "low-value," and then again by including both "low-value" and "high-value" irrigated crops.

Results of the water amount saved are 2/9 of the amount consumed, or approximately one acre-foot of water for each acre of *Arundo*. For each acre-foot of water saved, 1.85 dryland acres can be converted to low-value crop acres, and 0.71 can be converted to high-value crop acres. Regional economic results indicate a present value of farm-level benefits ranging from $98 to $160 million. Benefit-cost ratios are calculated with normalized prices and indicate a range from 4.38 to 8.81. Sensitivity analyses provide a robust set of results for *Arundo* agricultural water use, effectiveness of control agents, replacement species' water use, *Arundo* expansion rate after control, value of water, and the cost of the program.

The pre-production processes and farm-gate economic impact analyses are estimated using multipliers from the IMPLAN model. Regional results reveal a range of $9 to $18 million annually in economic output and 197 to 351 jobs associated with the increase in gross revenues due to the control of *Arundo donax* for the year 2025. Values for other select years are also provided. Further results suggest a life-cycle cost per acre-foot of water saved of $44. This amount is comparable to other projects designed to conserve water in the region.

The USDA–ARS, Weslaco, Texas *Arundo donax* biological control project will realize positive results as indicated by the benefit-cost ratios, economic impact analyses, and competitive results for the per-unit cost of saving water. These results indicate this project will have positive economic implications for the U.S. and the Texas Lower Rio Grande Valley.

Economic Implications of Biological Control of *Arundo donax* in the Texas Rio Grande Basin

INTRODUCTION

Water supply in the Texas Lower Rio Grande Valley (also referred to as the Valley) is an acute issue as the regional economy and population continue to expand at a rapid rate (U.S. Census Bureau 2000). The main source of water for this region is the Rio Grande [River] along the Texas-Mexico border, which is primarily fed by releases from two reservoirs -- Amistad, located near Del Rio, and Falcon, located south of Laredo (Rubinstein 2008). With water a high-priority issue, local water resource managers and community leaders are considering alternative methods to enhance the currently available water supply for the region. One such area of interest is control of the invasive plant species *Arundo donax,* also commonly referred to as *Arundo,* or giant reed.

*Arundo donax***, a.k.a. Giant Reed**

Arundo donax is a large, aquatic plant that is invading the riparian areas of the southwestern United States, particularly the Rio Grande Basin and California (Goolsby and Moran 2009; Tracy and DeLoach 1999), and causing damage to infrastructure, transforming habitats of riparian areas, and consuming large quantities of water (Jackson, Katagi, and Loper 2002). *Arundo donax* can grow from 20 up to 27 feet tall (Bell 1997), exhibits a growth rate approaching 4 inches a day (Dudley 1998; Hoshovsky 1986), and consumes large quantities of water (i.e., more than 5.5 acre-feet per acre of *Arundo* (Watts 2009; Iverson 1994)) to support its rapid growth rate. *Arundo* grows in thick stands, spreads through vegetative reproduction (Decruyenaere and Holt 2001), and creates areas of high density. This dense infestation not only consumes vast quantities of water, but can also deter the U.S. Border Patrol's infrared sensors from detecting movement of illegal immigrants across the Texas-Mexico border (Goolsby 2008b).

Objective and Purpose

Four insects are under consideration by scientists at United States Department of Agriculture-Agricultural Research Service (USDA–ARS) in Weslaco, Texas for release into the *Arundo*-infested areas: *Tetramesa romana* (wasp), *Rhizaspidiotus donacis* (scale), *Cryptonevra spp.* (fly), and *Lasioptera donacis* (leafminer) (Goolsby 2008b). The goal of the insects is to control the spread and mitigate the density of *Arundo,* thereby reducing its water uptake (Goolsby 2007; Goolsby 2008a): Scientists have collaborated and continue to collect the insects in Spain, where scientists believe the genotype for the *Arundo* growing along the Rio Grande Basin is native (Goolsby and Moran 2009).[1]

A primary purpose of the economic research is to estimate the economic benefits of the water saved from the reduction in the size, density, and area infested by *Arundo donax* over a 50-year period (2009 through 2058). In addition to the estimation of benefits, a comprehensive economic impact analysis for the Texas Lower Rio Grande Valley is calculated for the same time period.

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[1] The wasp was recently found living naturally in the California counties of Santa Barbara and Ventura, as well as in selected areas along the Texas Rio Grande prior to the introduction of the insect in the test (Dudley et al. 2007; Goolsby 2008b; Moran and Goolsby 2009).

Lastly, the per-unit life-cycle cost of water saved (Rister et al. 2009) via the biological control project is derived to facilitate comparisons with other study estimates of costs of water saved through Valley irrigation district rehabilitation projects (e.g., Rister, Lacewell, and Sturdivant 2007).

The economic and financial results derived in this research provide the USDA–ARS, local community leaders, U.S. and Mexico government officials, and others with information regarding the expected economic benefits of pursuing the release of the biological control agents. The basis of the economic estimates is through an anticipated increase in irrigated acres in the four lower counties of the Texas Lower Rio Grande Valley. Water saved as a result of reduced *Arundo* is expected to be used to convert dryland crop production to irrigated production and create economic activity and employment, as irrigation increases crop yields and contributes to planting additional acreage with higher-value crops. Potential benefits to Mexico are not considered.

LITERATURE REVIEW

A wide range of literature has been reviewed to develop a better understanding of the parameters surrounding the research. Although there are numerous examples of invasive plants such as hyacinth and salt cedar (Knutson 2009; Supercinski 2006; Grodowitz et. al 2000), this review and report are limited to *Arundo*. This literature review includes the biology and growth of the plant; alternatives of control and treatment of *Arundo* in limited, specific locations; economic methods used in the field of invasive species; and water valuation, impact, and benefit-cost analyses.

Giant Reed

Arundo donax is native to the Mediterranean climate (Perdue 1958), making the Rio Grande Basin of Texas ideal for establishment and expansion of the plant (Goolsby 2007; Tracy and DeLoach 1999). The *Arundo donax* of the Rio Grande Basin is dominated by one particular genotype of the reed (Goolsby and Moran 2009). Scientists are currently conducting research to determine the precise origination area of the genotype, and are focusing their efforts on areas with a climate similar to North America (e.g., Spain). While the source has not yet been precisely located, different genotypes of the host-specific wasp, *Tetramesa romana*, have been captured and tested to determine the insect's suitability as a biological control agent of giant reed in the Rio Grande Basin (Goolsby and Moran 2009).

Water Consumption

Arundo's rapid growth rate is supported by its large consumption of water. The literature that addresses the water intake of *Arundo donax* presents varied results. The "*Arundo* Removal Protocol" (Jackson, Katagi, and Loper 2002) states that the plant consumes 3,800 acre-feet of water per 1,000 acres per year, (i.e., 3.8 acre-feet of water, per acre, per year). Bell (1997) identifies a water uptake of 528 gallons per standing meter[2] of *Arundo donax* per year for California. Iverson (1994) compares *Arundo*'s water consumption to that of rice, or 5.62 acre-feet of water per acre per year. Oakins (2001), Jackson, Katagi, and Loper (2002), and Zembal and Hoffman (2000) also state giant reed consumes three times more water than typical native vegetation. A recent study by David Watts (2009) suggest *Arundo* water use at greater than 5.5 acre-feet per acre.

Insect Information

The mass release of the insects in areas along the Rio Grande, as well as its tributaries, strives for a self-sustaining *Arundo* control strategy and is predicted to increase available water supply to the Texas Lower Rio Grande Valley. The four insects considered in this control strategy all affect different aspects of the giant reed plant. *Tetramesa romana*, the non-stinging wasp, has approximately a one-month life cycle and is effective at mitigating the new growth of giant reed by ovipositing eggs into the shoot of the plant. As the eggs develop, a gall begins to form in the shoot tips of *Arundo*. Eventually the larvae (from the egg development) mature to pupae, which mature into an adult wasp. The new adult wasps then emerge by chewing exit holes in the shoot (Moran and Goolsby 2009). *Rhizaspidiotus donacis*, the scale, has a three-month life cycle and attacks the roots and the sheath of the plant (Goolsby 2007).

The fly, *Cryptonevra spp.*, also has a one-month life cycle and is similar to the wasp in the method of control. However, this insect targets the older growth rather than the new growth of the plant. Currently, details of the potential role of *Lasioptera donacis*, the leafminer, in USDA–ARS' *Arundo* biological control program are unknown, as research on this insect is still in its early stages. It is anticipated this agent will not be introduced for several years, awaiting stabilization and efficacy results for the wasp and the scale. That is, the protocols and timing thereof for introducing the fly and the leafminer into the total control program are yet to be determined (Goolsby 2009).

Arundo Impacts

Arundo donax imposes a variety of costs on a region due to its growth and expansion attributes. In addition to the high-water consumption rate, giant reed is responsible for changing the landscape of the riparian. The growth of the plant causes a faster, narrower stream flow, reducing water recreation, and ultimately, undercutting the banks of the river (Oakins 2001). When undercutting occurs, large stands of *Arundo* break away from the bank and float to infrastructure downstream, often causing damage to bridges, roads, and water intake facilities (Dudley et al. 2007). In addition, the reduction in native vegetation causes the canopy structure to diminish around the stream, as over-hanging trees no longer exist to provide shade over the water. The reduced canopy exposes the river to more sunlight and creates a higher pH level in the water, affecting fish and other wildlife native to the area (McGaugh et al. 2006; Bell 1993). These changes to the natural habitat are also an area of concern for the endangered Ocelot, located in the Big Bend area (Dudley et al. 2007).

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[2] Standing meter is interpreted as a square meter of standing *Arundo*. Based on the height and density estimations per hectare and perceptions of existing acres of *Arundo* received from the USDA–ARS for the Rio Grande Valley, the interpretation of 528 gallons per standing meter of biomass mathematically results in the plant consuming more water than actually flows through the Rio Grande. When the data are interpreted at 528 gallons per square meter of standing *Arundo*, water estimates appear in the same range as other estimates for *Arundo* water use (i.e., 3.8 acre-feet (Jackson, Katagi, and Loper 2002), more than 5.5 acre-feet (Watts 2009; Iverson 1994)).

Economic Literature

Measuring the value of water is a key issue in determining the economic implications of saved water. Kaiser and Roumasset (1999) state in a working paper that water is usually undervalued and underpriced. Water markets increase the efficiency of pricing water; however, the actual value of water is still difficult to obtain from the market (Griffin 2006; Kaiser and Roumasset 1999). In agriculture, however, many variables ultimately influence crop yields (e.g., changes in technology, inputs, weather, etc.). Thus, the value measured for water may also include other exogenous variables (Ward and Michelsen 2002). Additionally, water is a public good, used by the entire population; therefore, the valuation must include social aspects to account for the impact to the public.

The Valley is unique in that a water market exists without creating water-right problems or other issues for individuals downstream; i.e., the region includes the terminus of the Rio Grande. Consequently, no other users exist below the water market area (Griffin 2006). Further, drainage is away from the Rio Grande and to the Gulf of Mexico with the River receiving no return flows, eliminating third-party effects in other irrigated or municipal regions.

Agriculture Composite Acre

Water valuation methods using crop enterprise budgets are outlined in Gibbons (1986) and are commonly used in agricultural economic analyses for the U.S. Army Corps of Engineers (Lacewell 2008). In Sturdivant et al. (2004), a composite agriculture crop acre is developed and applied to calculate the benefits to agriculture of flood-control infrastructure along the Rio Grande. In this study, the composite acre is a reflection of the irrigated and dryland cropping patterns in the Texas Lower Rio Grande Valley. Returns to land are estimated for a composite dryland acre and returns to land and water are identified for an irrigated composite acre.

Lacewell and Freeman (1990) outline the use of the composite acre for crop yields based on soil composition in "ABE: Agricultural Benefits Estimator." Further use of the composite acre for soil type and the Agricultural Benefits Estimator is documented in Lacewell et al. (1995), in association with the reports for the agricultural benefits of drainage and flood-control projects. This study defines the composite acre as a representative acre of soil type and crops in the study area. The composite acre includes a weighted proportion of the differing soil types and allows estimation of a weighted proportion of yields for regional crops. The study also uses (a) enterprise crop budgets to calculate net returns by crop for the farmer, (b) normalized prices generated by the United States Department of Agriculture-Economic Research Service to calculate the benefits to society and benefit-cost ratios, and (c) present values discounted at 7.75% over 50 years to calculate the present value of the benefits to society. The study also takes into account risk and performs a sensitivity analysis to account for data input uncertainty.

Economic Impact Analysis

Economic impact analysis is a method to determine how changes in demand for one industry or economic sector affect the economy (Jenson 2001). The analyses are based on input-output models, or models that create a "framework" into which data can be "collected, categorized, and analyzed" (Shaffer, Deller, and Marcouiller 2004). The input-output model is based on the supply and demand relationship for a particular commodity (Deller 2004). The structural approach of cause and effect allows for the determination of the impacts to the economy due to changes in consumption, demand, government policies, etc. (Shaffer, Deller, and Marcouiller 2004).

The concept of using input-output models as a predictive measure for an economy's response to a "shock" in a sector was developed by Wassily Leontief in the 1930s (Shaffer, Deller, and Marcouiller 2004). In the paper "Estimating the Economic Impact of Disease on a Local Economy: The Case of Diabetes in the Lower Rio Grande Valley of Texas," Estrada, Brown, and Hazarika (2005) examine the possible economic impacts associated with loss of work and wages for individuals with diabetes in the region. There are numerous other examples of impact analysis.

Input-output analyses rely on several crucial assumptions to generate economic impact results. Two main assumptions include (a) constant returns to scale, indicating linear production functions, and (b) an equilibrium state between inputs used and output produced (Shaffer, Deller, and Marcouiller 2004). The IMPLAN model, which includes 509 North American Industry Classification System (NAICS) sectors, can be used to estimate economic multipliers depicting the economic impact (including economic output, value-added, and employment for a designated county, region, or state) from a change in a contributing activity or shock scenario. Additionally, the model assumes resources are unlimited, i.e., in the model, firms will be able to obtain more inputs, even if in reality, the inputs are not available (Minnesota IMPLAN Group, Inc. 2004).

The economic output multiplier measures the change in sales due to the change in activity (i.e., increased water) and includes purchases from one sector to another. The value-added multiplier measures the contribution to gross domestic product (GDP) resulting from the change in activity, and the employment multiplier measures the number of jobs associated with the change in activity (Miller and Armbruster 2003; Coppedge 2003). Value-added (GDP) is equivalent to the value of production for a sector minues its intermediate inputs purchased from other industries. These multipliers only capture the backward linkages (i.e., sectors up to and including the farm level) and do not include forward linkages (i.e., further processing) (Minnesota IMPLAN Group, Inc. 2004).[3]

Per-Unit Cost of Water Conserved

In the "Economic and Financial Methodology for South Texas Irrigation Projects-RGIDECON©," Rister et al. (2009) documented the methodology used to determine the cost per acre-foot of water saved. To determine the cost per acre-foot, annuity equivalents were estimated for both a program's cost stream and the acre-feet of water saved. Dividing the annuity equivalent of the cost stream by the annuity equivalent of the water saved from the construction and implementation of a project results in the estimated cost per acre-foot of water saved. The water amounts can also be converted to 1,000 gallon units, and subsequently, the cost per 1,000 gallons can be calculated (Rister et al. 2009).

Rister et al.'s (2009) methodology has been used to estimate costs per acre-foot of water saved for several irrigation district rehabilitation projects in the Texas Lower Rio Grande Valley over 2002-2007, where the projects were designed to increase the water supply to the region. The cost

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[3] Further data is needed from further processing businesses to accurately reflect the further processing sector for the region.

of saving water with rehabilitation projects in the Valley range from $12-$427 per acre-foot, averaging $45 per acre-foot. Such projects include canal lining, installation of meters and telemetry, and installation of pipelines, among others. These projects are associated with raw water, i.e., water which has not undergone any purification treatment. Thus, the cost per acre-foot of raw water savings associated with the Valley irrigation district rehabilitation projects (Sturdivant et al. 2007) is used as a comparison to the cost per-acre foot of water saved as a result of the *Arundo* biological control program.

Benefit-Cost Analysis

Benefit-cost analysis is a tool helpful in determining a return on the social investment of implementing certain policies/projects and is used in determining the economics of many federal water projects (U.S. Water Resources Council 1983). This tool allows for the identification of the present value of benefits and costs to determine the social impacts of a particular policy or project. It shows the sensitivity of assumptions in relation to results and is required by the federal government for proposed regulations, as well as large water projects (Hahn and Dudley 2007).

Griffin and Stoll (1983) identify the importance of using a benefit-cost analysis when comparing benefits and costs over time. In a benefit-cost analysis, the benefits are summed over time and discounted at a determined rate. The present value of costs are determined in the same manner. The present value of benefits is then divided by the present value of costs, resulting in a benefit-cost ratio. Any ratio greater than one indicates the project has positive economic returns. A ratio of less than one indicates the project is not economically feasible (Griffin and Stoll 1983; Griffin 2006; Tietenberg 2006).

METHODOLOGY

Due to the multi-disciplinary nature and early stages of this project, a form of the Delphi technique (Dalkey 1969) was employed to estimate certain data (e.g., efficacy of biological control) which are not precisely known. Other data, such as the current acreage infested with giant reed, are based on the spatial quantification of aerial photos (Yang 2008). This research is directed to estimating unimpeded *Arundo* acreage expansion and then anticipated effects of control including water savings, and associated economic and financial implications of the USDA–ARS, Weslaco, Texas *Arundo donax* biological control project. Because the evaluation, release, and effectiveness of the biological control agents remain under investigation, the results presented herein are considered preliminary.

USDA–ARS scientist Chenghai Yang provided data for estimated *Arundo* infested acres on both the U.S. and Mexico sides of the River along the 530 miles between San Ignacio and Lajitas, Texas (**Figure 1**): Estimated acres were 15,715 for 2002 and 18,072 acres for 2008, with a total expansion rate of 15% over the six-year time period (Yang 2008). Distributing the growth equally among the years and assuming a geometric growth rate suggests an annual growth rate of 2.36%.[4] This yearly rate is adopted and used to linearly forecast expected annual growth for each of the 50 years in the planning horizon (2009 through 2058); the annual forecast acres represent

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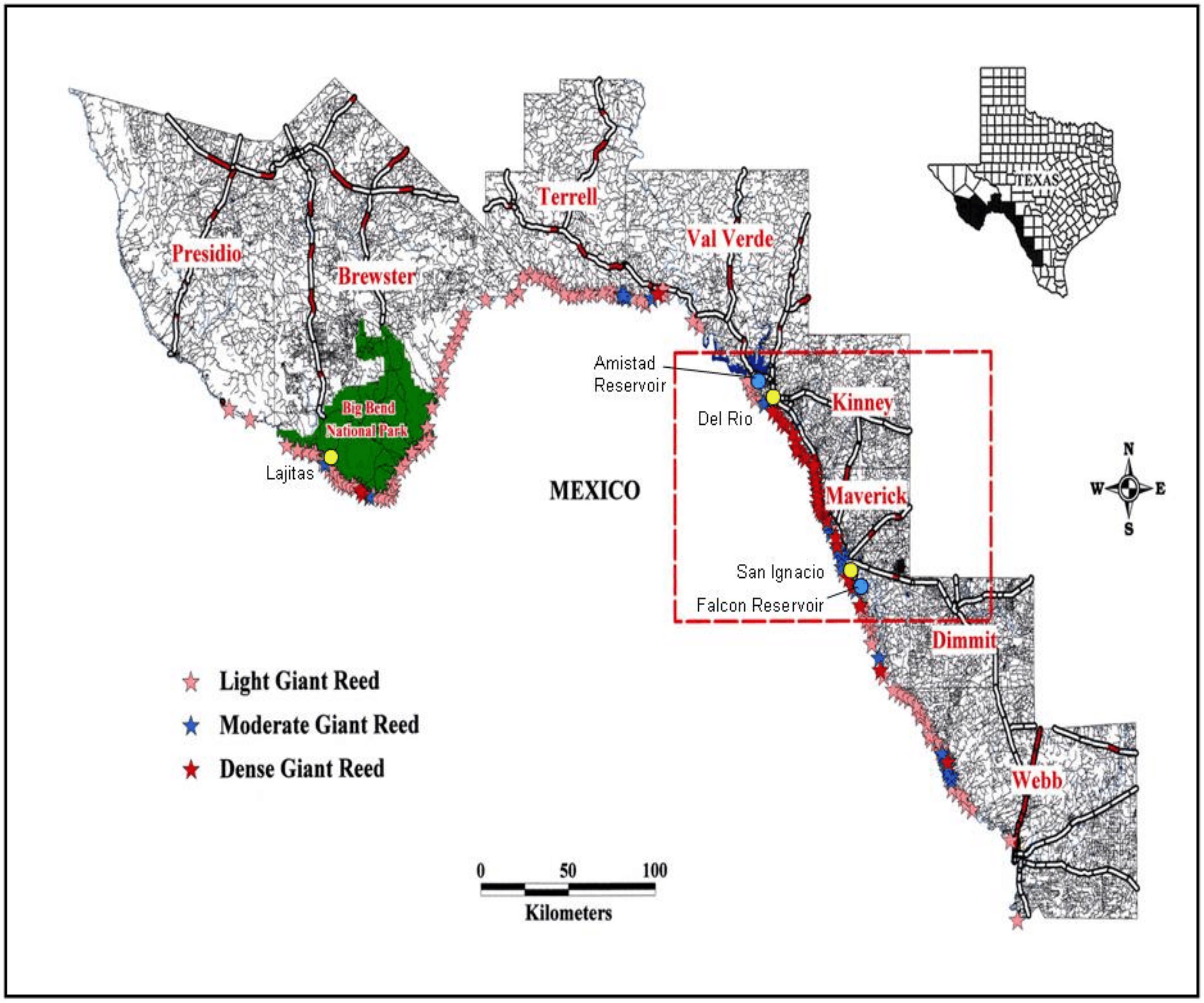
[4] 15% = $(1+0.0236)^6$-1.0, with 6 representing the number of years of growth between 2002 and 2008.

the baseline scenario used to estimate impacts of *Arundo* control. USDA–ARS scientists estimate that 80% of the *Arundo donax* infestation occurs between San Ignacio and Del Rio, while the remaining 20% of the infestation occurs between Del Rio and Lajitas (Yang 2008) (**Figure 1**). Recognizing the study area of the biological control agents for the USDA–ARS project occurs solely in the 170 river miles between San Ignacio and Del Rio, Texas, this analysis is limited to the riparian area of these 170 miles of the Rio Grande.[5]



Source: Modified from Everitt et al. 2004.

Figure 1. Map of the Rio Grande Showing the Study Area of the USDA–ARS, Weslaco, Texas *Arundo donax* Biological Control Program, 2009

In 2007, a natural occurrence of *Tetramesa romana* (the wasp, one of the four insects selected for biological control) was discovered near Laredo, Texas (Goolsby and Moran 2009), possibly impacting the future expansion of *Arundo donax*. The USDA–ARS provided an estimate of approximately 5% control of the giant reed in a restricted section approximately one mile long (Goolsby 2008b) to account for the impact of the natural wasp infestation at Laredo. The

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[5] Any incidental control and benefits realized in the 360-miles between Del Rio and Lajitas, Texas are not included in this research.

natural-control effect in this limited section is assumed to be evenly distributed between San Ignacio and Del Rio. The distributed effect is multiplied by the number of *Arundo donax* acres between San Ignacio and Del Rio to obtain the revised/adjusted baseline acres used for the economic analyses.

Although the mathematical results in this analysis identify water saved from the expected reduction of *Arundo donax* acres, actual reduction of *Arundo* from the biological agents' release will not likely occur only in the form of fewer existing acres, but rather also in the form of a reduction in the density and height of the plant. With the biological control, however, some reduction in acreage from the projected baseline is expected. This study uses calculated, reduced acres as a proxy for reduction in *Arundo* biomass. This proxy is based on mathematics and is an assumption of convenience for the analysis, and assumes the analytical results are comparable to reality.

Biological Control Protocol

All costs, past, current, and expected, for the biological control program are estimated by USDA–ARS scientists at Weslaco, Texas. The expected amount of biological control of *Arundo* due to the release of *Tetramesa romana* (the wasp) and *Rhizaspidiotus donacis* (the scale) along the Rio Grande is directly related to the available funds. Release of the biological control agents began in year 2009 (Year 1 of treatment/control) and continue through 2014 (Year 6 of treatment/control), with residual effects of the 2014 treatment occurring in 2015. The program is projected, therefore, to treat one mile in Year 1, 11.27 miles in Year 2, 22.53 miles in Year 3, 33.80 miles in Year 4, 45.07 miles in Year 5, and 56.33 miles in Year 6. Release of the wasp has been implemented as of April 2009.

Control Effectiveness

After estimating the area of control, the efficacy of the insects (i.e., control effectiveness) is estimated. Based on observed success in the quarantine facilities, the USDA–ARS scientists estimate the treated acres within the specified zone will experience 45% control during the first year of treatment, followed by 22% residual control from the section's original release in the subsequent year, for a total of 67% control over two years. Thereafter, steady state conditions are assumed (i.e., remaining stands will be fixed at 33% of original stands). Results of several sensitivity analyses are reported to examine the effects of deviations from the control assumptions of the modeling framework used.

Annual average acres of *Arundo donax* per mile are multiplied by the number of miles treated in a given year "i" to obtain the number of acres to which control is applied, or the annual treated acres. These treated acres are multiplied by the pertinent annual rate of control, with "j" representing either the first or second year of control for a specific release set of agents (Equation 1).

Equation 1: $\text{Acres Controlled}_{ij} = \text{Annual Treated Acres}_{i} * \text{Control Rate}_{j}$

The assumption of two years for the realization of the wasp's and scale's control effects on *Arundo* follows the plant's life cycle, as shoots from the plant are perennial, reach mature height within the first year of growth (Rieger and Kreager 1989), and become lignified as the first growing season ends and fall begins, i.e., the shoot reaches maturity in one to two years (Decruyenaere and Holt 2001). The assumed total 67% control rate also relates to regions of the world where *Arundo* stands have experienced the emergence of herbivory control (e.g., insects, aphids, etc., mitigating the growth of the plant) that evolved to maintain the plant at about 1/3, or 33%, of its potential (Goolsby 2008a).

Potential Water Saved

Water is stored at Amistad Reservoir and only released to Falcon Reservoir when required to meet a water request from downstream agricultural, municipal, and industry users. Thus, any added water from *Arundo* control downstream from Amistad Reservoir allows for water to remain in Amistad Reservoir longer, reducing the Falcon Reservoir losses (occurring via evaporation and seepage), suggesting all "saved" water as a result of *Arundo* control is available and will not be lost to conveyance or percolation as these losses already occur (Rubinstein 2008).

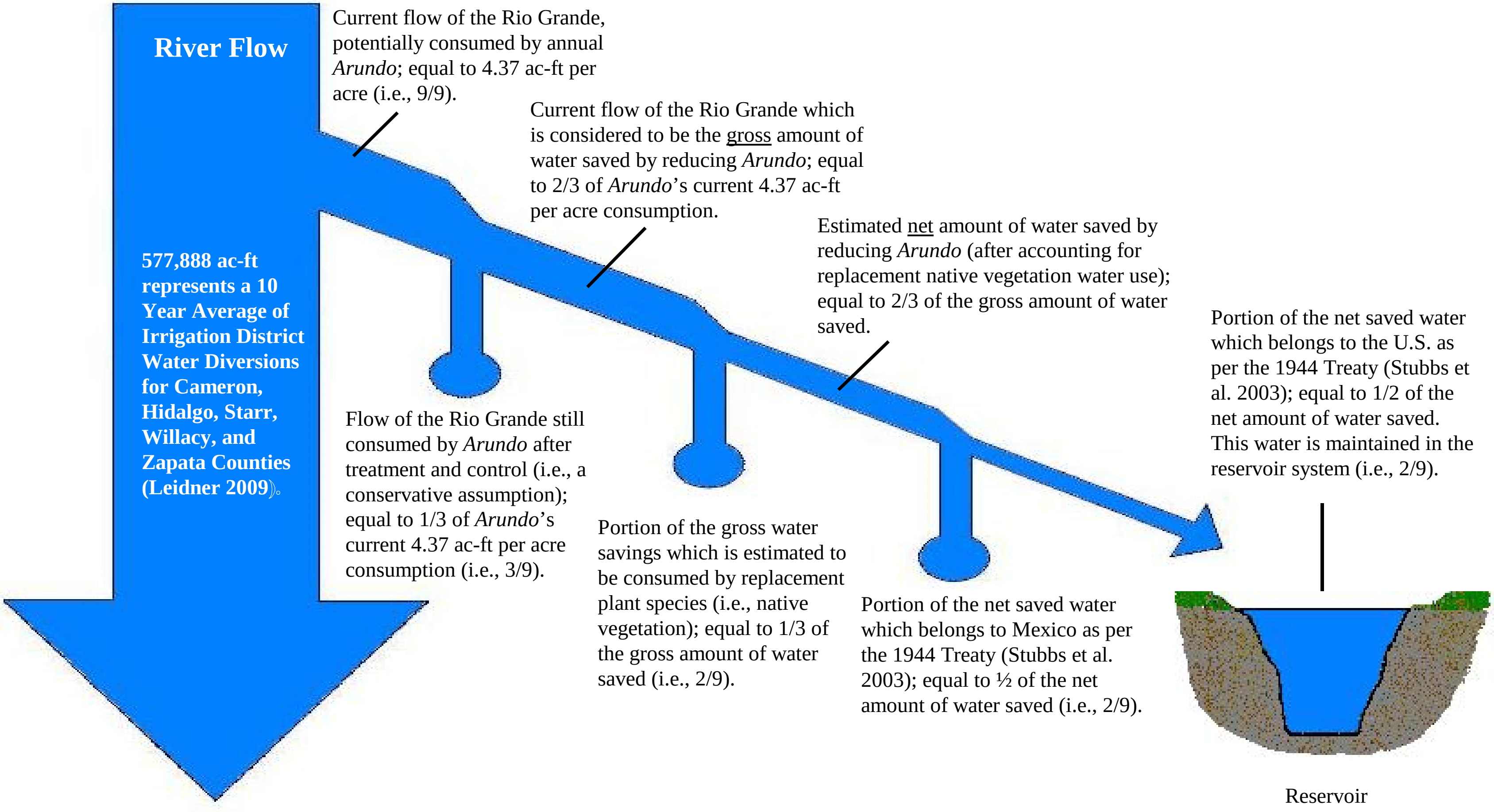
The annual difference between the untreated baseline acreage situation and the reduced treatment acres is calculated to obtain the number of *Arundo* acres eliminated/prevented through the use of biological control agents. The cumulative number of acres prevented each year are multiplied by the amount of *Arundo* water use per acre to obtain the gross annual amount of water saved. That is, the level of *Arundo* water consumption reported in the literature is applied to the estimate of reduced acreage of giant reed to project the gross amount of potential water saved as a result of the biological control program.

Figure 2 is an illustration of the Rio Grande water flow, acknowledging *Arundo*'s current assumed consumption of 4.37 acre-feet per acre of infestation with a visual focus on the expected effects of the biological control program. The assumption of 67% control of *Arundo* leads to water saved of 67% of the 4.37 acre-feet. The revised use of this 67% water saved is a distribution from *Arundo* to (a) replacement, native vegetation, (b) Mexico, and (c) U.S. (Texas) irrigated agriculture. Under the assumption of this study, replacement native vegetation is assumed to emerge in the acres cleared of *Arundo* and use 1/3 of the original *Arundo* water uptake for the area. The remaining water saved is divided equally between the U.S. and Mexico. Consequently, added, effective value for the U.S. is realized for only 2/9 of the original 4.37 acre-feet consumed per acre of *Arundo* (**Figure 2**).

According to Leidner (2009), an average of 577,888 acre-feet of water are diverted each year to irrigation districts for Cameron, Hidalgo, Starr, Willacy, and Zapata counties. The current 14,453 acres of *Arundo* in the 170-mile reach of the Rio Grande between San Ignacio and Del Rio, Texas, consumes an amount of water equivalent to 10.93% of the irrigation water diverted by Valley irrigation districts, assuming *Arundo*'s annual 4.37 acre-feet per acre water consumption.

Economic Analysis

The focus of this study is the economic and financial implications of the USDA–ARS, Weslaco, Texas biological control program directed to *Arundo donax* in the Rio Grande Basin. Because the net water saved is assumed to be used to increase Texas irrigated acreage through the conversion of dryland agricultural acreage, a composite acre is developed to reflect the average



577,888 ac-ft represents a 10 Year Average of Irrigation District Water Diversions for Cameron, Hidalgo, Starr, Willacy, and Zapata Counties (Leidner 2009).

Current flow of the Rio Grande, potentially consumed by annual *Arundo*; equal to 4.37 ac-ft per acre (i.e., 9/9).

Current flow of the Rio Grande which is considered to be the <u>gross</u> amount of water saved by reducing *Arundo*; equal to 2/3 of *Arundo*'s current 4.37 ac-ft per acre consumption.

Estimated <u>net</u> amount of water saved by reducing *Arundo* (after accounting for replacement native vegetation water use); equal to 2/3 of the gross amount of water saved.

Portion of the net saved water which belongs to the U.S. as per the 1944 Treaty (Stubbs et al. 2003); equal to 1/2 of the net amount of water saved. This water is maintained in the reservoir system (i.e., 2/9).

Flow of the Rio Grande still consumed by *Arundo* after treatment and control (i.e., a conservative assumption); equal to 1/3 of *Arundo*'s current 4.37 ac-ft per acre consumption (i.e., 3/9).

Portion of the gross water savings which is estimated to be consumed by replacement plant species (i.e., native vegetation); equal to 1/3 of the gross amount of water saved (i.e., 2/9).

Portion of the net saved water which belongs to Mexico as per the 1944 Treaty (Stubbs et al. 2003); equal to ½ of the net amount of water saved (i.e., 2/9).

Figure 2. Illustration of the divisions of current water use in the Rio Grande Basin as a result of the USDA–ARS, Weslaco, Texas *Arundo donax* biological control program, 2009

aggregate effects of additional irrigated acreage, accounting for variations in water intake and profitability across the different crops.

A composite acre is developed for both low- and high-value[6] irrigated crops to determine the net returns to water, using both market and normalized prices.[7] Low-value irrigated crops are cotton, sorghum, and corn while high-value irrigated crops also include vegetables, sugarcane, and citrus. Both market prices and normalized prices are applied, with normalized prices used to account for significant price fluctuations in the short term (Roberts 2007), as well as for removing the effects of federal government farm programs. A composite acre is also constructed for dryland crops in the Valley. The crop based weighted dollar amounts, obtained from the Texas AgriLife Extension Crop Enterprise Budgets (2007), are then summed to obtain the net returns to land for the dryland composite acre. These values are used in conjunction with the baseline model developed for *Arundo* expansion to calculate the market benefits at the farm level, the benefits to society, and the benefit-cost, sensitivity, and economic impact.

Additionally, returns obtained from the irrigated crop budgets are used to calculate returns to land and water, as only water delivery costs (i.e., not the cost of water itself) are subtracted from the gross revenue in the Texas AgriLife Extension Service budgets (2007). The initial estimate of the value of *Arundo* control is based on the increase in returns due to the increased availability of irrigated water and conversion of dryland crops to irrigated crop acres over a 50-year planning horizon (i.e., 2009 through 2058). This net value is estimated annually, accounting for the increasing degree of *Arundo* acreage mitigation through time as a result of the biological control program.

Direct Economic Impact

Since Rio Grande Valley Basin municipalities have a legal first priority for water and receive sufficient water to meet their needs (Griffin 2006), any increase in Rio Grande water is logically used for irrigation; i.e., agriculture is the residual beneficiary of any increases in water supplies. To determine the direct impact of the saved water from the control of *Arundo donax*, the net value of water in irrigation (above what would occur under dryland production) is used as the appropriate (i.e., conservative) measure of benefits.

The values for the low- and high-value irrigated crop composite acres calculated with market prices are used to estimate a range in the direct impact (i.e., value) of additional water available to Valley farmers (**Table 1**). By multiplying the value of water for low- and high-value irrigated crop composite acres by the water saved in acre-feet, a range for the value of saved water to the Valley is obtained. That is, since the actual crop mix (with the new saved water) is unknown, a range is provided by assuming all “low-value,” and then again by assuming inclusion of “high-value” irrigated crops. The results are an estimate of the direct economic impact to the Rio Grande Valley farmers in association with the water saved due to the effectiveness of the

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[6] The high-value composite acre consists of the irrigated crops utilized for the low-value composite acre in addition to the high-value irrigated crops listed later in the paragraph.

[7] Market prices are determined by voluntary trading in a market economy (Tietenberg 2006). Normalized prices smooth seasonal price variation for each commodity (U.S. Department of Agriculture 2009) and remove any price impact due to government farm programs/subsidies. Normalized prices are typically used in determining the social benefits for agricultural projects (U.S. Department of Agriculture 2009; Miller 1980).

biological control agents.[8] These calculations are repeated for each year over 50 years, 2009 through 2058. An annual inflation rate of 2.043% (Rister et al. 2009) is used to obtain the nominal value of dollars for each year. The nominal values are then discounted by 6.125% to obtain the value of the saved water in 2009 dollars (Rister et al. 2009). The summation over 50 years of each year's total value of saved water calculated with the low-value crops represents the lower bound of the present value of saved water to the Valley over 50 years, while the upper bound is that for the inclusion of high-value irrigated crops.

Table 1. Market and Normalized Crop Prices for the Texas Rio Grande Valley[a] and the State of Texas, respectively, 2007

Commodity	Unit	Market Prices	Normalized Prices
Corn	bushel	$ 3.25	$ 2.56
Cotton Lint	lb	$ 0.55	$ 0.43
Cotton Seed[b]	ton	$ 105.45	$ 105.45
Sorghum	cwt	$ 4.80	$ 4.15
Citrus[c]	ton	$ 88.88	$ 88.88
Vegetables[d]	sack	$ 8.00	$ 8.00
Sugarcane[e]	ton	$ 26.69	$ 21.62

Source: Seawright (2009).

[a] Market prices are obtained from the 2007 Texas AgriLife Extension Service Enterprise Crop Budgets. Normalized Prices are obtained from the 2007 USDA website of normalized prices for the State of Texas. The Texas Rio Grande Valley includes the lower four Texas counties of Cameron, Hidaldo, Starr, and Willacy.

[b] The market price listed for cotton seed in the Valley was lower than the normalized price for cotton seed. Since normalized prices smooth the prices over time and remove government subsidies, the market price is assumed to be equivalent to the normalized price.

[c] Grapefruit is used as the proxy for all citrus. Additionally, no government subsidies exist for citrus; thus, the normalized price is equivalent to the market price.

[d] Onion prices are used at the proxy for vegetables prices in the Valley. Since no government programs exist for vegetables, the market price is equivalent to the normalized price.

[e] The normalized price obtained from the USDA's website appeared higher than the market price used to calculate the crop budgets. Since government programs exist for sugarcane, the normalized price should have been lower. In this case, the market price for sugar is obtained from the Rio Grande Valley Sugar Growers, Inc. (2008).

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[8] Each net acre-foot of water saved from the reduction of *Arundo* is water that can be used for irrigated crops. The net value for each acre-foot of water saved using market prices indicates a value of water saved, based on the potential returns to land and water with irrigated crops from the increase in water supply, net of the dryland composite acre value.

Benefit Cost Analysis

To estimate total social benefits, the normalized prices for corn, cotton, and sorghum obtained from the USDA–Economic Research Service (Roberts 2007) and an estimated normalized price for sugarcane are applied. The market prices for vegetables and citrus are based on the crop enterprise budgets and are used as the normalized prices, i.e., no federal government farm program subsidies exist for vegetables and citrus (**Table 1**).[9]

The present value of benefits to society over 50 years is divided by the present value of the social costs over 50 years to calculate the benefit-cost ratio. This ratio reflects the dollars of benefits per dollar of public expenditure. A benefit-cost ratio exceeding a value of one indicates benefits exceed costs to society (Griffin 2006).

Sensitivity Analyses

Sensitivity analyses of regional benefits are performed to account for uncertainty related to key data input variables used in the analyses. Sensitivity data tables for the benefit-cost ratios are calculated in which *Arundo* water use is varied while the (a) control effectiveness of the program (b) *Arundo* expansion rate after expected control, (c) natural vegetation water use, (d) value of water, or (e) costs of the program are simultaneously varied as the second variable, respectively, using the low-value irrigated composite acre.

Economic Impact Analysis

Economic impacts across the Texas Lower Rio Grande Valley, in terms of added economic activity and employment due to the projected saved water, are estimated using the IMPLAN model, Version 2.0 (2006 data). Market prices for crops are used to generate the gross revenues for each crop and to estimate the broader economic impacts to the region due to the *Arundo* biological control program.

Dividing the total volume of water saved by the composite acre water use (low- and high-value irrigated composite acre, respectively) results in the number of converted acres from dryland to low- or high-value irrigated agriculture, respectively. The change in the number of acres for the respective crops according to their proportional representation in the composite acre results in a change in gross revenue for each crop. This net change in gross revenues are deflated to 2006 dollars, to be consistent with the 2006 data in the IMPLAN model. The deflated change in gross revenues is multiplied by appropriate multipliers to generate the marginal economic impacts of the program.

Per Unit Life-Cycle Costs of Saved Water

The per-unit life-cycle cost of saved water is calculated to have a life-cycle cost value which is comparable to life-cycle costs for other programs that add water to the region's supply. These calculations are performed by dividing the annuity equivalent of program costs by the annuity equivalent of the water saved. To obtain this value, the total nominal cost of the program is discounted to 2009 dollars by 6.125% (Rister et al. 2009). Additionally, cumulative water (acre-feet) is discounted at the social discount rate of 4.00%. The annuity equivalent (value per year)

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[9] So that benefits to society are not over estimated by double counting, normalized prices are used (as opposed to market prices which are used in calculating value to agriculture). In short, normalized prices "smooth out" market price fluctuations and ignore impacts of federal programs (Lacewell 2008).

for both dollars and water is calculated over the 50-year planning horizon.[10] The values are then divided, obtaining the per-unit life-cycle cost of saving water via the biological control program.[11]

RESULTS

The results projected in this analysis indicate positive returns and impact to the Texas Lower Rio Grande Valley in association with controlling giant reed. The results can be refined with the developed model, *Arundo*Econ©, as improved input data become available.

Arundo Acres Controlled

In the absence of the biological control agents, the continued expansion of *Arundo* acres is projected. For example, without control, *Arundo* acres are projected to be 16,592 acres in 2015, 20,882, in 2025, 26,281 in 2035, 33,077 in 2045, 41,629 in 2055, and 45,640 in 2058 (**Table 2**). On the acres treated, the USDA–ARS expects 45% control from the insects during the first year of treatment, and 22% residual control during the following year, yielding a total control of two-thirds (67%) control over two years.

Table 2. Projected Beginning-Year Acres of *Arundo donax* with the Natural Wasp (*Tetramesa Romana)* Impact Between San Ignacio and Del Rio, Texas and Del Rio to Lajitas, Texas, 2009-2058[a]

Year	Acres of *Arundo*
2009	14,453
2015	16,592
2025	20,882
2035	26,281
2045	33,077
2055	41,629
2058	45,640

Source: Seawright (2009).

[a] Refer to the Map of Texas (**Figure 1**) for locations along the Rio Grande.

[b] The natural wasp (*Tetramesa romana*) was observed in a one-mile segment of the Rio Grande between Laredo and Del Rio; thus, the expansion of giant reed along the River segment between Del Rio and Lajitas, Texas is not impacted by the insect.

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[10] As noted in Rogers et al. (Forthcoming 2009), “An annuity equivalent (or ‘annualized life-cycle cost’) converts the NPV of costs for one plant, over its useful life, into a per-unit amount which assumes an infinite series of purchasing and operating similar plants into perpetuity. Reference Barry, Hopkin, and Baker (1983, p. 187) and Penson and Lins (1980, p. 97) for clarification of this concept and examples.”

[11] The water saved is raw water and does not include the cost of water delivery for irrigation at the farm level or water processing.

Once the acres in a river section have been treated with the wasp and scale, growth and expansion are assumed to be held constant thereafter for that section. The total acres controlled by segment are: 57 acres in the first (one mile) segment (treated in 2009), 657 acres in the second segment (treated in 2010), 1,344 acres in the third segment (treated in 2011), 2,063 acres in the fourth segment (treated in 2012), 2,814 acres in the fifth segment (treated in 2013), and 3,600 acres in the sixth segment (treated in 2015). The total acreage controlled is 38 acres in 2009 (Year 1), 460 acres in 2010 (Year 2), 1,118 acres in 2011 (year 3), 1,827 acres in 2012 (Year 4), 2,568 acres in 2013 (Year 5), 3,342 acres in 2014 (year 6), and 1,182 acres in 2015 (Year 7) (**Table 3**).

With the control of *Arundo* by the biological control agents, the total number of *Arundo* acres remaining at the end of 2009 (first year of treatment application) are 14,749. The anticipated 67% control of the entire study area will be reached at the end of 2015 with 5,189 acres remaining at that time. This acreage amount is projected to hold constant over the 50-year planning horizon as an equilibrium between the biological control insects and *Arundo*. This acreage is compared to the base or uncontrolled *Arundo* acres to estimate water savings.

Water Savings

The reduced *Arundo* acreage (resulting from the biological control program) is multiplied by the per acre amount of water used by *Arundo donax* (4.37 acre-feet), resulting in the expected gross amount of water saved. After accounting for water uptake from natural vegetation regrowth and Mexico's allotment, the amount of U.S. water saved in year one totals 59 acre-feet (**Table 4**).

The amount of water saved continues to increase throughout the 50-year study horizon as the acres treated and controlled increase, with 765 acre-feet saved in 2010, 2,499 acre-feet saved in 2011, 5,371 acre-feet saved in 2012, 9,471 acre-feet saved in 2013, 14,888 acre-feet saved in 2014, and 17,173 acre-feet saved in 2015 (**Table 3**). The overall control of *Arundo* in the 170-mile stretch of the Rio Grande over 50 years amounts to more than 58,000 acre-feet of water saved in year 2058 (**Table 4**). The net annual water savings for the U.S. amounts to approximately 1.0 acre-foot for each acre of *Arundo* that is controlled, i.e., 2/9 * 4.37 = 0.97.

Estimated returns to water of $187.98 per acre-foot using market prices, and $139.22 per acre-foot using normalized prices, are projected for the low-value irrigated crop composite acre (**Table 5**). Returns to water per acre-foot of the high-value irrigated crop composite acre (including corn, cotton, sorghum, citrus, vegetables, and sugarcane) are also presented in **Table 4**. For the high-value composite acre alternative, there are estimated returns to water of $307.29 per acre foot using market prices, and $279.99 per acre-foot using normalized prices. The water use per acre for low- (0.54 acre-feet per acre) versus low- and high-value crops (1.40 acre-feet per acre) impacts the number of acres converted from dryland crops to irrigated crops using the water saved from the control of giant reed. For each acre-foot of water saved, 1.85 dryland acres can be converted to low-value irrigated crops, compared to 0.71 dryland acres for low- and high-value irrigated crops.

Table 3. Rio Grande Miles Treated and *Arundo* Acres Controlled with the USDA–ARS *Arundo donax* Biological Control Program Between San Ignacio and Del Rio, Texas, 2009-2015[a]

	Arundo Acres			*Arundo* Acres					
Year	Beginning of Year	Density per Mile	Miles Treated	Acres Treated	Controlled Year 1	Residual Controlled Year 2	Total Controlled	Cumulative Controlled	Remaining After Control
2009	14,453.3	85.0	1.0	85.0	38.3	---	38.3	38.3	14,749.4
2010	14,702.6	87.0	11.3	980.2	441.1	18.7	459.8	498.0	14,608.8
2011	14,041.6	89.0	22.5	2,006.0	902.7	215.6	1,118.3	1,616.4	13,770.5
2012	12,315.7	91.1	33.8	3,078.9	1,385.5	441.3	1,826.8	3,443.2	12,158.5
2013	9,451.7	93.2	45.1	4,200.7	1,890.3	677.4	2,567.7	6,010.9	9,713.0
2014	5,373.1	95.4	56.3	5,373.1	2,417.9	924.2	3,342.0	9,352.9	6,371.0
2015	0.0	0.0	0.0	0.0[b]	0.0[b]	1,182.1	1,182.1	10,535.0	5,188.9
PROJECT TOTAL			170.0	15,724.0			10,535.0		

Source: Seawright (2009).

[a] It is anticipated there will be 45% control in the first year (*Arundo* Acres Controlled Year 1), and another 22% control in the second year (Residual *Arundo* Acres Controlled Year 2) for a total of 67% control. This process of two-year treatment stages continues along the Rio Grande for each segment treated.

[b] No acres are treated in year 2015; thus, only residual control occurs from the acres treated in the previous year.

Table 4. Annual Acre-Feet of Water Saved and Accruing to the United States with *Arundo* Control in the Rio Grande Basin, San Ignacio to Del Rio, Texas, for Select Years from 2009 through 2058

	Acre-feet of Water Saved		
Year	Gross Amount	After Subtracting Consumption by Native Vegetation	After Subtracting Mexico's Share[a]
2009	176	117	59
2010	2,294	1,529	765
2011	7,496	4,997	2,499
2012	16,114	10,743	5,371
2013	28,412	18,941	9,471
2014	44,665	29,777	14,888
2015	51,518	34,345	17,173
2025	70,701	47,134	23,567
2035	94,845	63,230	31,615
2045	125,232	83,488	41,744
2055	163,475	108,984	54,492
2058	176,772	117,848	58,924

Source: Seawright (2009).

[a] This amount of water is "saved" and available for use by U.S. (Texas) agriculture for irrigation.

Table 5. Per Acre Irrigated Crop Water Use Estimates and Returns per Acre-Foot: Low- and High-Value Irrigated Composite Acre, Texas Lower Rio Grande Valley, 2009

		Value of Water Returns to Water ($/Acre-Foot)	
Composite Acre (of irrigated crops) Value Classification	Average Water Use[a] (acre-feet per acre)	Market Prices	Normalized Prices[b]
Low-Value[c]	0.54	$ 187.98	$ 139.22
High-Value[d]	1.40	$ 307.29	$ 279.99

Source: Seawright (2009).

[a] Average water use is calculated using the crop mixes and proportions used to determine the composite acres for both low- and high-value crops.

[b] Normalized prices reflect crop prices without any effects from short-term price fluctuations or government farm programs.

[c] Low-value crops include corn, cotton, and sorghum.

[d] High-value crops include the low-value crops and sugarcane, vegetables, and citrus.

Direct Impacts (Total Value of Water Saved)

The estimated range of value for water saved and used for irrigation across the Valley is calculated by multiplying water saved by the low- and high-value irrigated crop composite acre returns to water on an annual basis. The estimated value or direct economic impact to the Rio Grande Valley of water saved using the low-value irrigated crop composite acre and market prices of crops is over $11,017 for 2009, $3.23 million in 2015, $4.43 million for 2025, $5.94 million in 2035, $7.85 million in 2045, $10.24 million in 2055, and $11.08 million in 2058 (**Table 6**). Inflated at an annual rate of 2.043% and discounted at a rate of 6.125%, the present value over 50 years in 2009 dollars is $97.80 million using low-marginal-value crops (**Table 6**). Returns to water by alternatively applying normalized crop prices is an estimated present value of $72.43 million.

Table 6. Annual Nominal Value of Water Saved on Low- and High-Value Crops Calculated with Market Prices, Texas Lower Rio Grande Valley, 2009

Year	Returns to Water Low-Value[a] ($ Million)	Returns to Water High-Value[b] ($ Million)
2009	$ 0.01	$ 0.02
2015	$ 3.23	$ 5.28
2025	$ 4.43	$ 7.24
2035	$ 5.94	$ 9.72
2045	$ 7.85	$ 12.83
2055	$ 10.24	$ 16.75
2058	$ 11.08	$ 18.11

Source: Seawright (2009).

[a] Low-value composite crop acre returns to water (cotton, corn, and sorghum).

[b] High-value composite crop acre returns to water (cotton, corn, sorghum, sugar cane, fruits, and vegetables).

Results for the high-value crops are similarly obtained, producing a total value of $18,011 for 2009, $5.28 million for 2015, $7.24 million for 2025, $9.72 million for 2035, $12.83 million for 2045, $16.75 million for 2055, and $18.11 million for 2058. The annual savings for each of the 50 years of the study horizon, inflated at an annual rate of 2.043% and discounted at 6.125%, provides a present value of $159.87 million in 2009 dollars, as shown in **Table 7**. Returns to water by alternatively applying normalized crop prices is an estimated present value of $145.67 million.

Benefit-Cost Analysis

The nature of the control protocol is dependent upon the amount of money available; therefore, the expected available annual budget is used to calculate the number of river miles treated per year during the program's development and implementation. The (nominal) costs of the program are $1.00 million for each year from 2007 to 2010, $2.00 million in year 2011, $3.00 million in year 2012, $4.00 million in year 2013, $5.00 million in year 2014, $1.50 million in year 2015, and $0.50 million in year 2016 (Goolsby 2008b). The present value of the program costs is an estimated $16.54 million, using a discount rate of 6.125% (**Table 7**).

Normalized prices are used in the benefit-cost analyses to reflect the total social benefits of the saved water. Present values are estimated for the water saved with the low-value irrigated composite acre. The low-value irrigated crop mix has a present value (normalized) of $72.43 million, while the high-value irrigated crop mix present value (normalized) is $145.67 (**Table 7**). Thus, the low-value irrigated returns crop mix has a benefit-cost ratio of 4.38:1, and the high-value irrigated returns crop mix has a benefit-cost ratio of 8.81:1. That is, society is projected to experience benefits between $4.38 and $8.81 for every $1 of project costs. Since the present value of the benefits are greater than the present value of the costs (i.e., the benefit-cost ratios are greater than one), these results suggest the *Arundo* biological control project is economically viable (**Table 7**).

Table 7. Present Value of Irrigated Agriculture Returns to Saved Water due to *Arundo donax* Control Using Market and Normalized Prices, Texas Lower Rio Grande Valley, 2009-2058

Composite Acre (of irrigated crops) Value Classification	Present Value of Returns to Water (in Million $)		
	Market Prices	Normalized Prices	Benefit-Cost Ratio
Low-Value Irrigated Crop Mix	$ 97.80	$ 72.43	4.38
High-Value Irrigated Crop Mix	$ 159.87	$ 145.67	8.81
Present Value of Costs	$16.54		

Source: Seawright (2009).

Sensitivity Analyses

Sensitivity analyses are performed to account for uncertainty in selected input variables, using both low- and high-value irrigated composite crop acres (water value) with normalized prices, providing a range of values encompassing the baseline deterministic results. Normalized prices were selected as the basis for the sensitivity analyses, as they are lower than market prices and establish expected lower (i.e., conservative) bounds on estimates. These sensitivity analyses include varying the assumptions for (a) percent control from beneficial insects, (b) *Arundo* acreage expansion rate after expected control, (c) natural vegetation water use, (d) value of water, (e) costs of the program, and for all cases (f) water use rate of *Arundo*. These sensitivity results are presented in a pair-way fashion (i.e., with only two variables varying at a time): (a) water use rate of *Arundo* and (b) one of the other variables noted.

Sensitivity analyses depicting ranges in the present value of benefits, annuity equivalent of benefits, and the benefit-cost ratio for both low- and high-value irrigated crops are provided for the combination of *Arundo* water use and the percent of *Arundo* controlled by the release of the beneficial insects. Additional sensitivity analyses on other key data-input variables depict a range in the benefit-cost ratio of low-value irrigated crops.[12]

Amount of Water Consumed by Arundo and Efficacy of Biological Control Agents

In **Tables 7**, **8**, and **9**, the amount of water consumed by *Arundo* is varied about the baseline, 4.37 acre-feet per year (across the top row), and the efficacy of the biological control agents is varied about the expected 67% total control from the release of the biological agents (down the left column). These variations are performed for both low- and high-value irrigated crop mixes in the upper and lower halves of the tables, respectively. The baseline deterministic values calculated in the model are bold and located in the shaded cells.

Presented in the top-half of **Table 8** is the range of the 2009 low-value irrigated composite acre crop present value of expected benefits from varying the amount of water consumed by *Arundo* and the control efficacy of the beneficial insects. The present value (benefits) results of the *Arundo* biological control program's effects over 2009 through 2058 ***range from $25.83 million*** at 40% control from the beneficial insects with 2.00 acre-feet of water consumed by *Arundo* ***to $128.37 million*** at 80% control efficacy from the beneficial insects and *Arundo* water use at 7.00 acre-feet per year in 2009.

Also presented at the lower-half of **Table 8** is the range in the 2009 high-value irrigated composite acre crop present value of expected benefits from varying *Arundo* water use and the control efficacy of the beneficial insects. The high-value irrigated crop (composite acre) results of the program ***range from $51.94 million*** at 40% control from the beneficial insects with 2.00 acre-feet of water consumed by *Arundo* ***to $258.16 million*** at 80% control efficacy from the beneficial insects and *Arundo* water use at 7.00 acre-feet per year.

Overall, the program produces positive expected benefits for the Texas Lower Rio Grande Valley, ranging from $25.83 million and $258.16 million in 2009. These expected benefits depend on *Arundo*'s water consumption rate, the efficacy of the insects, and the irrigated crop mix (acres converted from dryland to irrigated). As expected, less water consumed by *Arundo* and decreased efficacy of the biological control agents produces smaller total expected benefits of the control program. To the contrary, the highest expected benefits are produced with the greatest level of *Arundo* water consumption combined with the highest efficacy rate of the biological control agents in the scenarios considered.

The annuity equivalents (i.e., annual amounts) of benefits for the low-value irrigated crops from varying the *Arundo* water use and the efficacy of the biological control agents are identified in the top-half of **Table 9**. The results ***range from $1.67 million per year*** at 40% control efficacy from the beneficial insects and *Arundo* water use at 2.00 acre-feet of water per year ***to $8.29 million*** at 80% control efficacy from the beneficial insects and *Arundo* water use of 7.00 acre-feet per year in 2009 dollars.

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[12] It is anticipated that the low-value irrigated crops are the likely recipients of any additional water to the Texas Lower Rio Grande Valley region, as high-value irrigated crops experience higher returns and thus, are assumed to already receive the necessary water amount to produce maximum yields.

Table 8. Sensitivity Analysis, Present Value ($ Million) of Benefits with Variations in Annual Water Consumption of *Arundo* and Control Rate from Beneficial Insects (Total %), Using Normalized Prices, with Low- and High-Value Irrigated Crops in the Texas Lower Rio Grande Valley, 2009[a]

Low-Value Irrigated Crop Composite Acre		variation in annual water consumption (ac-ft)						
		-2.37	-1.37	-0.37	0	0.63	1.63	2.63
		Annual Water Consumption of *Arundo* (ac-ft/year)						
		2.00	3.00	4.00	**4.37**	5.00	6.00	7.00
Control Rate from Beneficial Insects (Total %)	40.00 %	$25.83	$38.74	$51.65	$56.43	$64.56	$77.48	$90.39
	50.00 %	$28.54	$42.81	$57.08	$62.36	$71.35	$85.61	$99.88
	60.00 %	$31.25	$46.87	$62.50	$68.28	$78.13	$93.75	$109.38
	67.00 %	$33.15	$49.72	$66.30	**$72.43**	$82.87	$99.45	$116.02
	70.00 %	$33.96	$50.95	$67.93	$74.21	$84.91	$101.89	$118.87
	75.00 %	$35.32	$52.98	$70.64	$77.17	$88.30	$105.96	$123.62
	80.00 %	$36.67	$55.02	$73.35	$80.14	$91.69	$110.03	$128.37

High-Value Irrigated Crop Composite Acre		Annual Water Consumption of *Arundo* (ac-ft/year)						
		2.00	3.00	4.00	**4.37**	5.00	6.00	7.00
Control Rate from Beneficial Insects (Total %)	40.0 %	$51.94	$77.91	$103.87	$113.48	$129.84	$155.81	$181.78
	50.0 %	$57.39	$86.09	$114.79	$125.40	$143.48	$172.18	$200.87
	60.0 %	$62.85	$94.27	$125.70	$137.32	$157.12	$188.55	$219.97
	67.0%	$66.67	$100.00	$133.34	**$145.67**	$166.67	$200.00	$233.34
	70.0 %	$68.30	$102.46	$136.61	$149.25	$170.76	$204.91	$239.07
	75.0 %	$71.03	$106.55	$142.06	$155.21	$177.58	$213.10	$248.61
	80.0 %	$73.76	$110.64	$147.52	$161.17	$184.40	$221.28	$258.16

Source: Seawright (2009).

[a] The value for which the corresponding background is shaded are associated with the assumptions embedded in the baseline scenario.

Table 9. Sensitivity Analysis, Annuity Equivalent ($ million/year) of Benefits with Variations in Annual Water Consumption of *Arundo* and Control Rate from Beneficial Insects (Total %), Using Normalized Prices, with Low- and High-Value Irrigated Crops in the Texas Lower Rio Grande Valley, 2009[a]

Low-Value Irrigated Crop Composite Acre		variation in annual water consumption (ac-ft)						
		-2.37	-1.37	-0.37	0	0.63	1.63	2.63
		Annual Water Consumption of *Arundo* (ac-ft/year)						
		2.00	3.00	4.00	**4.37**	5.00	6.00	7.00
Control Rate from Beneficial Insects (Total %)	40.00 %	$1.67	$2.50	$3.33	$3.64	$4.17	$5.00	$5.83
	50.00 %	$1.84	$2.76	$3.68	$4.03	$4.61	$5.53	$6.45
	60.00 %	$2.02	$3.3	$4.03	$4.41	$5.04	$6.05	$7.06
	67.00 %	$2.14	$3.21	$4.28	**$4.68**	$5.35	$6.42	$7.49
	70.00 %	$2.19	$3.29	$4.39	$4.79	$5.48	$6.58	$7.67
	75.00 %	$2.28	$3.42	$4.56	$4.98	$5.70	$6.84	$7.98
	80.00 %	$2.37	$3.55	$4.74	$5.17	$5.92	$7.10	$8.29

High-Value Irrigated Crop Composite Acre		Annual Water Consumption of *Arundo* (ac-ft/year)						
		2.00	3.00	4.00	**4.37**	5.00	6.00	7.00
Control Rate from Beneficial Insects (Total %)	40.00 %	$3.35	$5.03	$6.71	$7.33	$8.38	$10.06	$11.73
	50.00 %	$3.70	$5.56	$7.41	$8.10	$9.26	$11.11	$12.97
	60.00 %	$4.06	$6.09	$8.11	$8.86	$10.14	$12.17	$14.20
	67.00 %	$4.30	$6.46	$8.61	**$9.40**	$10.76	$12.91	$15.06
	70.00 %	$4.41	$6.61	$8.82	$9.63	$11.02	$13.23	$15.43
	75.00 %	$4.59	$6.88	$9.17	$10.02	$11.46	$13.76	$16.05
	80.00 %	$4.76	$7.14	$9.52	$10.40	$11.90	$14.28	$16.67

Source: Seawright (2009).

[a] The value for which the corresponding background is shaded are associated with the assumptions embedded in the baseline scenario.

Table 10. Sensitivity Analysis, Benefit-Cost Ratio of Benefits with Variations in Annual Water Consumption of *Arundo* and Control Rate from Beneficial Insects (Total %), Using Normalized Prices, with Low- and High-Value Irrigated Crops in the Texas Lower Rio Grande Valley, 2009[a]

Low-Value Irrigated Crop Composite Acre		variation in annual water consumption (ac-ft)						
		-2.37	-1.37	-0.37	0	0.63	1.63	2.63
		Annual Water Consumption of *Arundo* (ac-ft/year)						
		2.00	3.00	4.00	**4.37**	5.00	6.00	7.00
Control Rate from Beneficial Insects (Total %)	40.00 %	1.56	2.34	3.12	3.41	3.90	4.68	5.47
	50.00 %	1.73	2.59	3.45	3.77	4.31	5.18	6.04
	60.00 %	1.89	2.83	3.78	4.13	4.72	5.67	6.61
	67.00 %	2.00	3.01	4.01	**4.38**	5.01	6.01	7.02
	70.00 %	2.05	3.08	4.11	4.49	5.13	6.16	7.19
	75.00 %	2.14	3.20	4.27	4.67	5.34	6.41	7.48
	80.00 %	2.22	3.33	4.44	4.85	5.54	6.65	7.76

High-Value Irrigated Crop Composite Acre		Annual Water Consumption of *Arundo* (ac-ft/year)						
		2.00	3.00	4.00	**4.37**	5.00	6.00	7.00
Control Rate from Beneficial Insects (Total %)	40.00 %	3.14	4.71	6.28	6.86	7.85	9.42	10.99
	50.00 %	3.47	5.21	6.94	7.58	8.68	10.41	12.15
	60.00 %	3.80	5.70	7.60	8.30	9.50	11.40	13.30
	67.00 %	4.03	6.05	8.06	**8.81**	10.08	12.09	14.11
	70.00 %	4.13	6.20	8.26	9.02	10.33	12.39	14.46
	75.00 %	4.30	6.44	8.59	9.39	10.74	12.89	15.03
	80.00 %	4.46	6.69	8.92	9.75	11.15	13.38	15.61

Source: Seawright (2009).

[a] The value for which the corresponding background is shaded are associated with the assumptions embedded in the baseline scenario.

For the high-value irrigated crops (in the composite acre), the annuity equivalents from varying the *Arundo* water use and the efficacy of the biological control agents are presented in the lower-half of **Table 9**. These annual values ***range from $3.35 million*** at 40% control efficacy from the beneficial insects and *Arundo* water use at 2.00 acre-feet of water per year ***to $16.67 million*** at 80% control efficacy and *Arundo* water use of 7.00 acre-feet per year.

Overall, the benefits of the program range between $1.67 million and $16.67 million annually, depending on *Arundo*'s water consumption rate, the efficacy of the insects, and the irrigated crop mix (acres converted from dryland to irrigated). Actual realized benefits are expected to fall in this range. As expected, less water consumed by *Arundo* and decreased efficacy of the biological control agents produces smaller annual expected benefits of the control program. In contrast, the highest annual expected benefits are produced with the greatest level of *Arundo* water consumption combined with the highest efficacy rate of the biological control agents in the scenarios considered.

The benefit-cost ratio is presented in **Table 10** for the low-value irrigated crops due to varying the *Arundo* water use rate and the efficacy of the biological control agents. The ratio ***ranges from 1.56:1*** at 40% control efficacy from the beneficial insects with *Arundo* water use at 2.00 acre-feet of water per year ***to a ratio of 7.76:1*** at 80% control efficacy from the beneficial insects and *Arundo* water use of 7.00 acre-feet per year. At the lowest, most conservative set of assumptions examined in this analysis, *the return on the project would be $1.56 for every $1.00 of resources invested by the public sector, indicating the project is feasible.*

The benefit-cost ratio of the high-value irrigated crops ***ranges from 3.14:1*** at 40% control efficacy from the beneficial insects with *Arundo* water use at 2.00 acre-feet of water per year ***to a ratio of 15.61:1*** at 80% control efficacy from the beneficial insects and *Arundo* water use of 7.00 acre-feet per year. With the most conservative scenario examined, *the return on the project would be $3.14 for every $1.00 of money invested by the public, indicating the project is feasible.*

Overall, the benefits of the program range from $1.56 to $15.61 for every $1 of public funds expended, depending on *Arundo*'s water consumption rate, the efficacy of the insects, and the new adopted crop mix (acres converted from dryland to irrigated). This range indicates a positive net outcome in all scenarios indicated. Actual realized benefits are expected to fall in this range. As expected, less water consumed by *Arundo* and decreased efficacy of the biological control agents produces a smaller return to the investment of the control program. To the contrary, a higher *Arundo* water consumption rate combined with the greatest efficacy scenario considered of the biological control agents produces the greatest return to the program.

The remaining sensitivity tables report on a range in the benefit-cost ratio as caused by variations in *Arundo* water consumption paired with each of the other data-input variables, separately. Only the sensitivity results for the low-value irrigated crop mix are presented, as the land used for these crops (e.g., corn, cotton, and sorghum) is expected to convert from dryland to irrigation rather than to the high-value irrigated crops. Therefore, the low-value irrigated crops are the likely recipients of the water saved from the reduction in giant reed due to the biological control program.

Amount of Water Consumed by Arundo and Value of Water
The 2009 benefit-cost ratio results from varying the *Arundo* water use and the value of water (**Table 11**) ***range from 0.72:1*** with the value of water at $50 per acre-foot and *Arundo* water use at 2.00 acre-feet of water per year ***to a ratio of 11.34:1*** with the value of water at $200 per acre-foot and *Arundo* water use of 7.00 acre-feet per year. At the most conservative set of assumptions examined in this analysis, *the return on the project would be $0.72 for every $1.00 of money public investment, indicating the project is not economically feasible at this level*. However, under all other scenarios considered, the project is feasible.

As shown in the sensitivity table, less water consumed by *Arundo* and a lower value of water produces the smallest returns to the control program. At this point, the benefit-cost ratio is infeasible, where the value of water is $50.00 per acre-foot and the *Arundo* water consumption is 2.00 acre-feet. The project becomes economical at 2.00 acre-feet when the value of water increases to $100 per acre-foot or when the *Arundo* water use increases to 3.00 acre-feet when water is valued at $50.00 per acre-foot (i.e., more water would be saved from the reduction of *Arundo*). Thus, the project will generate more value in benefits than the value spent in cost (i.e., economically feasible) in all scenarios above the most conservative scenario presented. The highest expected returns with respect to the costs are produced with the greatest level of *Arundo* water consumption (i.e., more water saved from the reduction of giant reed) combined with the highest value of water in the scenarios considered.

Amount of Water Consumed by Arundo and Cost of the Program
The benefit-cost ratio that results from varying the *Arundo* water use and the cost of the USDA–ARS, Weslaco, Texas *Arundo donax* biological control program ***range from 1.54:1*** with the cost of the program at 30% greater than the baseline calculations and *Arundo* water use at 2.00 acre-feet of water per year, ***to a ratio of 10.02:1*** with the cost of the program at 30% less than the baseline calculations and an *Arundo* water use amount of 7.00 acre-feet per year (**Table 12**). At the most conservative set of assumptions examined in this analysis, *the return on the project would be $1.54 for every $1.00 of public investment, indicating the project is feasible*.

Amount of Water Consumed by Arundo and Arundo Expansion Rate
In the sensitivity table with *Arundo* water use and *Arundo* expansion after the expected-realized control from the biological agents (**Table 13**), the benefit-cost ratio is greater than one in all scenarios presented. These results indicate that even at the most conservative scenario, the project will generate more value in benefits than the value spent in cost (i.e., economically feasible). As expected, less water consumed by *Arundo* and a lower *Arundo* expansion rate after the realized impacts of the control program produces lower returns to the control program. In contrast, the highest expected returns with respect to the costs are produced with the greatest level of *Arundo* water consumption combined with the lowest rate of *Arundo* expansion after the realized impacts of the control program in the scenarios considered.

The low-value irrigated crops benefit-cost ratio ***varies from 2.00:1*** at an expansion rate of 1.50% with *Arundo* water use at 2.00 acre-feet ***to a ratio of 7.02:1*** at an expansion rate of 0.00% and an *Arundo* water use amount of 7.00 acre-feet (**Table 13**). At the most conservative scenario examined in this analysis, *the return on the project would provide $2.00 for every $1.00 invested by the public, indicating the project is economically feasible*.

Table 11. Sensitivity Analysis, Benefit-Cost Ratio of Benefits with Variations in Annual Water Consumption of *Arundo* and the Value of Water, Using Normalized Prices, with Low-Value Irrigated Crops in the Texas Lower Rio Grande Valley, 2009[a]

Low-Value Irrigated Crops		variation in annual water consumption (ac-ft)						
		-2.37	-1.37	-0.37	0	0.63	1.63	2.63
		Annual Water Consumption of *Arundo* (ac-ft/year)						
		2.00	3.00	4.00	**4.37**	5.00	6.00	7.00
Value of Water	$50.00	0.72	1.08	1.44	1.57	1.80	2.16	2.52
	$100.00	1.44	2.16	2.88	3.15	3.60	4.32	5.04
	$125.00	1.80	2.70	3.60	3.93	4.50	5.40	6.30
	$139.22	2.00	3.01	4.01	**4.38**	5.01	6.01	7.02
	$150.00	2.16	3.24	4.32	4.72	5.40	6.48	7.56
	$175.00	2.52	3.78	5.04	5.51	6.30	7.56	8.82
	$200.00	3.24	4.86	6.48	7.08	8.10	9.72	11.34

Source: Seawright (2009).

[a] The value for which the corresponding background is shaded are associated with the assumptions embedded in the baseline scenario.

Table 12. Sensitivity Analysis, Benefit-Cost Ratio of Benefits with Variations in Annual Water Consumption of *Arundo* and the Cost of the Program, Using Normalized Prices, with Low-Value Irrigated Crops in the Texas Lower Rio Grande Valley, 2009[a]

Low-Value Irrigated Crops		variation in annual water consumption (ac-ft)						
		-2.37	-1.37	-0.37	0	0.63	1.63	2.63
		Annual Water Consumption of *Arundo* (ac-ft/year)						
		2.00	3.00	4.00	**4.37**	5.00	6.00	7.00
Cost of Program	-30.00%	2.86	4.30	5.73	6.26	7.16	8.59	10.02
	-20.00%	2.51	3.76	5.01	5.47	6.26	7.52	8.77
	-10.00%	2.23	3.34	4.45	4.87	5.57	6.68	7.80
	0.00%	2.00	3.01	4.01	**4.38**	5.01	6.01	7.02
	10.00%	1.82	2.73	3.64	3.98	4.56	5.47	6.38
	20.00%	1.67	2.51	3.34	3.65	4.18	5.01	5.85
	30.00%	1.54	2.31	3.08	3.37	3.85	4.63	5.40

Source: Seawright (2009).

[a] The value for which the corresponding background is shaded are associated with the assumptions embedded in the baseline scenario.

Table 13. Sensitivity Analysis, Benefit-Cost Ratio of Benefits[a] with Variations in Annual Water Consumption of *Arundo* and Annual Expansion Rate of *Arundo* After Control, Using Normalized Prices, with Low-Value Irrigated Crops in the Texas Lower Rio Grande Valley, 2009[b]

Low-Value Irrigated Crops		variation in annual water consumption (ac-ft)						
		-2.37	-1.37	-0.37	0	0.63	1.63	2.63
		Annual Water Consumption of *Arundo* (ac-ft/year)						
		2.00	3.00	4.00	**4.37**	5.00	6.00	7.00
Arundo Expansion Rate After Control (annual %)	**0.00 %**	2.00	3.01	4.01	**4.38**	5.01	6.01	7.02
	0.25 %	2.00	3.01	4.01	4.38	5.01	6.01	7.01
	0.50 %	2.00	3.00	4.00	4.37	5.01	6.01	7.01
	0.75 %	2.00	3.00	4.00	4.37	5.00	6.00	7.00
	1.00 %	2.00	3.00	4.00	4.37	5.00	6.00	7.00
	1.25 %	2.00	3.00	4.00	4.37	5.00	6.00	7.00
	1.50 %	2.00[a]	3.00	4.00	4.36	4.99	5.99	6.99

Source: Seawright (2009).

[a] The benefit-cost results may appear similar, as minor changes are not reflected in the rounding of the numbers. As the expansion rate increases, the benefits decline by a small amount compared to the costs. Changes in the results become visible when rounded to the thousandth decimal place.

[b] The value for which the corresponding background is shaded are associated with the assumptions embedded in the baseline scenario.

Table 14. Sensitivity Analysis, Benefit-Cost Ratio of Benefits with Variations in Annual Water Consumption of *Arundo* and Natural Vegetation, Using Normalized Prices, with Low-Value Irrigated Crops in the Texas Lower Rio Grande Valley, 2009[a]

Low-Value Irrigated Crops		variation in annual water consumption (ac-ft)						
		-2.37	-1.37	-0.37	0	0.63	1.63	2.63
		Annual Water Consumption of *Arundo* (ac-ft/year)						
		2.00	3.00	4.00	**4.37**	5.00	6.00	7.00
Natural Vegetation Water Use (% of *Arundo*)	20.00 %	2.41	3.61	4.81	5.26	6.01	7.22	8.42
	25.00 %	2.26	3.38	4.51	4.93	5.64	6.77	7.89
	30.00 %	2.10	3.16	4.21	4.60	5.26	6.31	7.37
	33.33 %	2.00	3.01	4.01	**4.38**	5.01	6.01	7.02
	40.00 %	1.80	2.71	3.61	3.94	4.51	5.41	6.31
	45.00 %	1.65	2.48	3.31	3.61	4.13	4.96	5.79
	50.00 %	1.50	2.26	3.01	3.28	3.76	4.51	5.26

Source: Seawright (2009).

[a] The value for which the corresponding background is shaded are associated with the assumptions embedded in the baseline scenario.

Amount of Water Consumed by Arundo and Native Vegetation Water Use
The 2009 benefit-cost results from varying the *Arundo* water use and the water use amount of native (replacement) species ***range from a ratio of 1.50:1*** with the native vegetation water consumption rate at 50% of *Arundo* water use and *Arundo* water use at 2.00 acre-feet of water per year ***to a ratio of 8.42:1*** with the native vegetation water consumption rate at 20% of *Arundo* water use and *Arundo* water use of 7.00 acre-feet per year (**Table 14**). At the most conservative set of assumptions examined in this analysis, *the return on the project would be $1.50 for every $1.00 of public investment, indicating the project is feasible*.

In the sensitivity table with *Arundo* water use and water use by native vegetation, the benefit-cost ratio is greater than one in all scenarios presented. These results indicate that even at the most conservative scenario, the project will generate more value in benefits than the cost (i.e., economically feasible). As expected, less water consumed by *Arundo* and the highest water consumption rate of native (replacement) vegetation produces smaller returns on the cost of the control program. To the contrary, the highest expected returns with respect to the costs are produced with the greatest level of *Arundo* water consumption combined with the lowest water consumption rate of native (replacement) vegetation in the scenarios considered (more water is saved, as less water is consumed).

Economic Impact

Multipliers for economic activity, value-added, and employment are applied to changes in gross revenue attributable to increased irrigated acres in the Texas Lower Rio Grande Valley to assess expected impacts associated with the irrigation use of the water saved. The impacts are estimated based on deflated increases in gross returns to crops for the Texas Lower Rio Grande Valley (i.e., the Texas lower four counties of Cameron, Hidalgo, Starr, and Willacy). Impact analysis is conducted for this four-county region[13] over the 50-year planning horizon.[14] The IMPLAN model (Minnesota IMPLAN Group, Inc. 2004) is the source of the economic multipliers.

The base for the impact analysis is the 2007 Texas AgriLife Extension crop budgets and the U.S. Department of Agriculture–National Agricultural Statistics Service acreage data (Texas AgriLife Extension Service 2007, National Agricultural Statistics Service 2008a, 2008b). In 2007, the designated four-county Valley region realized a total gross revenue from crop production of $350.6 million, of which $282.3 million are from irrigated crops and $68.3 million are from dryland crops (National Agricultural Statistics Service 2008a; Texas AgriLife Extension Service 2007). Changes in the base gross revenues (as a result of the USDA–ARS, Weslaco, Texas *Arundo* biological control program) and the associated economic impact occur due to conversion in acreage from dryland to irrigated, as farmers utilize more water. The change, or increase, in gross returns to crop production by year is the subtraction of pre-*Arundo* control gross returns

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[13] Since 100% of the direct impacts are assumed to be spent within the four-county region of the Texas Lower Rio Grande Valley, state impacts are not analyzed in this study, as the outcome is similar to regional impacts.

[14] Although the sector mix of the economy is not likely to remain unchanged, this study assumes the structure of the economy remains constant over the 50-year planning horizon.

converted dryland acres from post-*Arundo* control gross returns on the acres converted to irrigated production.[15]

Low-Value Irrigated Composite Acre — Economic Impacts to the Valley

In 2009, with the 59 acre-feet of potential net water saved and 0.54 acre-feet of water use for the low-value irrigated composite acre, a total of 108 acres could be converted from dryland to irrigated. Of these 108 acres converted to irrigation, 33 are from dryland cotton and 75 from dryland sorghum. These source amounts of the new irrigated composite acre are calculated by multiplying the total acres converted by the weighted proportion used for each crop in calculating the dryland composite acre.

A similar procedure based on proportionate compositions of the low-value irrigated composite acre is applied to predict that corn will gain 25 irrigated acres (23% of the acres converted), cotton will gain 28 irrigated acres (26% of the acres converted), and sorghum will gain 55 irrigated acres (51% of the acres converted). No acres are gained for citrus, vegetables, or sugarcane, as they are not included in the low-value irrigated composite acre. The respective crop acres are calculated for conversion in 2015, 2025, 2035, 2045, 2055, and 2058, indicating 31,516, 43,252, 58,022, 76,611, 100,006, and 108,140 acres are converted from dryland (rain-fed) to irrigation for the respective years (**Table 15**).

Table 15. Number of Acres Converted from Dryland to Irrigated Acres for Low-Value and High-Value Irrigated Crops in the Texas Lower Rio Grande Valley, 2009-2058

Year	Low-Value Irrigated Crop Acres Converted to Irrigation	High-Value Irrigated Crop Acres Converted to Irrigation
2009	108	43
2015	31,516	12,599
2025	43,252	17,291
2035	58,022	23,195
2045	76,611	30,627
2055	100,006	39,980
2058	108,140	43,231

The additional irrigated acres are added to the current acreage amount and then multiplied by the uninflated[16] gross revenues per acre, by crop, to obtain the new gross revenues by year. These

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[15] Converted crop acres will differ significantly for low-value irrigated crops and high-value irrigated crops, as the crops with the low-value crops require less water than crops with a high-value (i.e., 0.54 acre-feet per acre and 1.36 acre-feet per acre, respectively). This difference allows for different amounts of acreage to be converted from dryland to irrigated for the two scenarios.

[16] 2007 base year prices were used in the future revenue estimation.

new gross revenues are deflated to 2006 dollars by the projected IMPLAN deflator.[17] The deflated gross revenues associated with reductions in dryland cotton and sorghum acres are subtracted from the expected new irrigated acreage gross revenues to estimate the anticipated net increase in gross revenues, by year. These net new gross revenues are the direct benefits for the Valley.

The multipliers for economic output, value added, and employment are then multiplied by the respective increases in gross revenue to estimate the annual impact for each year of the 50-year planning horizon. For example, the multiplier for value-added for corn is 0.712 for the four-county Valley (i.e., the multiplier suggests a regional value-added of $0.71 for each dollar increase in corn gross revenue). The economic activity generated is $1.387 for each dollar increase in corn revenue. Lastly, the employment multiplier indicate 34.9 jobs are associated with a $1.0 million increase in corn gross revenue. All other multipliers are interpreted in a similar manner.

Estimating the economic impacts of the projected crop mix changes so far into the future is a challenge. While the structure of the economy in the region could and likely will change over time, affecting the multipliers, the multipliers used in this analysis are current and are used as an approximation of future impacts based on the best information available at the time of this study.

As displayed in **Table 16**, the annual increase in economic output using the low-value irrigated crop mix for the four counties in the Texas Lower Rio Grande Valley in 2009 is $22,138, and for 2015, it is $6.56 million. In 2025, the estimated economic output generated is $8.90 million, $11.94 million in 2035, $15.77 million in 2045, $20.58 million in 2055, and $22.26 million in 2058.

The impact of the water savings has a positive effect on economic output, value-added, and the number of jobs in the region, and is a positive impact to the Texas Lower Rio Grande Valley. Presented in **Table 14**, value-added is estimated to increase by $11,015 in 2009, by $3.23 million in 2015, $4.43 million in 2025, $5.94 million in 2035, $7.84 million in 2045, $10.24 million in 2055, and by $11.07 million in 2058.

Additionally, no additional employment is associated with the change in gross revenues for 2009, 143 jobs are associated with the change in gross revenues for 2015, 197 for 2025, 264 for 2035, 349 for 2045, 455 for 2055, and 492 for 2058 as shown in **Table 16**. The employment associated with the change in gross revenue per $1 million is not additive, but is rather the total for that year and includes those jobs per $1 million added to the regional economy in previous years.

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[17] The deflation of the 2007 dollars to 2006 dollars is necessary, as the IMPLAN model uses 2006 data to project the multipliers for each sector.

Table 16. Regional Economic Impact to the Texas Lower Rio Grande Valley in 2006 Dollars from the USDA–ARS, Weslaco, Texas *Arundo donax* Biological Control Program Using Low-Value Irrigated Crops, 2009-2058[a]

Year	Deflated Change in Gross Revenue ($ million, 2006)	Economic Output ($ million)	Value-Added ($ million)	Employment
2009	$ 0.02	$ 0.02	$ 0.01	0
2015	$ 4.58	$ 6.56	$ 3.23	143
2025	$ 6.28	$ 8.90	$ 4.43	197
2035	$ 8.43	$ 11.94	$ 5.94	264
2045	$ 11.13	$ 15.77	$ 7.84	349
2055	$ 14.53	$ 20.58	$ 10.24	455
2058	$ 15.71	$ 22.26	$ 11.07	492

[a] Region includes the lower four counties of the state of Texas: Cameron, Hidalgo, Starr, and Willacy.

High-Value Irrigated Crop Acre — Economic Impacts to the Valley

The same process for calculating the economic impacts of the low-value irrigated crop acre is repeated for the economic impacts of the high-value irrigated crop acre. In order to calculate the economic impacts, the acreage changes from dryland to high-value irrigated acres are determined with the high-value irrigated composite acre using the same process as discussed in the calculation of converted acres with the low-value irrigated composite crop acre. In 2009, 43 dryland acres are converted to irrigated acres, compared to 12,599 acres converted to irrigated in 2015, 17,291 acres converted in 2025, 23,195 acres converted in 2035, 30,627 acres converted in 2045, 39,980 acres converted in 2055, and 43,231 acres converted to irrigation in 2058 (**Table 13**).

As displayed in **Table 17**, a (deflated) net increase in gross revenue of $32.95 thousand is realized in the Texas Lower Rio Grande Valley region for 2009, based on the high-value irrigated crop mix. In 2015, a (deflated) net increase in gross revenue of $9.54 million is realized, $13.09 million in 2025, $17.56 million in 2035, $23.19 million in 2045, $30.27 million in 2055, and $32.73 million in 2058. Economic output increases by $44.63 thousand in 2009, $13.08 million in 2015, $17.94 million in 2025, $24.07 million in 2035, $31.79 million in 2045, $41.49 million in 2055, and $44.87 million in 2058 as a result of the increase in gross revenues, and is presented in **Table 17**.

In the Texas Lower Rio Grande Valley region, value-added increases by $29.37 thousand in 2009, $8.60 million in 2015, $11.81 million in 2025, $15.84 million in 2035, $20.92 million in 2045, $27.30 million in 2055, and $29.52 million in 2058, based on the high-value irrigated crop mix (**Table 17**). The Valley also realizes an increase in employment, with one new job associated with the increase in gross revenues for 2009, 256 jobs associated with the increase in gross revenues for 2015, 351 for 2025, 471 for 2035, 622 for 2045, 812 for 2055, and 878 for 2058 in association with the increase in gross revenues using high-value irrigated crops from the additional saved water by the reduction in *Arundo donax*.

Table 17. Regional Economic Impact to the Texas Lower Rio Grande Valley in 2006 Dollars from the USDA–ARS, Weslaco, Texas *Arundo donax* Biological Control Program Using High-Value Irrigated Crops, 2009-2058[a]

Year	Deflated Change in Gross Revenues ($ million, 2006)	Economic Output ($ million)	Value-Added ($ million)	Employment
2009	$ 0.03	$ 0.05	$ 0.03	1
2015	$ 9.54	$ 13.08	$ 8.60	256
2025	$13.09	$ 17.94	$ 11.81	351
2035	$17.56	$ 24.07	$ 15.84	471
2045	$23.19	$ 31.79	$ 20.92	622
2055	$30.27	$ 41.49	$ 27.30	812
2058	$32.73	$ 44.87	$ 29.52	878

[a] Region includes the lower four counties of the state of Texas: Cameron, Hidalgo, Starr, and Willacy.

Per-Unit Costs of Saved Water

Annuity equivalents of the respective present values for the cost of the program and the acre-feet of water saved are estimated for the 50-year planning horizon (i.e., 24.2 thousand acre-feet of water saved per year, or 7.9 million gallons of water saved per year). Dividing the annuity equivalent of costs by the annuity equivalent of water saved results in a program cost of $44.08 per acre-foot of raw water, or $0.1353 per 1,000 gallons of raw water.

The per-unit cost of water saved due to the USDA–ARS, Weslaco, Texas *Arundo donax* biological control program is comparable to the average cost of $45 per acre-foot for several of the on-going projects in the Rio Grande Valley designed to conserve raw water (prevent water loss) (Sturdivant et al. 2007).

DISCUSSION

While the preliminary results indicate an expected positive net benefit of the *Arundo* biological control program, several of the critical data-input variable values are uncertain, including (a) the actual growth curve of *Arundo* acres in the riparian of the River, (b) discrepancies among estimates of the amount of water the plant uses, (c) the growth rate and water use of the replacement natural vegetation, and (d) whether a reduction in the height/density (biomass) of *Arundo* is equivalent to the acreage reduction assumed in this thesis.

This research uses sensitivity analyses to account for variations in certain variables that could influence the outcome of the analysis. Further sensitivity analyses (e.g., native vegetation water use) can be found in “Select Economic Implications for the Biological Control of *Arundo donax* along the Rio Grande” by Seawright (2009). Additional research is currently being conducted as well as tracking experience with releases of the beneficial insects which will provide application of the economic model for improved estimates of benefits. Because of the early stages of the research project, the economic results must be viewed as preliminary and subject to revisions as more concrete data are identified.

While many issues were addressed in this research, certain areas were not considered, including potential benefits to the Department of Homeland Security, recreational activities, environmental values, and benefits to Mexico as a result of the program. Only the USDA–ARS program and U.S. benefits received from the control of *Arundo donax* from the release of two out of four of the insects, *Tetramesa romana* and *Rhizaspidiotus donacis* (the wasp and scale, respectively), in the limited project study area (i.e., 170 river miles between San Ignacio and Del Rio, Texas) are included.

CONCLUSIONS

The increased urgency of water availability from rapid population growth and rising concerns of illegal immigration into the United States contribute to the importance of researching the implications of controlling *Arundo donax* in the Rio Grande Basin. This study evaluates the infestation and control of giant reed in the Texas Rio Grande Basin and provides an estimation of the value for saved water in agriculture using crop budgets for crops with both low- and high-value irrigated returns. These values are applied to an expected amount of water to be saved from *Arundo* reduction, resulting in a present value range of benefits from $97.80 to $159.87 million over a 50-year planning horizon (2009 through 2058). Although benefits are expected to accrue to Mexico, border security, and for recreational purposes, analyses regarding these areas have not been evaluated in this research.

The benefit-cost analysis suggests returns of $4.38 to $8.81 for every public dollar invested. These results suggest net positive returns for the *Arundo donax* biological control project. Additionally, the results reveal a positive impact to the regional economy, increasing
(a) economic output by $22,138 in 2009, $11.94 million in 2035, and $22.26 million in 2058,
(b) value-added by $11,015 in 2009, $5.94 million in 2035, and $11.07 million in 2058, and
(c) employment increases by 264 jobs in 2035, and by 492 jobs in 2058. Additionally, the per-unit cost of water saved as a result of the USDA–ARS *Arundo* biological control program is $44.08 per acre-foot and is comparable to the per-acre-foot costs of current programs in use or under consideration for increasing water supply. These results indicate a competitive economic alternative for increasing the water supply to the Texas Lower Rio Grande Valley.

The data for different aspects of this project are continuing to be observed and collected. It is expected more accurate data will be identified as the project continues. Based on the current available data and the results of the economic research reported in this research, however, the release of the two biological control agents, *Tetramesa romana* (wasp) and *Rhizaspidiotus donacis* (scale), to control *Arundo donax* in the Rio Grande Basin (a) increases water availability to the Rio Grande Valley, (b) creates a positive impact both at the farm level and for the regional economy, and (c) is a defendable project for use of federal dollars.

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