SELECT ECONOMIC IMPLICATIONS FOR THE BIOLOGICAL CONTROL OF *ARUNDO DONAX* ALONG THE RIO GRANDE

A Thesis

by

EMILY KAYE SEAWRIGHT

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2009

Major Subject: Agricultural Economics

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Approved by:

Co-Chairs of Committee,	M. Edward Rister
	Ronald D. Lacewell
Committee Members,	Bill L. Harris
	Dean A. McCorkle
Head of Department,	John P. Nichols

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ABSTRACT

Select Economic Implications for the Biological Control of *Arundo donax*
along the Rio Grande. (August 2009)

Emily Kaye Seawright, B.S., Texas A&M University

Co-Chairs of Advisory Committee: Dr. M. Edward Rister,
Dr. Ronald D. Lacewell

Arundo donax, or giant reed, is a large, bamboo-like plant native to Spain that has invaded several thousand acres of the Rio Grande riparian in Texas. The plant grows to 18-24 feet, consuming large quantities of water per acre per year. 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 select 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 analysis, (c) regional economic impact analysis, 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$^{\copyright}$ is used to perform a deterministic analyses using low- and high-marginal-composite acre values. Regional results indicate present values of farm-level benefits ranging from $97.80 to $159.87 million. Benefit-cost ratios are calculated with normalized prices and range from 4.38 to 8.81. Sensitivity analyses provide a robust set of results for *Arundo* water use, 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 analysis is estimated using multipliers from the IMPLAN model. Regional results reveal a range of $8.90 to $17.94 million annually in economic output and 197 to 351 new jobs for the year 2025. Further results show the cost per acre-foot of water saved is $44.08. This amount is comparable to other projects designed to conserve water in the region.

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

DEDICATION

To my family and friends

ACKNOWLEDGMENTS

Many people have contributed leadership, mentorship, moral support, computer support, and encouragement during the research and writing of this thesis. I would like to thank Dr. Rister, my committee co-chair, for his leadership and support during this process. I am very grateful to have him as my mentor. I would also like to thank Dr. Lacewell, my committee co-chair; his mentorship and expertise have greatly contributed to my growth as an economist and a person. I am also grateful to my other committee members, Dr. Bill L. Harris and Dr. Dean McCorkle, who have also contributed greatly to my learning process, and to Dr. John Goolsby for his leadership and collaboration on this project. I would like to give a big thank you to Allen Sturdivant, whose computer expertise and moral support has encouraged me through my research, and to Michele Zinn, whose endless encouragement and travel support have made this experience easier and more enjoyable.

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DISCLAIMER

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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 two reservoirs -- Amistad, located near Del Rio, and Falcon, located south of Laredo (Rubinstein 2008). The Rio Grande is a highly-controlled stream, meaning the water flow is managed based on downstream water demand, conservation, flood control, various environmental issues, and other factors such as bi-national compacts and agreements. With water continuing to be a high-priority issue, local water resource managers and community leaders are considering alternative methods to enhance the current 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

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). *Arundo donax* can grows 18-24 feet tall and exhibits a growth rate approaching 4 inches a day (Dudley 1998). The plant grows

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This thesis follows the style of the *American Journal of Agricultural Economics*.

most aggressively during the spring and summer months (Decruyenaere and Holt 2001), particularly along the Rio Grande, consuming large quantities of water 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

The United States Department of Agriculture-Agricultural Research Service (USDA–ARS) in Weslaco, Texas is investigating four potential herbivorous biological control agents (i.e., wasp, scale, leaf miner, and fly) for these agents' abilities to separately and collectively control the spread and mitigate the density of *Arundo*, thereby reducing its water uptake (Goolsby 2007; Goolsby 2008a). A primary purpose of the economic research comprising this thesis 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. Lastly, the per-unit life-cycle cost of water saved (Rister et al. 2008) 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).

In keeping with the scientific method (Howson and Urbach 1989), the null hypothesis of this research is: “The USDA–ARS biological control program for *Arundo donax* is not economically feasible.” The corresponding alternate hypothesis is: “The USDA–ARS biological control program for *Arundo donax* is economically feasible.” The research in this thesis evaluates this set of hypotheses and a conclusion is reached in regards to either (a) fail to reject the null hypothesis or (b) reject the null hypothesis and accept the alternative hypothesis.

There are additional methods for control of *Arundo*, such as using herbicides and mechanical-removal which could also increase available water in the Basin. The focus of the research in this thesis is, however, the economic implications of the USDA–ARS, Weslaco, Texas *Arundo* biological control program in the Rio Grande Basin.

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.

In this thesis, a literature review is presented followed by a description of the methodology used in the construction of the economic analysis model, *Arundo*Econ$^{©}$. Results are then presented, followed by sections of discussion, limitations, and conclusions to the study.

LITERATURE REVIEW

A wide range of literature has been reviewed to develop a better understanding of the parameters surrounding the research. This literature review includes the biology and growth of the plant; alternatives of control and treatment for *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). It is classified as a C3 grass (Milton 2004), meaning it is efficient in water use. With the warm, temperate climate of the Texas Rio Grande Basin, *Arundo* can grow throughout the year, with growth slowing in the cooler, winter months (Dudley 1998). The plant is rooted by a rhizome which sprouts shoots from nodes located within the root. In the first year of growth, shoots grow primarily in height. Each shoot also has narrow leaves that can grow up to two feet long (Dudley 1998), alternating growth on different sides of the plant (Speck and Spatz 2003). After the first growing season, the shoot becomes lignified (woody), loses its leaves on the lower portion of the plant and begins to branch (Decruyenaere and Holt 2001). The diameter of the plant will ultimately reach a size of one-half to one and one-half inches (Dudley 1998).

Arundo is rooted by a pachymorph (carbohydrate-storing) rhizome (Speck and Spatz 2003), which can grow up to one meter in diameter (Bell 1997). This particular rhizome (Figure 1) offers protection from fires and drought (Boland 2006; Cronk and Fennessy 2001) and contains nodes, from which new shoots sprout (Decruyenaere and Holt 2001). Younger plants are affected by drought, while the older plants tend to survive (Hoshovsky 1986; Perdue 1958).

Source: Seawright (2009).

Figure 1. Photograph of *Arundo donax* rhizome in riparian area of the Rio Grande [River] near Laredo, Texas

The plant grows in stands, consisting of primary shoots and plagiotropic (horizontal) shoots (Wijte et al. 2005). *Arundo* has a seed-head;[1] however, the seeds are sterile and reproduction occurs vegetatively from the nodes within the rhizome and the shoots (Bell 1997). Three forms of vegetative reproduction occur: fragmentation, layering, and rhizome reproduction (Boland 2006).

Fragmentation occurs when a piece of the shoot or rhizome breaks away and floats downstream, where it is then covered by soil and begins to sprout. *Layering* occurs primarily during periods of flooding in the flood zone of the river. With heavy rainfall and a fast-moving river, the shoot bends and the tip is then covered with silt. The node in the tip begins to sprout in the deposited soil, beginning a new plant. *Rhizome reproduction* occurs when nodes in the rhizome sprout new shoots (Boland 2006). Boland (2006) also measured the rate of lateral expansion and found a large amount of expansion occurs by layering in periods of heavy rain or floods and less so by fragmentation or through rhizome growth.

The *Arundo donax* of the Rio Grande Basin is dominated by one particular genotype of the reed (Goolsby and Moran 2009). Finding the source of the original genotype for *Arundo* present in the Rio Grande Basin is of great interest and useful for identifying

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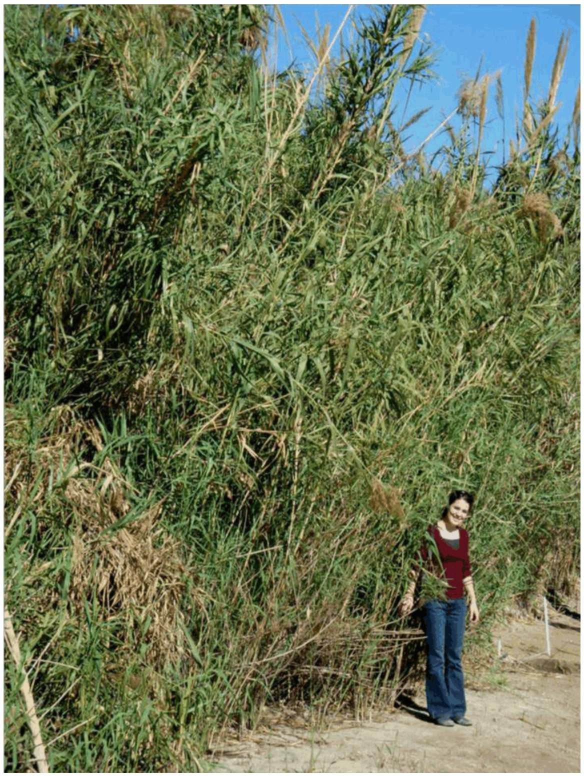
[1] *Phragmites australis* is a reed similar to *Arundo*, but is native to the Rio Grande Basin. These two species are difficult to distinguish from one another; however, small differences can be noted in the density and size of the plant (*Arundo* grows in much taller, denser stands that *Phragmites*) and the shape of the seedhead (*Arundo*'s seedhead grows as a straight plume while *Phragmites*' seedhead has a slight bend to its shape) (Goolsby 2007). Additionally, *Arundo*'s seedhead is sterile, while *Phragmites* has a fertile seedhead (Wijte et al. 2005; Wijte and Gallagher 1996).

potential biological control agents. 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 in the Rio Grande Basin (Goolsby and Moran 2009).

Arundo donax is also a serious invasive plant in California, causing damage to infrastructure, transforming habitats of riparian areas, and consuming large quantities of water (Jackson, Katagi, and Loper 2002). Interestingly, the *Arundo* in California is not the genetic clone found in the Rio Grande Basin, meaning the origin of the *Arundo* in the Rio Grande Basin is different from the origin of the California stands. Nevertheless, plant invasive growth characteristics are approximately the same (Goolsby and Moran 2009).

Biology of *Arundo donax*

The majority of the literature on the biology of *Arundo* addresses the vertical growth rather than the plant's lateral expansion or growth in density. *Arundo donax* exhibits seasonal growth in California, with the growing season beginning in February and lasting through October (Wijte et al. 2005); however, growth is more or less continuous throughout the entire year in South Texas. More growth is exhibited during the spring and fall, as might be expected for the temperate climatic conditions in this region (Goolsby 2008a). Studies have also shown that temperature affects shoot emergence, where sprouting occurs at and above approximately 44.6 degrees Fahrenheit (Spencer and Ksander 2006). Giant reed can grow at a rate of 27 inches (0.7 meters) per week (Hoshovsky 1986), or up to 4 inches (10.2 centimeters) per day (Dudley 1998), ultimately reaching a height of 18 to 24 feet (six to eight meters) tall (Bell 1997). The height of the plant is illustrated in Figure 2.



Source: Sturdivant (2009a).

Figure 2. Photograph of giant reed and Emily Seawright along the Rio Grande [River] at Laredo, Texas

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 consumption amounts for rice of 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.

The efficient water use of *Arundo* as a C3 grass encourages the fast growth and competitiveness of the plant, increasing its ability to expand into vulnerable areas. Certain control methods can actually contribute to the invasive nature of the plant, whereby *Arundo donax*, with its efficient water use and rapid growth rate, will out-compete the native vegetation. Thus, the habitat of the riparian area can quickly change from diverse native vegetation to a monoculture of dense stands of *Arundo* (McGaugh et al. 2006).

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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)).

Control Alternatives

Three primary control methods have been identified in efforts to control the growth and spread of *Arundo donax*: mechanical, chemical, and biological (Jackson, Katagi, and Loper 2002). A combination of chemical and mechanical control can also be used as an effective treatment (Bell 1997).

Mechanical Control

Effective mechanical control involves the physical removal of the entire plant, including the rhizome. This method is labor intensive and requires tools such as chain saws and shredders. Mechanical control is effective, but can be extremely expensive, as much as $5,000 per acre (McGaugh et al. 2006; Bell 1993b). The physical removal of plants often disrupts the soil and causes excessive erosion. Additionally, any node-containing pieces of the plant or rhizome left in the soil could further increase invasions (Bell 1997; Jackson, Katagi, and Loper 2002). Once the plant is removed, the biomass must be chopped to a one-quarter inch to one inch size, to ensure the node is destroyed (Jackson, Katagi, and Loper 2002). To simply mow or chop giant reed contributes to its spreading.

Burning is another form of mechanical control; however, it is ineffective and actually leads to increased expansion of the plant, as it will out-compete native vegetation in regrowth (McGaugh et al. 2006). When the plant is burned, the pachymorphic rhizome is not destroyed, as it exists for protection from fires and freezes (Boland 2006; Cronk and Fennessy 2001). Thus, after a burn, the *Arundo* re-sprouts and spreads, over-taking land that was previously native vegetation.

Chemical Control

Chemical control represents another popular and effective method used to control *Arundo donax*, with a foliar spray using herbicides being the most effective (Bell 1997). Glyphosates, such as Rodeo®, are approved for use in close proximity to water and are most effective when applied during the plant's most active growth period, as the chemical will be transported throughout the plant during this time. The chemical may also be applied immediately before the onset of winter, when nutrients are being transported to the rhizome (Jackson, Katagi, and Loper 2002).

Chemical and Mechanical Control Combination

Another effective method of *Arundo* control suggested in the literature is a combination of chemical and mechanical control called the "cut-stem" method. In this method, the plant is cut and the herbicide is applied directly to the stump within one or two minutes of being cut. In this time frame, the plant has not yet created a barrier for the wound. This method is also costly and labor intensive (Bell 1997).

Due to the high cost of mechanical and chemical control (Jackson, Katagi, and Loper 2002) and Mexico's international border concern regarding water quality, the

USDA–ARS in Weslaco, Texas has chosen to investigate biological control measures for *Arundo donax* (Goolsby 2007). The goal of the project is to mass release the insects in areas along the Rio Grande, as well as its tributaries, with the biological control agents, striving for a self-sustaining *Arundo* control strategy.

The use of biological control for other problematic plants has been successful in Texas, particularly with *Tamarisk*, the invasive tree commonly known as saltcedar. Charles Hart (Professor and Extension Specialist in Stephenville, Texas) estimates saltcedar uses three to four acre-feet of water per acre annually (Supercinski 2006). The tree was originally planted for erosion control along streams in Texas; however, saltcedar began to spread (similar to *Arundo*), out-competing native vegetation and consuming large quantities of water (Supercinski 2006).

Several forms of control have been applied to *Tamarisk*, including herbicides (e.g., Arsenal®) and biological control with the saltcedar leaf beetle (Supercinski 2006). The leaf beetle defoliates the leaves from the tree, forcing the tree to use its stored carbohydrates to survive. Simultaneously, the lack of foliage allows sunlight to penetrate previously covered ground, encouraging growth of native vegetation (Knutson 2009). According to Hart, the reduction in saltcedar from the use of biological control and the herbicides has resulted in an estimated net water saved of two acre-feet of water per treated acre (Supercinski 2006).

Investigation of Insects Considered for Biological Control of *Arundo donax*

Applying the biological control concept to *Arundo*, four insects are under consideration by scientists at USDA–ARS, Weslaco for release into the *Arundo*-infested areas: *Tetramesa romana* (wasp), *Rhizaspidiotus donacis* (scale), *Cryptonevra spp.* (fly), and *Lasioptera donacis* (leafminer) (Goolsby 2008b). Scientists have collaborated and continue to collect the insects in Spain, where scientists believe the genotype for the *Arundo* of the Rio Grande Basin is native.[3] To avoid the occurrence of any unexpected/unforeseen consequences of the proposed biological control program of *Arundo donax*, an extensive and complex research protocol developed by USDA–APHIS has been executed by John Goolsby (2007) with USDA–ARS.

The four insects under consideration for the biological control program were initially sent to members of a Technical Advisory Group (TAG),[4] which is responsible for investigating and researching how each insect will individually respond to native and other cultivated vegetation (in the area being considered for the insect's release). If deemed appropriate, the TAG presents a petition to each country potentially impacted by the release of the biological agent. In the United States,[5] an environmental assessment is

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[3] 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).

[4] Appendix A contains a complete listing of scientists and researchers involved in the research of *Arundo donax* and the USDA–ARS, Weslaco, Texas *Arundo* biological control program.

[5] This study only analyzes the economics for the United States; therefore, the procedures and protocols for the Mexican and Canadian governments are not identified.

written and posted on the Federal Register for comment. After the comment period, the United States Department of Agriculture-Animal and Plant Health Inspection Services (USDA–APHIS) may or may not choose to issue a permit for release of the biological control agent (USDA–APHIS 2009; Goolsby 2009b).

Insect Information

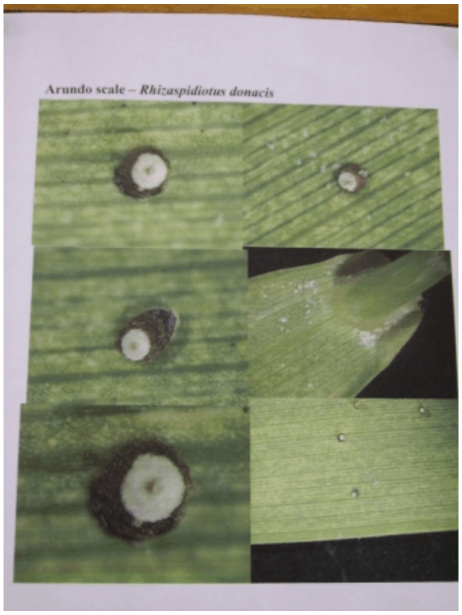
Tetramesa romana, the non-stinging wasp (Figure 3), has approximately a one-month life cycle and is effective at mitigating the new growth of giant reed by ovipositing eggs into the shoot of the plant. As the eggs develop, a gall begins to form in the shoot tips of *Arundo*. Eventually the larvae (from 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 (Figure 4), 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 2009b).

Source: Seawright (2009).

Figure 3. Photograph of wasp (*Tetramesa romana*) ovipositing into shoot of *Arundo donax*



Source: Goolsby (2008).

Figure 4. Photograph of a poster displaying various images of the scale *Rhizaspidiotus donacis*

The USDA–ARS investigative report (i.e., its TAG petition) of the wasp's potential impact on *Arundo* is complete as of March 2009 (Goolsby 2009b). Approval and recommendation from both the United States and Mexican governments for release of the wasp have been granted (Goolsby 2008b). The permit for release of the insect was granted in the spring of 2009 (Goolsby 2009b) and the first release of the wasp occurred on April 29, 2009 (Goolsby 2009d). The TAG petition for permission to release the scale has also been submitted as of March 2009 (Goolsby 2009b); however, USDA–APHIS has not yet granted the permit. A recommendation for release of the scale is also expected by the first week in the spring of 2009, and the permit for release is anticipated by summer 2009 (Goolsby 2009b). The fly and the leafminer are still under investigation at the quarantine facility on Moore Air Base in Mission, Texas (Goolsby 2008b; Goolsby 2009b).

Once permission for release of a specific insect has been granted to the USDA–ARS, the mass-rearing protocol of the insect begins. Scientists are currently working to develop a diet for the wasp and scale in anticipation of recommendation for release and permit approval. The release protocol of each agent is specifically designed to insure the survival and enhanced efficacy of each insect type.

Currently, scientists are planning an air release of *Tetramesa romana*. To successfully complete the release, the temperature of the wasps must be lowered to a point whereby they are effectively in a “hibernation” state. The wasps will be released from an airplane over the target zone, and are expected to thaw moments before reaching the ground (Goolsby 2008c).

The method for releasing the scale is more complicated, as they are unable to fly and need to be released near the root of the plants. Currently, scientists are considering an air release by placing the scale on pieces of cane, which would then be dropped into *Arundo* stands from an airplane. Further release of the scale entails planting whole scale-infected plants into the area to be treated. (Goolsby 2008a, 2008b, 2008c, 2009a).

Regional *Arundo donax* Effects

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 areas. 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). 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).

Due to the plant's highly flammable nature, massive areas of *Arundo* infestation also increase the region's vulnerability to fire (Scott 1993; Bell 1993a). Although the stands of *Arundo* may be destroyed during a fire, rhizomes remain intact and alive in the soil (Bell 1997). Since *Arundo* out-competes native vegetation for water during both its growth and re-growth phases, a fire further increases the level of *Arundo* invasion and damages the natural habitat to a greater extent (Bell 1997; McGaugh et al. 2006; Wijte et al. 2005).

The high-density levels of *Arundo* have also created difficulty for the U.S. Border Patrol along the Rio Grande. Infrared sensors are unable to detect body heat within the *Arundo* stands due to the density and height of the plant. Visibility of the River's banks is significantly reduced, increasing the danger and vulnerability of the Border Patrol, as well as the public in these regions of the River. The Department of Homeland Security has expressed interest, support, and involvement in the removal of giant reed from the River's banks (Goolsby 2008b).

Characteristics of the Texas Lower Rio Grande Valley

The Rio Grande serves as the border between Texas and Mexico. Within its basin is the Texas Lower Rio Grande Valley, or the Valley, which is considered to be the lower four Texas counties of Cameron, Hidalgo, Starr, and Willacy. Irrigated agriculture plays a significant role in the economy of these counties and consumes over 80% of the water (Stubbs et al. 2003). The Rio Grande is the main source of water for the Valley and serves mining, industry, municipal, and irrigation constituents, with municipalities having first rights to the water (Griffin 2006).

The Texas Lower Rio Grande Valley is the fourth-fastest growing metropolitan statistical area in the nation (U.S. Census Bureau 2000; Rogers 2008). The rapid population growth has increased pressure on local and state officials for increasing water availability. The use of biological control on *Arundo donax* is only one alternative to providing an increased water supply to the Valley. Other forms of water supply expansion include improved efficiency of irrigation district delivery systems, use of groundwater wells, improved water use conservation, the importation of water, and desalination of brackish groundwater and sea water (Griffin 2006; Rogers 2008; Stubbs et al. 2003).

Economic Literature

Several economic concepts, analytical procedures, and data are relevant to this study. Of importance are invasive species studies, water valuation, agriculture composite acre development, impact analysis, and per unit cost analysis.

Invasive Plant Species Studies

The economic literature regarding invasive plant species typically discusses the risk of potential invasion and the costs associated with conventional means of control. Olson and Roy (2002) use the exponential growth function to model the growth of invasive species, and then with stochastic dynamic programming, evaluate different strategies of control to find the optimal solution. In her 2004 article titled, "The Role of Resource Economics in the Control of Invasive Alien Plants in South Africa," Turpie discusses the different methods used for evaluating the economic impacts from invasive species. Included are methods such as the application of travel cost analysis, using replacement costs, estimating opportunity costs, and calculating costs for prevention and damages.

Water Valuation

In "Economic Values of Freshwater in the United States," Frederick, VandenBerg, and Hanson (1996) note the increasing concern for water availability as water demand increases. The study outlines different methods for water use valuation, including contingent valuation for non-market values, crop-water production functions, and the use of crop budgets for irrigation values. In the paper, the United States is divided into different water regions, with the Rio Grande being one of the regions. In this study's analysis of the Rio Grande "region," the average water value per acre-foot, across all uses, was $191, with waste disposal averaging one dollar, recreation/fish and wildlife habitat averaging $313, and irrigation averaging $33.

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). 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 regions.

Under economic theory, the value of water is measured based on a person's willingness to pay for the water (Ward and Michelsen 2002). Different methods exist to determine willingness to pay, such as measuring the change in income from an added unit of water and measuring changes in crop yields (value) from extra water. 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.

Ward and Michelsen (2002) present a marginal value of irrigation water of $27 per acre-foot for the Middle Rio Grande Conservatory District and an average value of $36 per acre-foot. El Paso has a marginal value of irrigation water of $95 per acre-foot. The $95 value was calculated during a time of drought and includes the $80 loss in income from lack of water. The cost of water used during the drought was also added, $15, to obtain the marginal value of water of $95 (Ward and Michelsen 2002).

In the paper, “Alternative Approaches to Estimate the Impact of Irrigation Water Shortages on Rio Grande Valley Agriculture,” Robinson (2002) identifies two methods to valuing water, including the value-of-water approach and the historical damages approach. Under the value-of-water method, a composite acre is developed using crop yields per acre, crop prices, and water use to determine the average direct economic impact of irrigation water on crop sales.

Agriculture Composite Acre

Water valuation methods using crop 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 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 the 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 stochastic analysis to account for uncertainty.

Economic Impact Analysis

Economic impact analysis is performed as 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 the model to determine 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, 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 Lower Rio Grande Valley. As part of understanding the impacts, this paper examines how Leontief transformed the standard macroeconomic model (Equation 1, where "Y" is gross domestic product, “C” is consumption, “I” is investment, “G” is government expenditures, and (X-M) is exports minus imports) to reflect the impact of exogenous forces (Equation 2, where “E’” is exogenous forces) and the assumption that consumption is less than income (Equation 3, where “c” is the average propensity to consume). This transformation can be seen in the following progression of equations.

Equation 1: $Y = C + I + G + (X - M)$

Equation 2: $E' = I + G + (X - M)$

Equation 3: $C = cY$

Through further substitutions and rearrangements, the formula containing the multiplier effect is obtained in Equation 4:

Equation 4: $\text{Multiplier} = (1-c)^{-1}$.

Input-output analyses relies on several crucial assumptions in order 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).

IMPLAN in one of several input-output models available for conducting impact analysis. The IMPLAN model was developed in the 1970s by the U.S. Forest Service and is now maintained by Minnesota IMPLAN Group, Inc (Shaffer, Deller, and Marcouiller 2004). The model, which includes 509 North American Industry Classification System (NAICS) sectors, can be used to estimate economic multipliers depicting the economic impact from a change in a contributing activity or shock scenario. The model uses county-level data to estimate the direct, indirect, and induced impacts (in the form of multipliers) from a change in a factor that contributes to the economy.[6] 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. The model also assumes the firm will not change output proportions with the shock, and that the firm will not make input product substitutions should fluctuations in input price occur (Minnesota IMPLAN Group, Inc. 2004). IMPLAN estimates multipliers for economic output, value-added, and employment for the designated county, region, or state.

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 additional value to the industry or product from having the change in activity, and the employment multiplier measures the number of

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[6] Direct economic impacts include the increased revenue resulting directly from changes in irrigated agricultural production associated with the saved water from *Arundo* control. Indirect impacts are a result of economic activity generated from added demand due to the saved water. Induced impacts are the economic activity generated from the extra income received by individuals (Minnesota IMPLAN Group, Inc. 2004).

jobs associated with the change in activity (Miller and Armbruster 2003; Coppedge 2003). 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).

Application of the IMPLAN model allows for estimating the change in employment and economic activity for a county, or any sub-set of counties, up to the state or national level (Minnesota IMPLAN Group, Inc. 2004). In this thesis, pre-production processes and farm-gate economic impact analysis of the potential production changes associated with the water saved by *Arundo* control are estimated using the IMPLAN model.

Per-Unit Cost of Water Conserved

In the "Economic Methodology for South Texas Irrigation Projects-RGIDECON$^{©}$," Rister et al. (2008) 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 the project results in the cost per acre-foot of water saved. The water amounts can also be converted to 1,000 gallon units instead of acre-feet, and subsequently, the cost per 1,000 gallons can be calculated (Rister et al. 2008).

Rister et al.’s (2008) methodology is used to estimate costs per acre-foot of water saved for several Valley irrigation district rehabilitation projects in the Lower Rio Grande Valley, with such projects during 2002-2007 designed to increase the water supply to the region. The cost 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. On an individual project type basis, water saved by lining irrigation canals averages $35 per acre-foot, installing meters and telemetry saves water for an average of $86 per acre-foot, and installing pipelines averages $56 per acre-foot cost of water saved (Sturdivant et al. 2007).

The same methodology has also been adopted and applied in several other studies, including (a) Rogers (2008) in “Economic Costs of Conventional Surface-water Treatment: A Case Study of the McAllen Northwest Facility,” (b) Sturdivant et al. (forthcoming 2009) in “An Analysis of the Economic and Financial Life-Cycle Costs of Reverse-Osmosis Desalination in South Texas: A Case Study of the Southmost Facility,” and (c) Boyer (2008) in “Economies of Size in Municipal Water Treatment Technologies: Texas Lower Rio Grande Valley” to determine the life-cycle costs associated with conventional and desalination water treatments. In each of these studies, the costs per unit of water results are substantially higher than those in studies strictly examining raw water, as potable water is used by municipalities for drinking water and necessarily requires extensive 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.

METHODOLOGY

The USDA–ARS, Weslaco, Texas *Arundo donax* biological control project encompasses many different disciplines, including teams from entomology, genetics, rangeland ecology, and resource economics (see Appendix A). That is, many types and sets of data are used in the robust economic and financial analyses contained in this thesis. Some data have been thoroughly assimilated and validated, while other data are the best estimates currently available from professional researchers involved with this project.

Due to the multi-disciplinary nature and early stages of this project, a form of the Delphi technique (Dalkey 1969) is employed to estimate certain data (e.g., efficacy of biological control) which are not precisely known. This technique involves the repeated interviewing of several experts until a consensus is reached. Other data, such as the current acreage infested with giant reed, is based on the spatial quantification of aerial photos (Yang 2008) and is not subjected to the Delphi technique. Because the evaluation, release, and effectiveness of the biological control agents remain under investigation, the results presented in this thesis are considered preliminary.

This research is directed to estimating unimpeded *Arundo* acreage expansion and then anticipated effects of control, water savings, and associated economic and financial implications of the USDA–ARS, Weslaco, Texas *Arundo donax* biological control project. Within this scope, several steps are required in estimating the various economic and financial impacts of the biological controls. For example, the temporal, unimpeded expansion of the plant must be approximated, along with water use, to establish a baseline for comparative use in subsequent analyses. Next, the expected control levels of the biological agents' effects on *Arundo* are estimated, with the associated water savings compared to the baseline. The value of the anticipated net water savings assumes the "saved" water is used toward irrigating crop acreage over a 50-year planning horizon. Next, a benefit-cost analysis and the economic and employment impacts of the water savings are estimated. Finally, the per-unit costs of water savings are calculated.[7]

***Arundo* Attributes and Biological Control Program**

The calculation of benefits from the *Arundo* biological control program to the Texas Lower Rio Grande Valley requires the modeling of certain *Arundo* attributes, such as the unimpeded rate of expansion (in acres) over time. Additionally, certain processes and parameters regarding the biological control program are modeled over time, e.g., biological control protocol and effectiveness. Finally, *Arundo*'s water use, or consumption, and the amount of net water saved attributable to the use of biological control agents are modeled. The quantity of water saved and the calculated value of water (for agricultural purposes) provide a basis to estimate expected program benefits.

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[7] The economic impacts are estimated based on the expected efficacy of the biological control program. Any further research which significantly changes scientists' anticipated control rates will change these associated economic and financial results. Sensitivity analyses on this and other control factors are included in this thesis to illustrate the possible range of outcomes forthcoming that may be different from the current designated expected values for such factors.

Acreage Expansion

An undisturbed baseline scenario with continuous, natural, unimpeded *Arundo donax* plant growth and acreage expansion is estimated to model the amount of water saved from control of *Arundo donax*. This benchmark in *Arundo* growth is established by comparing the number of known *Arundo* acres in 2002 to estimated 2008 acres (Yang 2008), and then using an inter-temporal expansion rate to project the number of *Arundo* acres beyond 2008. That is, uncontrolled *Arundo* acreage dynamics are estimated using a linear growth curve and are based on data of *Arundo* acreage (provided by Yang 2008) between 2002 and 2008.

USDA 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 5): 15,715 acres 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 assuming a geometric growth rate suggests an annual growth rate of 2.36%.[8] 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 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 5). Recognizing the study area

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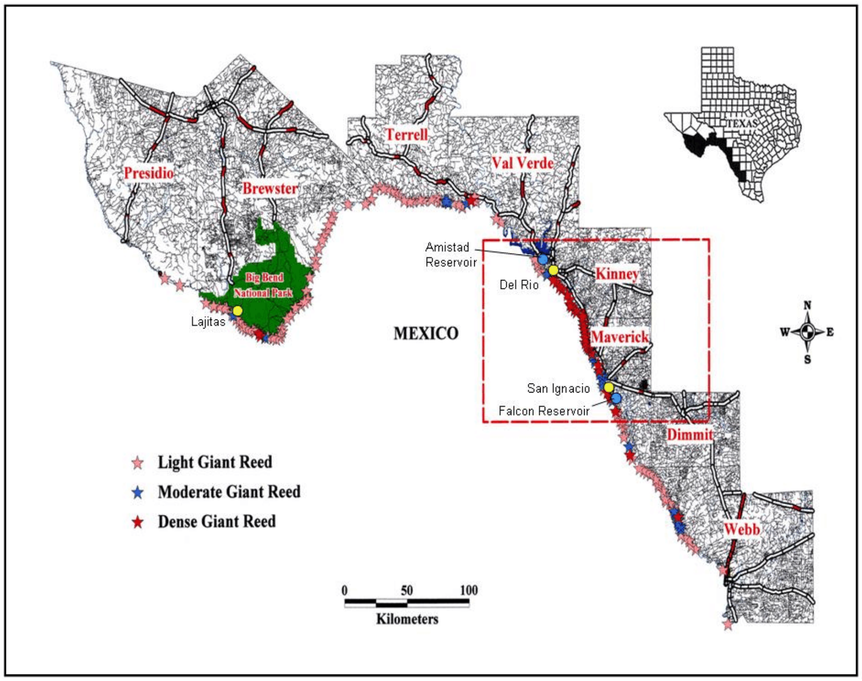
[8] $15\%=(1+0.0236)^6-1.0$, with 6 representing the number of years of growth between 2002 and 2008.

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.[9]



Source: Modified from Everitt et al. 2004.

Figure 5. Map of the Rio Grande [River] showing the study area of the USDA–ARS, Weslaco, Texas *Arundo donax* biological control program

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 to account for the impact of the natural wasp infestation at Laredo,

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

which is the only location in the project area observed to contain the natural wasp at this time. The natural-occurring wasp is exhibiting approximately 5% control against the giant reed in a restricted section approximately one mile long (Goolsby 2008b).

The total 5% control effect observed in this sub-section of the study area is adopted, subdivided, and allocated consistently across each mile of the 170-mile target control zone. The natural-control 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. The impact of the natural occurrence of the wasp, acting alone, suggests a minimal reduction in acres and/or control of *Arundo*.

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 in the form of fewer acres, but rather in the form of a reduction in the density and height of the plant, as well as possibly some modest acreage reduction from the projected baseline. This study uses calculated, reduced acres, however, as a proxy for reduction in *Arundo* biomass. This proxy is an assumption of convenience for the analysis, and assumes the analytical results are comparable to reality.

Biological Control Protocol

All costs, past and expected, for the biological control program are estimated by USDA–ARS scientists at Weslaco, Texas. The program receives $1 million per year for the first four years of operation (2007-2010). In 2011, the annual funding is anticipated to increase by $1 million per year, until a total of $5 million is reached in 2014. Subsequently, the program is assumed to begin shut-down operations, as anticipated funding decreases to $1.5 million in 2015 and $500 thousand in 2016. The program is scheduled to terminate at the end of 2016 (Goolsby 2008b).

Release of the biological control agents is expected to begin 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 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. That is, the number of miles for the biological control agent application each year are based on how many river miles the USDA–ARS, Weslaco *Arundo* project can treat with available funds.

In 2009, the release of the two biological control agents[10] will occur on a one-river-mile segment of *Arundo* acres at Laredo, Texas, at an estimated cost of one million dollars.

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[10] The initial release of the wasp occurred on April 29, 2009 and the release of the scale is expected to occur during the summer of 2009 (Goolsby 2009d). Although these releases begin at different times, the impact of the insects is calculated as if the insects were released simultaneously; thus, the compounding effect occurs in the calculations more quickly than likely to occur in reality.

This area is targeted specifically by the Department of Homeland Security and is an area in which control is a priority due to safety concerns of Border Patrol agents (Goolsby 2008b). After Year 1, five years of increased funding are expected for the program, with 169 miles remaining to be treated. To calculate the number of miles controlled per year during the remaining five years of the release program (2010-2014), an arithmetic progression (S_5) is used (Equation 5). Equation 6 uses the results from Equation 5 to detail the calculation of the proportion of *Arundo* miles treated during each of years 2 through 5 of the program:

Equation 5:
$$S_5 = \sum_{i=1}^{5} i = 1 + 2 + 3 + 4 + 5 = 15, \text{ and}$$

Equation 6:
$$\text{Control Factor for Year}_i = \frac{\text{Year Count of Program} - 1}{S_5}.$$

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 (Table 1).

Table 1. Implementation Schedule for *Arundo donax* Biological Control Program in the 170-Mile Reach of the Rio Grande [River] Between San Ignacio and Del Rio, Texas, 2009-2014

Year	Beginning Untreated Miles	Year of Program (i)	Control Factor[a]	Treated/ Controlled Miles	Remaining Untreated Miles
2009	170.00	1	---	1.00	169.00
2010	169.00	2	0.07	11.27	157.73
2011	157.73	3	0.13	22.53	135.20
2012	135.20	4	0.20	33.80	101.40
2013	101.40	5	0.27	45.07	56.33
2014	56.33	6	0.33	56.33	0.00
Total			1.00	170.00	

[a] The numerator is the year of the program minus one and the denominator is

$$S_5 = \sum_{i=1}^{5} i = 1 + 2 + 3 + 4 + 5 = 15.$$

Control Effectiveness

After estimating the area of control, the efficacy of the insects (i.e., control effectiveness) is estimated. The anticipated potential effectiveness of the proposed wasp and scale biological control program is needed to determine the amount and associated value of the expected water savings (expressed in acre-feet and dollars), as well as the potential economic impacts of the saved water to the Lower Rio Grande Valley. Certainly, crop prices, weather conditions, and other related factors influence the results, but the central focus of this research is on the value of water saved due to the release of the insects. Results of several sensitivity analyses are reported to examine the effects of deviations from the control assumptions of the modeling framework used.

Since at the time of this research the project is still in preliminary stages and the biological control agents have not yet been released, USDA–ARS, Weslaco, Texas scientists provided estimates of the biological agents' efficacy for control. The estimates are based on (a) results observed in the quarantine facility at Moore Air Base in Mission, Texas, where the insects are under investigation and (b) observations in Spain, where the agents are well established in native stands of *Arundo donax* (Moran and Goolsby 2009). 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.

Annual average acres of *Arundo donax* per mile are determined by dividing the adjusted total (i.e., 80% of the total 530 miles) untreated, infested acres between San Ignacio and Del Rio by the total remaining untreated river miles (in the 170-mile stretch) as shown in Equation 7, with "i" representing the respective year. Acres of *Arundo* per mile are then multiplied by the number of miles treated in a given year "i" (Equation 8). This calculation results in 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 9).

Equation 7: $$\frac{\text{Total Untreated Infested Acres}_i}{\text{Untreated Miles of 170 Mile Stretch}_i} = \text{Acres per Mile}_i$$

Equation 8: $$\text{Acres per Mile}_i * \text{Miles Treated}_i = \text{Annual Treated Acres}_i$$

Equation 9: $$\text{Annual Treated Acres}_i * \text{Control Rate}_j - \text{Acres Controlled}_{ij}$$

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, and reach mature height within the first year of growth (Rieger and Kreager 1989) and becomes lignified as the first growing season ends and fall begins (Decruyenaere and Holt 2001), (i.e., the shoot reaches maturity in one to two years). The scale attacks the root and sheath of the plant, while the wasp attacks the shoot and new growth (Goolsby 2007); thus, the combined potential control effects are expected to be realized during a two-year treatment time frame. 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). By the third year, mostly new growth will occur, creating ideal conditions for the wasp to thrive and be effective in mitigating *Arundo* stands without requiring additional releases into the previously-treated zone, while the scale will continue to attack the old growth.[11]

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[11] These control estimates account for control by both the wasp and scale simultaneously. Approval for the other two proposed insects (i.e., the fly and the leafminer) have not yet been granted, as the USDA–ARS, Weslaco, Texas has not yet completed the investigation of the insects. Consequently, the potential effect of the fly and the leafminer are not considered in this thesis research.

Potential Water Saved

The planned area of treatment will occur between Amistad Reservoir (at Del Rio) and Falcon Reservoir (south of Laredo) (Figure 5). Any water saved above Amistad Reservoir and between Amistad Reservoir and Falcon Reservoir is, in effect, water that does not have to be released from Amistad Reservoir (Rubinstein 2008). Amistad Reservoir is twice as efficient as the Falcon Reservoir in terms of water retention (i.e., less seepage and evaporation). Therefore, water is stored at Amistad Reservoir and only released to Falcon Reservoir when required to meet a water request from downstream. 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). That is, any marginal water gained in addition to water currently present in the river system is considered a 100 percent gain to the system (Rubinstein 2008).

As stated earlier, this study uses a simplifying assumption that 67% control of the size and density of the plant is equivalent to reducing total acreage by 67%. The annual difference between the untreated baseline acreage situation and the reduced treatment acres is calculated to obtain the number of *Arundo* acres 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 annual amount of water saved. 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. Water use and regrowth by native replacement vegetation must also be considered, however, to realize a net estimate of water savings.

Regrowth of native vegetation is assumed to occur at the same rate as *Arundo* is reduced, i.e., native vegetation reemerges simultaneously with *Arundo*'s mitigation.[12] Although water may be saved with the reduction of *Arundo*, emerging native riparian vegetation will use an estimated amount of water equivalent to one-third (33%) of that used by *Arundo* (Oakins 2001). This suggests a water savings of only two-thirds the original *Arundo* water use on the acres of control.[13] Of this remaining two-thirds (67%) amount of water saved from the reduction of *Arundo* after accounting for native vegetation water uptake, 50% belongs to Mexico and 50% to the U.S. (Rubinstein 2008). Thus, only one-

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[12] The simultaneous reduction in *Arundo* with native vegetation re-emergence is a conservative assumption, as a lag in regrowth is likely, i.e., the amount of saved water identified in this research may be a slight underestimate of the total net water saved.

[13] This research assumes that water savings from the reduction in the number of *Arundo* acres is equal to water savings from the reduction in *Arundo*'s size and density.

third (33%) of the gross water saved is net water saved that can be used for irrigation by farmers in the Rio Grande Valley.[14]

Figure 6 is an illustration of the Rio Grande water flow acknowledging *Arundo*'s current 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. 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*, i.e., two-thirds total savings multiplied by one minus the 1/3 amount consumed by native vegetation (2/3 * 2/3 = 4/9), with that amount divided equally between the U.S. and Mexico (Figure 6). Under the assumption of this study, the *Arundo* acres are reduced by 2/3's, hence 1/3 of the baseline acres remain in *Arundo*. 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. Thus, the estimate of 2/9 of the original 4.37 acre-feet of water consumed by *Arundo* is available for irrigated agriculture in the Texas Lower Rio Grande Valley.

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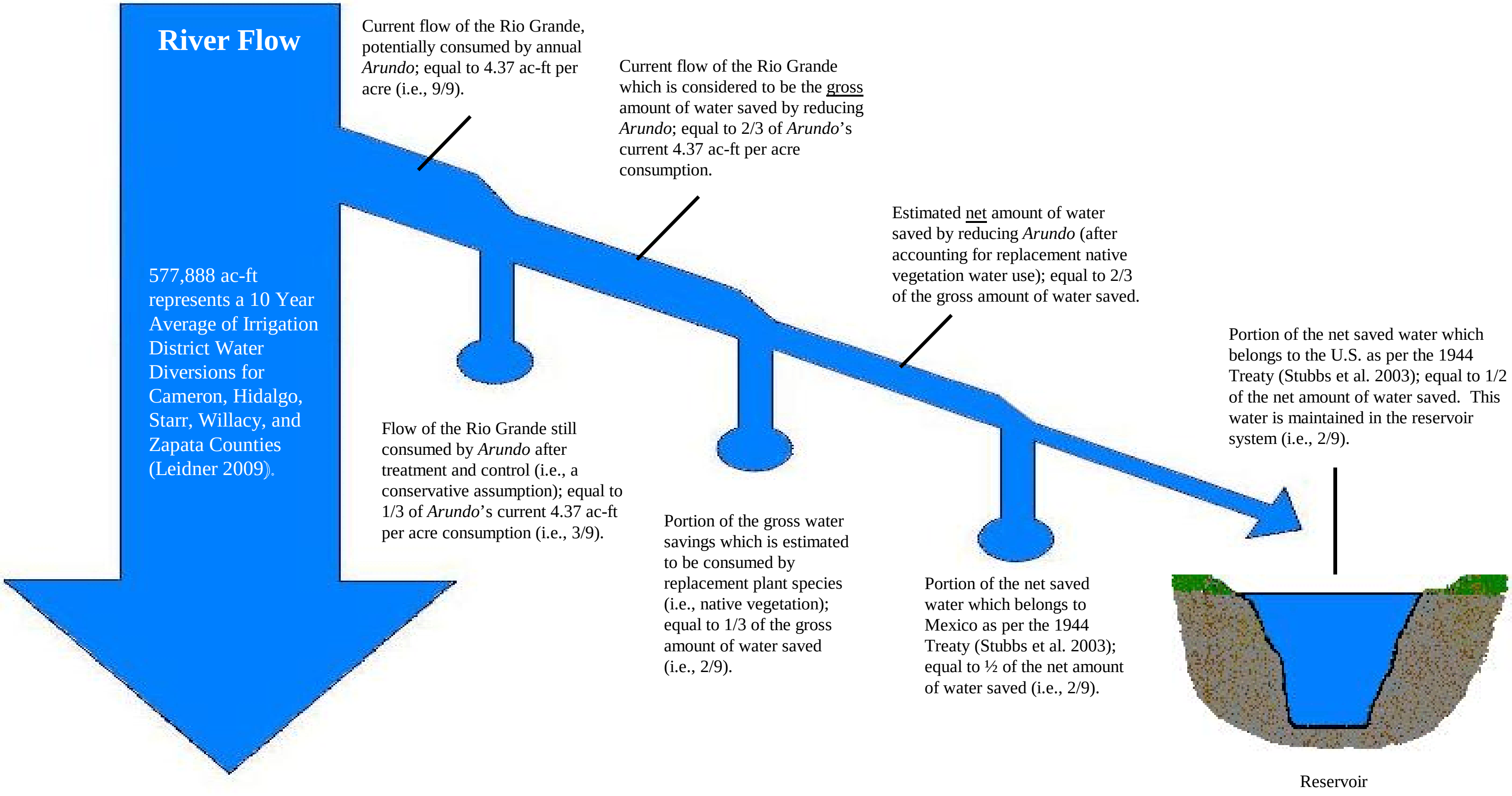
[14] The valuation of water for use on irrigated crops is based on the criteria that municipalities in the area have a priority for water supply and are already receiving the amount they need, i.e., they receive first priority to ensure sufficient supplies exist to handle their needs. As a result, all additional water realized through the mitigation of *Arundo donax* is assumed to be used in irrigated agriculture and adds value to crops. Farmers will convert some dryland crop acres to irrigated crop acres, as irrigated crops typically lead to higher yields and greater income, resulting in positive returns to water.



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 6. 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

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 used 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 on *Arundo donax* in the Rio Grande Basin. Because the net water saved is assumed to be used to increase irrigated acreage and convert some dryland agricultural acreage to irrigated agricultural crops, a crop enterprise budget is a major building block of the economic analysis. Based on historical acres of each crop, a composite acre is developed to reflect the average 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 marginal crops to determine the net returns to water, using both market and normalized prices.[15] These values are used in conjunction with the baseline model developed for *Arundo* expansion to

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

calculate the market benefits at the farm level, the benefits to society, and the benefit-cost, sensitivity, and economic impact analyses. The cost of the biological control program is compared to the amount of water saved to derive the per-unit cost of water saved.

Mexico is also participating in a biological control program for giant reed, similar to the United States, and will eventually be releasing the control agents on the Mexican side of the Rio Grande (Goolsby 2009a). Any benefits provided to Mexico from either the Mexico biological control program or the U.S. biological control program (including (a) any "U.S." insects spreading to Mexico, and (b) the value of saved water allotted to Mexico from the U.S. reduction in *Arundo* acres) are not accounted for in this analysis. Likewise, any benefits provided to the U.S. from Mexico's insects spreading to the U.S. are not included in this research. Since the analysis accounts for a reduction of giant reed on both sides of the Rio Grande, the benefits of the USDA biological control program from the reduction in *Arundo donax* are conservatively underestimated in this thesis research.

Crop Enterprise Budgets

Crop enterprise budgets are developed for specific crops by the Texas AgriLife Extension Service (AgriLife Extension) for several regions across Texas. The budgets include the crops' expected average market prices, yields, inputs, and input costs, and are used to assist farmers in planning for an upcoming growing season. In this study, the 2007 crop enterprise budgets for Texas Region 12[16] are used to aid in the determination of returns to water for the region (Texas AgriLife Extension Service 2007). When determining the value of the saved water, two sets of crop prices are used: (a) current expected prices received by farmers, and (b) normalized prices (U.S. Water Resources Council 1983; Griffin 2006), which are developed to account for significant price fluctuations in the short term (Roberts 2007), as well as for removing the effects of federal government farm programs.

Composite Acre Development

The most current available data on the number of planted acres and the appropriate 2007 Region 12 AgriLife Extension crop enterprise budgets are used to develop a composite acre for (a) dryland, and both (b) low- and (c) high-value marginal crops. A composite acre is a representative acre comprised of the respective proportionate composition of different crops in a certain region (Lacewell et al. 1995). The artificially-engineered, representative acre includes the appropriate percent of each crop that occurs in the study area. National Agriculture Statistics Service (NASS-USDA 2008a, 2008b) data for planted acres are averaged for the years ranging from 2000-2007 for each crop. Exceptions occur with vegetables and citrus, however, where only the 2002 census data are available, and sugarcane, where only 2000-2007 harvested acres data are available.

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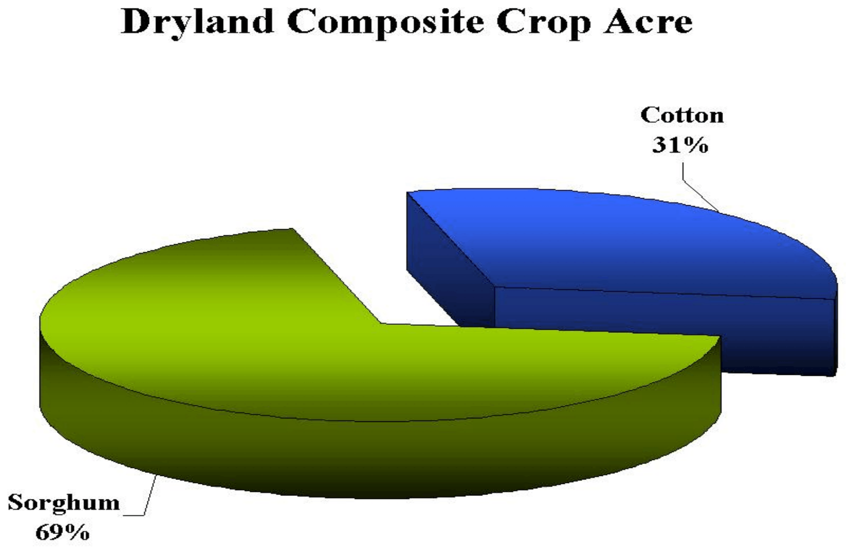
[16] Region 12 includes the counties of Atascosa, Brooks, Cameron, Dimmitt, Duval,, Frio, Hidalgo, Jim Hogg, Jim Wells, Kenedy, Kleberg, La Salle, Live Oak, Maverick, McMullen, Starr, Webb, Willacy, Zapata, and Zavala (Texas AgriLife Extension Service 2007).

A composite acre for dryland crops in the Valley is determined by obtaining weights for the two predominant dryland crops for which Texas AgriLife Extension 2007 enterprise crop budgets are available: cotton and sorghum (Figure 7). The construction of this dryland composite acre is accomplished by dividing the number of planted acres for each crop by the total of both crops' acreage. Once these proportionate weights are calculated, the weight for each crop is multiplied by its respective net returns to land, which are identified using the Texas AgriLife Extension Service 2007 crop enterprise budgets for cotton and sorghum. These weighted dollar amounts are then added to obtain the net returns to land for the dryland composite acre.



Source: Developed with Data from USDA–NASS 2008a.

Figure 7. Crop proportions for the dryland composite acre for the Lower Rio Grande Valley, 2007

To facilitate estimating a range of potential benefits, two irrigated-crop composite acre budgets are also established: (a) those with relatively low-marginal returns, such as cotton,[17] corn, and sorghum (Figure 8), and (b) those with high-marginal returns such as citrus and vegetables in addition to cotton, corn, and sorghum, as shown in Figure 9.

The estimate of benefits based solely on low-marginal return crops presumes a short-run perspective in which the irrigation water demands of high-marginal return crops are already satisfied in terms of water usage; as a consequence, additional supplies of "created" water will be used on lower-valued crops. Alternatively, the estimate based on a composite acre including high-marginal return crops may represent a longer-term scenario in which the existing acreage of higher-marginal value crops might increase based on market conditions. Since acreage is difficult to determine for individual crops in the citrus and vegetable category, the budgets and water use for grapefruit are used as a proxy for all citrus, and similar information for onions is used as a proxy for all vegetables[18] (Sturdivant et al. 2004).

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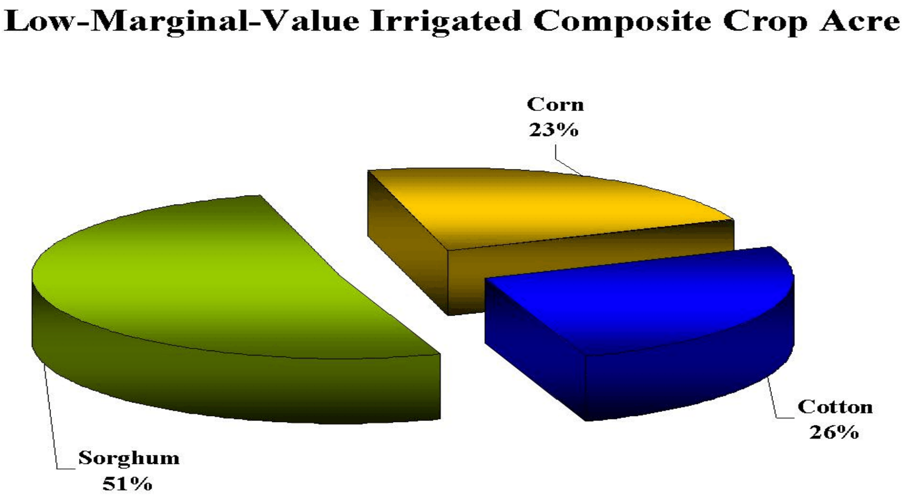
[17] The Texas AgriLife Extension Service 2007 crop budget for cotton identified cotton lint and cotton seed prices separately. When researching the normalized price for cotton seed, the market price appeared lower than the normalized price. Since normalized prices remove any government subsidies and smooth out the pricing over time, the normalized price for cotton seed is used in calculating the market gross revenues for this commodity.

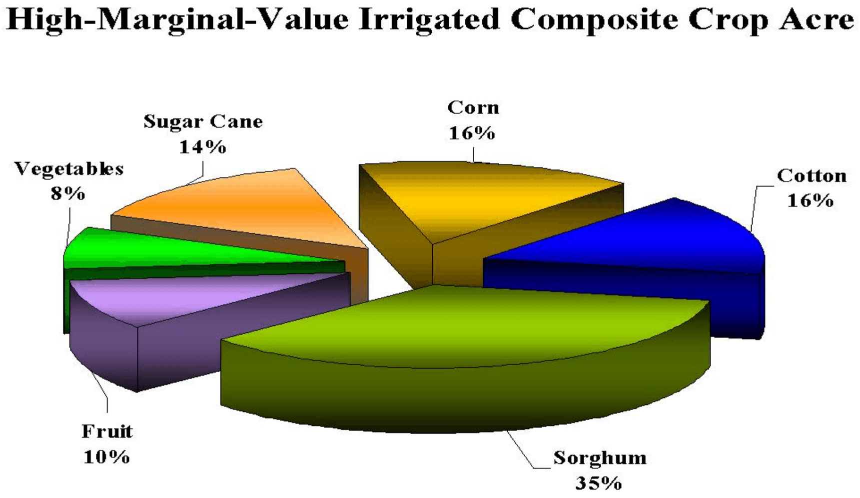
[18] Onion farmers receive highly-variable prices based on year and quality (Sturdivant 2009b). Prices were favorable in 2007, suggesting the price of onions, and thus, the price of vegetables used in this research may be overvalued for a typical year. However, vegetables are a relatively small proportion of the composite acre (i.e., 8%), suggesting any bias associated with the 2007 vegetable price is slight.



Source: Developed with Data from USDA–NASS 2008a.

Figure 8. Crop proportions for the low-marginal-value irrigated composite acre for the Lower Rio Grande Valley, 2007

The Texas AgriLife Extension Service 2007 crop budgets are also used to obtain the market prices for citrus (grapefruits) and vegetables (onions). The current market value for sugarcane is obtained from the September 2008 statement of fiscal operations for the Rio Grande Valley Sugar Growers, Inc.



Source: Developed with Data from USDA–NASS 2008a; 2008b.

Figure 9. Crop proportions for the high-marginal-value composite acre for the Lower Rio Grande Valley, 2007

Additionally, net returns obtained from the irrigated crop budgets are used to calculate net returns to land and water, as only water delivery costs (not the cost of water itself) are subtracted from the gross revenue in the Texas AgriLife Extension Service budgets. Since there are no statistics available on the number of planted acres differentiated according to types of farming practices (i.e., conventional versus reduced till), a simple average of the net returns to land and water is calculated across these different tillage practices on each applicable crop.

Consideration of the amount (i.e., acre-feet) of water used per respective composite irrigated acre facilitates determining a range of per-unit values of water used for irrigation. The difference in net returns between the two scenarios of composite irrigated acres (low-value versus high-value) and the composite dryland acre situation represent per-acre returns to water. To estimate an upper bound of the per-unit (acre-foot) returns to water, the returns to the dryland composite acre are subtracted from the returns to land and water for the high-value irrigated composite acre, and the result is divided by the weighted water use (acre-feet) on the high-value irrigated composite acre. The same process is followed for obtaining the lower bound, using information for the irrigated composite acre for crops with lower net marginal returns.

Associated with the control of *Arundo* is an expected increase in irrigated acres that are converted from dryland production in the defined study area. Such acreage conversion suggests increased yields and values of production. The initial estimate of the value of *Arundo* control is based on the increase in returns due to the increased availability of irrigated water 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.

Cost of Biological Control Protocol

The cost of the USDA–ARS, Weslaco, Texas biological control program began in 2007 at $1 million for the year. Since the nature of the control protocol is dependent upon the amount of money available, 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 available annual budget is expected to remain constant at $1 million until 2011, when the annual funds increase by $1 million successively through 2014, until $5 million is reached. In 2015, plans are for the program to begin phasing out, with the annual budget expected to be reduced to $1.5 million, and then to $500,000 in 2016, the final year of the program. The present value of the total budget for the program during 2007-2016 is inflated by 2.043% (for years 2007 and 2008) and discounted by 6.125% (for years 2010-2016) to 2009 dollars.

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 value of water in irrigation is used as the appropriate measure of benefits.

The values for the low- and high-marginal value irrigated crop composite acres calculated with market prices are used to estimate the direct impact of additional water available to Valley farmers. By multiplying the value of water for low- and high-value crops by the water saved in acre-feet, a range for the value of saved water to the Valley is obtained. 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 biological control agents.[19] These calculations are repeated for each year over 50 years, 2009 through 2058. An annual inflation rate of 2.043% (Rister et al. 2008) 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. 2008). The summation over 50 years of each year's total value of saved water calculated with the low-marginal values represents the lower bound of the present value of saved water to the Valley over 50 years. The summation over 50 years of each year's total value for saved water calculated with the high-marginal value of water represents the upper bound of the present value for saved water to the Valley.

Benefit-Cost Analysis

For an evaluation of the value to society of this program, the benefit-cost ratio is often used (U.S. Water Resources Council 1983). Benefits are estimated using normalized crop prices rather than market prices, as normalized prices remove the impacts from federal government farm program subsidies and smooth out short term price fluctuation (Miller 1980). To estimate total social benefits, the normalized prices for corn, cotton, and sorghum obtained from the USDA–Economic Research Service (Roberts 2007) are applied, while the market prices for vegetables and citrus are based on the crop enterprise

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[19] Each 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 normalized prices indicates a total value of water saved, based on the potential returns to farmers with irrigated crops from the increase in water supply, net of the dryland composite acre value.

budgets and are used as the normalized prices, i.e., no federal government farm program subsidies exist for vegetables and citrus (Table 2).

The normalized price for sugarcane reported in the USDA–ERS publication of the 2007 normalized prices is reported as boxes of sugarcane used for sugar. The implication of this definition is that the normalized price extends beyond the farm gate and includes the price received by the mill for refined sugar (i.e., includes processing returns). The market price for sugarcane from the Texas AgriLife Extension Service crop budgets only includes the price of sugarcane received at the farm level; thus, the price of sugarcane on the crop budget from Texas AgriLife Extension Service is much lower than the normalized price from the USDA–ERS. The inconsistency between these two numbers is accounted for (i.e., corrected) by taking a simple average of the ratios of normalized prices to market prices for other commodities (i.e., corn, cotton, and sorghum), and multiplying the market price for sugarcane by the calculated ratio of 0.81. The result is the calculated normalized price for sugarcane used in this study.

Table 2. 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

[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 subsidies 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.

The process for calculating the value of water per acre-foot using modified returns to water (normalized prices) is used to determine the values for both low- and high-value composite acres. The normalized composite acre values are multiplied by the number of acre-feet of water saved from the use of the biological control agents to determine the value to society of the saved water from the biological control program. The annual costs of the beneficial-insect control program and annual benefits are inflated at 2.043% and then discounted at 6.125% discount rate to calculate the present value of benefits and costs (Rister et al. 2008).

The society values based on normalized crop prices are used in developing the benefit-cost analysis of the project for the Rio Grande Basin. 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 are performed to account for uncertainty related to key data input variables used in the analyses. Sensitivity data tables are created where two variables are varied in the scenario holding all other variables constant (Walkenbach 2007). These tables provide a more robust set of outcomes whereby the decision maker and stakeholders are more informed as to the possible ranges of benefits.

Sensitivity data tables for the present value, annuity equivalent, and benefit-cost ratio are calculated using low- and high-marginal value composite acres, in which *Arundo* water use and the control effectiveness of the program are varied. Five additional sensitivity scenarios are investigated in which *Arundo* water use is varied while the

(a) *Arundo* expansion rate, (b) natural vegetation water use, (c) value of water, or (d) costs of the program are simultaneously varied as the second variable, respectively, using the low-marginal value composite acre. Sensitivity analyses are only performed for the regional benefits, i.e., state benefits are not evaluated.

Background for 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). The model is built around the North American Industry Classification System (NAICS) and contains 509 sectors of the economy (U.S. Census Bureau 2009). This model generates multipliers to estimate increased economic activity and employment resulting from an increase or change in gross revenue, by economic sector.[20] Multipliers can be developed for a county, a region such as the Lower Rio Grande Valley, a state, and the entire United States. The IMPLAN (input-output) approach to estimating economic impact (using multipliers) facilitates measuring the consequences (including benefits) of existing and potential activities (Coppedge and Youmans 1970).

Three types of multipliers are used in this study-economic output, value-added, and employment multipliers-each multiplier consisting of three components: (a) direct

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[20] The sectors used in this study include: (a) grains farming (used for both corn and sorghum), (b) cotton farming, (c) fruit farming, (d) vegetable and melon farming, and (e) sugarcane and sugar beet farming.

impacts, (b) indirect impacts, and (c) and induced impacts. Recalling from the literature review section, the multipliers used in the IMPLAN model only measure the impact up to and including the farm level (i.e., backward linkages). Additionally, an understanding of certain terms is critical for realizing the implications of the economic impact results.

Definitions for Each Multiplier Type

- **Economic output** - The total value of goods and services (production) by industry, including purchases received from one sector to another. Output multipliers measure the change in sales of goods and services throughout the economy resulting from an economic activity, or event (change in final demand).
- **Value added** - A measure of income including employee compensation, proprietor income, other property income, and indirect business taxes. Value added can also be measured as an industry's gross output, less the purchase of intermediate inputs (from other sectors). As such, value added for an industry is its contribution to gross domestic product (GDP). Value added multipliers measure the change in value added resulting from an economic activity, or event (change final demand).
- **Employment** - The number of jobs, full-time and part time, by industry. Employment multipliers measure the change in the number of jobs per million dollars of output.

Definitions for Components of Multipliers

- **Direct impact** - changes to “expenditures and/or production values specified as direct final demand changes” (Minnesota IMPLAN Group, Inc. 2004), e.g., irrigated and dryland farming, resulting directly from the additional water availability.
- **Indirect impact** - impacts to the study area associated with input industries (e.g., fertilizer companies experiencing increased business from the farmers).
- **Induced impacts** - impacts associated with the wage increase and spending from the increased business to these industries (Miller and Armbruster 2003).

Specifics for Economic Impact Analysis

Market prices for crops are used to generate the gross revenues for each crop and to estimate the employment and economic activity impacts to the region due to the *Arundo* biological control program. The irrigated composite acre for low- and high-value crops generates an increase in total revenue value (gross sales) for each assumed level of saved water value, respectively. Similarly, a composite dryland (non-irrigated) acre for agriculture represents reduced total revenue as that acre shifts to irrigated production.

The resulting net water saved is allocated to an irrigated composite acre based on specific crop irrigation water usage levels specified in the Texas AgriLife Extension Service 2007 crop enterprise budgets for the region (Texas AgriLife Extension Service 2007). Dividing the total volume of water saved by the composite acre water use (low-and high-marginal-value composite acres, respectively) results in the number of converted acres from dryland to low- or high-marginal value irrigated agriculture, respectively. The converted acres are multiplied by the proportionate crop percentage in the respective composite acre to obtain the number of acres converted from dryland to each particular crop. 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.

The net change (increase) in gross revenue associated with the additional irrigated acreage above the gross revenue for the replaced dryland acres provides an estimate of the net increase in gross returns attributable to the *Arundo* control program. The change in gross revenue is estimated for each year of the 50-year projection period (2009 through 2058), during which there is increasing *Arundo* control and hence, greater annual benefits to be realized over time. This net change in gross revenues is divided by the 2007 deflation factor in IMPLAN to deflate the 2007 value to 2006 dollars, as 2006 input data are used in the IMPLAN model.

The deflated change in gross revenues is multiplied by appropriate multipliers within IMPLAN to generate the marginal employment and economic activity effects of the program. Since more water is saved each year (as additional *Arundo* acreage is mitigated), more acres will switch from dryland to irrigated crops each year, creating different annual gross revenues and different annual economic impacts to the region.

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 (e.g., conservation and desalination programs used in the Texas Lower Rio Grande Valley). 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. 2008). Additionally, cumulative water (acre-feet) is discounted at the social discount rate of 4.00%. The annuity equivalent (value per year) for both dollars and water is calculated over the 50-year planning horizon using Equation 10.[21] The values are then divided, obtaining the per-unit life-cycle cost of saving water via the biological control program.[22]

Equation 10:

$$\text{Life} - \text{Cycle Cost} = \frac{\dfrac{\text{Present Value of Dollars}}{\left[\left(1-\left(1+\text{Standard Discount Rate}\right)^{-\text{Planning Horizon}}\right)\Big/\text{Standard Discount Rate}\right]}}{\dfrac{\text{Present Value of Water Saved}}{\left[\left(1-\left(1+\text{Social Discount Rate}\right)^{-\text{Planning Horizon}}\right)\Big/\text{Social Discount Rate}\right]}}$$

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[21] 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."

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

In the following section, the methods and assumptions described above are applied to determine the economic implications of the *Arundo* control program. For several estimates, ranges are provided to account for uncertainty related to prices, effects, biology, etc.

RESULTS

Programs such as the *Arundo* biological control project are complex and can have far-reaching implications. There are many factors to consider and any projections into the future are subject to economic, environmental, and policy changes. Therefore, this is a presentation of the “best” estimate of economic factors and related implications available at this point in the program. To date, the expected results indicate positive returns and a positive 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 **Infestation Level**

The estimates of 15,715 acres of Rio Grande riparian invaded by *Arundo* in 2002 and 18,072 acres in 2008 (Yang 2008) are based on USDA–ARS aerial photos. Given these values, the linear geometric (compounded) annual expansion rate of *Arundo* is 2.36%. Additionally, it is estimated that 80% of the acres infested are located between San Ignacio and Del Rio, Texas, accounting for 12,572 acres infested in 2002, while the remaining 20% is located between Del Rio and Lajitas, Texas, or 3,143 acres in 2002 (Yang 2008). At the end of 50 years (i.e., in 2058), in the absence of any mitigation efforts and/or other effects, the total number of *Arundo* acres is expected to be 57,912, as indicated in Table 3.

Table 3. Projected Beginning-Year Acres of *Arundo donax* with and without the Natural Wasp (*Tetramesa Romana)* Impact Between San Ignacio and Del Rio, Texas and Del Rio to Lajitas, Texas, 2009-2058[a]

	Acres of *Arundo*					
	No Natural Wasp Present[b]			Natrual Wasp Present		
Year	San Ignacio to Del Rio	Del Rio to Lajitas	Total	San Ignacio to Del Rio	Del Rio to Lajitas	Total
2009	14,458	3,614	18,072	14,453	3,614	18,068
2015	16,626	4,157	20,783	16,592	4,157	20,748
2025	20,987	5,247	26,233	20,882	5,247	26,129
2035	26,491	6,623	33,113	26,281	6,623	32,904
2045	33,439	8,360	41,798	33,077	8,360	41,436
2055	42,209	10,552	52,761	41,629	10,552	52,181
2058	46,330	11,582	57,912	45,640	11,582	57,223

[a] Refer to the Map of Texas (Figure 5) 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.

The mitigation effects of the natural wasp infestation are mathematically applied only to the *Arundo* acres between San Ignacio and Del Rio, Texas. This mathematical reflection matches the observations of the limited natural presence of the wasp located in a one-mile segment of the Rio Grande observed at Laredo, Texas. Since the one-mile area where the wasp has been observed is experiencing approximately 5 percent control, 0.05 was divided by 170 miles of the principle project area to obtain the percent control per mile, i.e., 0.0294118%.

As presented in Table 3, when the effect of the limited natural wasp presence in the one-mile observed area is considered and allocated across the total acres in the study area,

- 2009: 14,453 acres remain compared to 14,458 "no natural wasp" *Arundo* acres;
- 2015: 16,592 acres remain compared to 16,626 "no natural wasp" *Arundo* acres;
- 2025: 20,882 acres remain compared to 20,987 "no natural wasp" *Arundo* acres;
- 2035: 26,281 acres remain compared to 26,491 "no natural wasp" *Arundo* acres;
- 2045: 33,077 acres remain compared to 33,439 "no natural wasp" *Arundo* acres;
- 2055: 41,629 acres remain compared to 42,209 "no natural wasp" *Arundo* acres; and
- 2058: 45,640 acres remain compared to 46,330 "no natural wasp" *Arundo* acres.

The acreage of "no natural wasp" *Arundo* acres between San Ignacio and Del Rio Texas, combined with the acreage with no natural wasp presence between Del Rio and Lajitas, Texas, total to 18,068 acres in 2009; 20,748 in 2015; 26,129 in 2025; 32,904 in 2035; 41,436 in 2045; 52,181 in 2055; and 57,223 in 2058 (Table 3). A maximum number of *Arundo* acres, 57,223 acres, is forecast for the 530 miles between San Ignacio and Lajitas, Texas in 2058, accounting for the effects of the natural wasp presence, compared to 57,912 *Arundo* acres with no form of control. Thus, the impact of the observed natural wasp presence at Laredo, Texas is a reduction of 689 acres of *Arundo* in 2058, suggesting a minimal expected impact of the natural wasp without the use of additional (i.e., introduced) biological or other control agents.

The implications of the biological control program recorded in this study are applicable only to the riparian area immediately along the Rio Grande from San Ignacio to Del Rio, Texas after accounting for the impact of the natural wasp (i.e., Table 2). This is the planned target area for the biological control agents.

With the baseline model of the number of *Arundo* acres in the targeted study area (i.e., San Ignacio to Del Rio, Texas) established, the number of *Arundo* acres per mile in the first year of treatment (2009) is determined by dividing the 2008 ending *Arundo* acres (i.e., 2009 beginning acres) of 14,453 (Table 3) by the total number of river miles in the targeted study area (170 miles). The resulting calculated "density" of 85.0 *Arundo* acres per mile is then multiplied by the number of miles to be treated (i.e., one) to determine the number of acres treated for 2009, 85.0. This process of calculating the year’s density is then repeated for the subsequent years of the *Arundo* biological control program recognizing the number of miles already treated and the appropriate density in the remaining, untreated miles for each year, while accounting for the expansion of the giant reed over time in the untreated areas.

As displayed in Table 4, the USDA–ARS is planning to treat one mile with a density of 85.0 *Arundo* acres, or 85.0 acres in Year 1 (2009). In Year 2, there is an additional 11.27 miles to be treated where the density is 87.0 *Arundo* acres, or 980.2 total acres; in Year 3, 22.53 miles are treated at a density of 89.02 *Arundo* acres per mile, or 2,006.0 acres; 33.8 miles are treated at a density of 91.1 *Arundo* acres in Year 4, or 3,078.9 acres; 45.1

miles are treated at a density of 93.2 *Arundo* acres, or 4,200.7 acres in Year 5; and in Year 6, the remaining 56.3 miles are treated at a density of 95.4 *Arundo* acres, or 5,373.1 acres. At the end of Year 6, all 170 miles will have been treated with the biological control agents.

Arundo Control Protocol

Control effectiveness by the insects is applicable to the number of acres treated per year. The treatment consists of the release of the biological agents, *Tetramesa romana* (wasp) and *Rhizaspidotus donacis* (the scale), within a different target area (segment of the river) each year. 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. 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. That is, growth does not continue to occur after the section has been treated and “controlled,” as an equilibrium is reached between the insects and *Arundo*. Thus, the number of acres controlled in the first mile treated in 2009 is 38 during year one and 19 during year two, for a total of 57 acres controlled (Table 4). As described earlier, actual control is expected to reduce the *Arundo* to one-third of the untreated size and density (after accounting for the minimal amount of control for the naturally-occurring wasp), i.e., $\frac{(85-57)}{85}=\frac{28}{85}=33\%.$ For

Table 4. Rio Grande [River] 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	0.0	1,182.1	1,182.1	10,535.0	5,188.9
PROJECT TOTAL			170.0	15,724.0			10,535.0		

[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.

convenience of discussion, the interpretation for this study is that two-thirds of the acres will be eradicated of *Arundo.*[23]

The number of acres controlled (on the "new" treated acreage) during the second year of treatment (2010) is 441.1 and 215.6 in the following year of residual control (2011), for a total of 656.7 controlled *Arundo* acres for the second segment of river treated (Table 4). This process continues through 2014 until all 170 miles are treated, and through 2015 when the residual effects of the 2014 treatment are realized. Thus, the total acres controlled by segment are: 57 acres in the first 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 4).

The application of the control agents is planned to be intensive[24] (Goolsby 2008a); therefore, the growth or expansion of *Arundo* in a treated segment is assumed to halt two years after the application of the biological agents, i.e., “steady state” conditions. With

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[23] Refer to details provided on page 38 in the sub-section titled “Control Effectiveness” regarding the various control data and assumptions.

[24] Large scale releases of *Tetramesa romana* will be conducted on the Rio Grande. Release rates of the scale have not yet been determined (Goolsby 2009a).

the control of *Arundo* by the biological control agents and added growth, the total number of *Arundo* acres remaining at the end of 2009 (first year of treatment application) is 14,749. The anticipated 67% control of the entire study area will be reached at the end 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* is expected.

The difference between the number of uncontrolled acres and the number of acres controlled by the agents represents the number of prevented acres of *Arundo* due to the biological control program. Prevented *Arundo* acres are estimated to be 40 acres in 2009, 525 acres in 2010, 1,715 acres in 2011, 3,687 acres in 2012, 6,502 acres in 2013, 10,221 acres in 2014, 11,789 acres in 2015, 16,179 acres in 2025, 21,704 acres in 2035, 28,657 in 2045, 37,409 acres in 2055, and 40,451 acres in 2058 (Table 5; Figure 10).

Table 5. Projected Acres of *Arundo* Before and After Control from San Ignacio to Del Rio, Texas, 2009 through 2058

Year	Prior to Biological Control (Baseline)[a]	Post Biological Control (Remaining Acres)	Prevented Acres of Expansion
2009	14,453	14,749	40
2010	14,790	14,609	525
2011	15,134	13,770	1,715
2012	15,486	12,159	3,687
2013	15,846	9,713	6,502
2014	16,215	6,371	10,221
2015	16,592	5,189	11,789
2025	20,882	5,189	16,179
2035	26,281	5,189	21,704
2045	33,077	5,189	28,657
2055	41,629	5,189	37,409
2058	45,640	5,189	40,451

[a] Corresponds to the beginning-year acres “With Natural Wasp Infestation,” San Ignacio to Del Rio column in Table 3 on page 65.

For this project, an *Arundo* water consumption rate of 4.37 acre-feet per acre is used as a base to estimate the impacts of reduced *Arundo* acres, i.e., the amount of water saved as a result of controlling one acre of *Arundo*. The level of control, or the number of *Arundo* acres prevented due to the biological control program, is the difference between the untreated baseline and the controlled acres (Table 5; Figure 10).

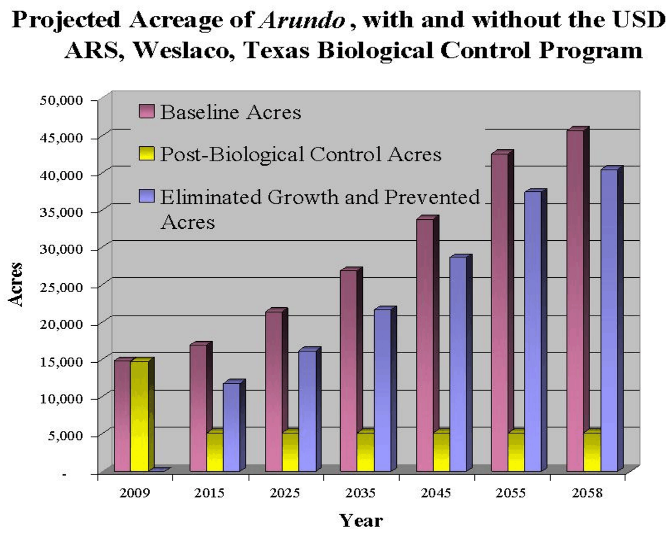

Figure 10. Representation of the number of *Arundo* acres prior to the biological control program and expected acres after the biological control program for the study area between San Ignacio and Del Rio, Texas, 2009

The reduced *Arundo* acreage (resulting from the biological control program) is multiplied by the amount of water used by *Arundo donax*, resulting in the expected gross amount of water saved. The replacement natural vegetation is assumed to grow and expand at the same rate as the *Arundo* reduction rate and consume only one-third of the amount of water that the invasive *Arundo* consumes. The annual net water savings is two-thirds of the amount that would be used by the mitigated *Arundo* acreage.[25] Of the

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[25] The one-third water use by continuing *Arundo* (level reached in equilibrium after the biological control project) is not included in the water use of the mitigated, or controlled, acreage (Figure 6). Therefore, when referencing solely the controlled acreage water use (i.e., 2/3 of the total water use), 1/3 of the water use from the controlled acreage is consumed by native vegetation. The remaining two-thirds after native vegetation water consumption is divided equally between the United States and Mexico. When referencing the total water consumption from the River, the continuing *Arundo* water use of one-third is considered (Figure 6). Thus, 1/3 of the total water use continues to be consumed by *Arundo,* while 2/9 is allocated to native vegetation, 2/9 is allocated to the United States, and 2/9 is allocated to Mexico.

two-thirds net water savings for the controlled acreage, only one-half of the saved water is realized as an annual net savings for use in the U.S., as Mexico receives a water allocation of 50% from the Rio Grande (Rubinstein 2008).

After accounting for water uptake from natural vegetation regrowth and Mexico's allotment of the water, the amount of U.S. water saved in year one totals 59 acre-feet. The amount of water saved continues to increase throughout the 50-year study horizon as the acres treated and controlled increases, 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 6). 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 6). The net annual water savings for the U.S. amounts to approximately 1.5 acre-feet for each acre of *Arundo* that is controlled, i.e., 1/3 * 4.37=1.45.

Table 6. 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, 2009 through 2058

Year	Gross Amount of Water Saved	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

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

Composite Acre

A representative composite acre is developed for dryland and two irrigated scenarios to calculate the value of saved water based on its use in converting dryland to irrigated crop production. The composite acre concept is assumed to reflect a representative acre of the crops in the Lower Rio Grande Valley for (a) dryland crops, (b) low-value irrigated crops, and (c) high-value irrigated crops. The returns to water on a per acre basis are found by subtracting the returns (i.e., dollars) to unirrigated land (identified in the dryland composite acre) from the returns to land and water for the low-value composite irrigated crop acre, and then again for the high-value irrigated crop acre. The per acre values for the two irrigated composite acre alternatives are divided by the respective water use (acre-feet) amounts for each (0.54 and 1.40 acre-feet per acre,[26] respectively), yielding the returns to water (dollar per acre-foot).

Returns to water per acre-foot for the composite acre with low-marginal value crops (including corn, cotton, and sorghum) are presented in Table 7. 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-marginal value crop composite acre. Returns to water per acre-foot of the high-marginal value crop composite acre (including corn, cotton, sorghum, citrus, vegetables, and sugarcane) are also presented in Table 7. For this 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.

Table 7. Per Acre Irrigated Crop Water Use Estimates and Returns per Acre-Foot: Low- and High-Marginal-Value Composite Acre, Texas Lower Rio Grande Valley, 2009

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

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

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[26] For each type of composite acre, each crop's water use amount is multiplied by the crop's respective proportion of the total composite acre and then added to the water use proportions of the remaining crops in the composite acre to determine the water use amount for the entire composite acre. This process is used for both the low- and high-marginal value composite acres.

The water use per acre for low- (0.54 acre-feet per acre) versus 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. Understandably, due to lower per-unit irrigated requirements, more low-value irrigated acreage than high-value irrigated acreage can be converted from dryland with a fixed quantity of saved water. That is, 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 high-value irrigated crops.

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 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-marginal-value irrigated crop composite acre and market prices of crops is over $11.02 thousand 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 8). 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 9).

Table 8. Annual Nominal Value of Water Saved on Low- and High-Marginal 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

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

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

Results for the high marginal-value crops are similarly obtained, producing a total value of $18.01 thousand 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 (Table 8). 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 9.

Table 9. Present Value of 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
Low-Marginal Value Crops	$ 97.80	$ 72.43
High-Marginal Value Crops	$ 159.87	$ 145.67

Benefit-Cost Analysis

Normalized prices are used in the benefit-cost analyses to reflect the total social benefits of the saved water. Similar to the market-price analyses, present values are estimated for the water saved with both low- and high-marginal value composite acres; however, normalized prices are used in the calculation. The low-marginal-value crop mix has a present value (normalized) of $72.43 million, and the high-marginal-value crop mix has a normalized present value of $145.67 million (Table 9).

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 (Table 10) (Goolsby 2008b). The present value of the program costs is an estimated $16.54 million (Table 10), using a discount rate of 6.125% (Table 10). The present value of benefits is divided by the present value of the project costs to calculate the benefit-cost ratio. The low-marginal returns crop mix has a benefit-cost ratio of 4.38:1, and the high-marginal returns crop mix has a benefit-cost ratio of 8.81:1 (Table 11). That is, society is projected to experience benefits between $4.38 and $8.81 for every $1 of project costs.

Table 10. Costs (Nominal and Real) of the USDA–ARS, Weslaco, Texas *Arundo donax* Biological Control Program

Year	Nominal Value ($ Million)[a]	Real Value ($ Million)[b]
2007	$ 1.00	$ 1.04
2008	$ 1.00	$ 1.02
2009	$ 1.00	$ 1.00
2010	$ 1.00	$ 0.94
2011	$ 2.00	$ 1.78
2012	$ 3.00	$ 2.51
2013	$ 4.00	$ 3.15
2014	$ 5.00	$ 3.71
2015	$ 1.50	$ 1.05
2016	$ 0.50	$ 0.33
Total	$ 20.00	$ 16.54

[a] Data for program costs were provided by Goolsby (2008b).

[b] Real value costs, in 2009 dollars are inflated at 2.043% (for years 2007 and 2008) and discounted at a discount rate of 6.125% for years 2010 through 2016.

Table 11. Benefit-Cost Implications for the *Arundo* Biological Control Program in the Rio Grande Basin between San Ignacio and Del Rio, Texas, 2009

	Social Benefits (Using Normalized Prices)		
Result Item	Low Value of Water[a]	High Value of Water[b]	Costs
Present Value ($ Million)	$ 72.43	$ 145.67	$ 16.54
Annualized Benefits ($ Million)	$ 4.68	$ 9.40	---
Benefit-Cost Ratio	4.38:1	8.81:1	---

[a] "Low Value of Water" refers to the low-marginal returns for water calculated using the composite acre for low value crops (i.e., corn, cotton, and sorghum), a value of $139.22. The values calculated with the low value of water represent the lower bound of the social benefits to be realized over the 50-year planning horizon.

[b] "High Value of Water" refers to the high-marginal returns for water calculated using the composite acre for high value crops (i.e., fruits, vegetables, sugar cane, corn, cotton, and sorghum), a value of $279.99. The values calculated with the high value of water represent the upper bound of the social benefits to be realized over the 50-year planning horizon.

The benefit-cost ratio is an indication of the returns to society per dollar of government cost. Since in both cases, 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.

Sensitivity Analyses

Sensitivity analyses are performed to account for uncertainty in selected variables, using both low- and high-marginal values of water 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, (c) natural vegetation water use, (d) value of water, (e) costs of the program, and for all cases (f) water use 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 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-marginal-value 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 only depict a range in the benefit-cost ratio of low-marginal-value crops.[27]

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

In Tables 12, 13, and 14, 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), for both low- and high-marginal-value crops in

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

Table 12. 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-Marginal-Value Crops in the Texas Lower Rio Grande Valley, 2009

		variation in annual water consumption (ac-ft)						
Low-Marginal-Value Crops		-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-Marginal-Value Crops		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

Table 13. 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-Marginal-Value Crops in the Texas Lower Rio Grande Valley, 2009

Low-Marginal-Value 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
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-Marginal-Value Crops		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

Table 14. 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-Marginal-Value Crops in the Texas Lower Rio Grande Valley, 2009

		variation in annual water consumption (ac-ft)						
Low-Marginal-Value Crops		-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-Marginal-Value Crops		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

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 12 is the range of the 2009 low-marginal-value 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 12 is the range in the 2009 high-marginal-value crops present value of expected benefits from varying *Arundo* water use and the control efficacy of the beneficial insects. The high-marginal-value 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 new adopted 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-marginal-value crops from varying the *Arundo* water use and the efficacy of the biological control agents are identified in the top-half of Table 13. 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.

For the high-marginal-value crops, 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 13. 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 new adopted 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 14 for the low-marginal-value 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-marginal-value 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 spent, 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 on the costs 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 possible return on the costs of the program.

The remaining sensitivity tables only 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-marginal-value 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-marginal value crops. Therefore, the low-marginal-value 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 Arundo Expansion Rate

In Table 15, the amount of water consumed by *Arundo* is varied across the top row and the annual expansion rate of *Arundo* after expected-realized control is varied down the

Table 15. Sensitivity Analysis, Benefit-Cost Ratio of Benefits with Variations in Annual Water Consumption of *Arundo* and Annual Expansion Rate of *Arundo* After Control, Using Normalized Prices, with Low-Marginal-Value Crops in the Texas Lower Rio Grande Valley, 2009

Low-Marginal-Value 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

[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.

left column using low-marginal value crops. The baseline deterministic value calculated in the model is in bold and located in the shaded cell.

The low-marginal-value crops benefit-cost ratios vary from 2.00:1 at an expansion rate of 0.00% with *Arundo* water use at 2.00 acre-feet to a ratio of 6.94:1 at an expansion rate of 1.50% and an *Arundo* water use amount of 7.02 acre-feet (Table 15). At the most conservative scenario examined in this analysis, the return on the project would provide $2.00 for every $1.00 of money invested by the public, indicating the project is economically feasible.

In the sensitivity table with *Arundo* water use and *Arundo* expansion after the expected-realized control from the biological agents (Table 15), 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 greater 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.

Amount of Water Consumed by Arundo and Native Vegetation Water Use

In Table 16, the amount of water consumed by *Arundo* is varied across the top row and the water use amount of the native (replacement) vegetation is varied down the left column using the low-marginal value of water. The baseline deterministic value calculated in the model is bold and located in the shaded cell.

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 16). 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 money 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 value spent in 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.

Table 16. Sensitivity Analysis, Benefit-Cost Ratio of Benefits with Variations in Annual Water Consumption of *Arundo* and Natural Vegetation, Using Normalized Prices, with Low-Marginal-Value Crops in the Texas Lower Rio Grande Valley, 2009

		variation in annual water consumption (ac-ft)						
Low-Marginal-Value Crops		-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

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).

Amount of Water Consumed by Arundo and Value of Water

In Table 17, the amount of water consumed by *Arundo* is varied across the top row and the value of water is varied down the left column using the low-marginal value of water as the base for the analysis (in the bold, shaded cell).

The 2009 benefit-cost ratio results from varying the *Arundo* water use and the value of water range from 0.72:1 with the value of water at $50 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 and *Arundo* water use of 7.00 acre-feet per year (Table 17). 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 feasible at this level. However, under most 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 on the cost of the control program. At this point, the benefit-cost ratio is infeasible, where the value of water is $50.00 and the *Arundo* water

Table 17. 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-Marginal-Value Crops in the Texas Lower Rio Grande Valley, 2009

Low-Marginal-Value 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

consumption is 2.00 acre-feet. The project becomes economical at 2.00 acre-feet when the value of water increases to $100 or when the *Arundo* water use increases to 3.00 acre-feet at $50.00 (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

In Table 18, the amount of water consumed by *Arundo* is varied across the top row and the cost of the USDA–ARS *Arundo donax* biological control program is varied down the left column for the low-marginal value of water. The deterministic value calculated in the model is bold and located in the shaded cells.

The 2009 benefit-cost ratio 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 18). At the most conservative set of assumptions

Table 18. 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-Marginal-Value Crops in the Texas Lower Rio Grande Valley, 2009

Low-Marginal-Value 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

examined in this analysis, the return on the project would be $1.54 for every $1.00 of money public investment, indicating the project is feasible.

In the sensitivity table with *Arundo* water use and the cost of the program (Table 18), 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 the highest scenario for the cost of the control program (i.e., higher costs than the deterministic value) produces smaller returns on the cost of the control program. At the other end of the spectrum, the highest expected returns with respect to the costs are produced with the greatest level of *Arundo* water consumption combined with the highest scenario for the cost of the control program (i.e., lower costs than the deterministic value) in the scenarios considered.

Economic Impact

Multipliers for economic activity, value-added, and employment are applied to changes in gross revenue attributable to increased irrigated acres in the Lower Rio Grande Valley to assess expected impacts associated with the irrigation use of the water saved due to controlling *Arundo* in the Rio Grande Basin. The impacts are estimated based on deflated increases in gross returns to crops for the Texas Lower Rio Grande Valley (i.e., the Texas southern-most four counties of Cameron, Hidalgo, Starr, and Willacy). Impact analysis is conducted for this four-county region[28] over the 50-year planning horizon.[29] The IMPLAN program (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 USDA–NASS acreage data, as 2007 data were the most recent available at the time of this work. 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 (NASS 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 simply the subtraction of pre-*Arundo* control gross returns converted dryland acres from post-*Arundo* control gross returns on the same acres converted to irrigated production.[30]

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[28] 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.

[29] 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.

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

Low-Marginal-Value 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-marginal value irrigated composite acre, a total of 108 acres could be converted from dryland to irrigated. Of the 2009 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-marginal-value irrigated composite acre is applied to the low-marginal-value crops 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-marginal-value 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 19).

Table 19. Number of Acres Converted from Dryland to Irrigated Acres for Low-Marginal-Value and High-Marginal-Value crops in the Texas Lower Rio Grande Valley, 2009-2058

Year	Low-Marginal-Value Crop Acres Converted to Irrigation	High-Marginal-Value 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[31] gross revenues per acre, by crop, to obtain the new gross revenues by year. These new gross revenues are deflated to 2006 dollars by the projected IMPLAN deflator.[32] The deflated gross revenues associated with reductions in dryland cotton and sorghum acres are subtracted from the expected new irrigated gross revenues to identify 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 (Table 20) 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

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[31] 2007 base year prices were used in all future revenue estimation, thus reflecting the increasing amount of *Arundo* controlled through time and in the multipliers.

[32] 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.

dollar increase in corn gross revenue). The economic activity generated is $1.387 for each dollar increase in corn revenue. Lastly, the employment multiplier suggests 34.9 jobs are created per $1.0 million increase in corn gross revenue. All other multipliers are interpreted in a similar manner.

Table 20. Regional Economic Multipliers (in IMPLAN) for the Texas Lower Rio Grande Valley Counties of Cameron, Hidalgo, Starr, and Willacy, 2006

Crop	Economic Output (in Million $)	Value-Added (In Million $)	Employment per $1.0 Million
Corn	1.387	0.712	34.933
Cotton	1.499	0.685	21.478
Sorghum	1.387	0.712	34.933
Cotton (Dryland)	1.499	0.685	21.478
Sorghum (Dryland)	1.387	0.712	34.933
Citrus	1.149	0.892	22.376
Vegetables	1.483	1.037	17.730
Sugarcane	1.395	0.622	53.849

Estimating the economic impacts of the projected crop mix changes this 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 21, the annual increase in economic output using the low-marginal-value crop mix for the four counties in the Texas Lower Rio Grande Valley in 2009 is $22.14 thousand, and for 2015, it is $6.56 million. In 2025, the 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 saved water increases 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 21, value-added is estimated to increase by $11.01 thousand 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 21. The increase in employment 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.

Table 21. 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-Marginal Return Crops, 2009-2058[a]

Year	Change in Gross Revenue ($ million, 2007)	Deflated Change in Gross Revenue ($ million, 2006)	Economic Output ($ million)	Value-Added ($ million)	Employment
2009	$ 0.02	$ 0.02	$ 0.02	$ 0.01	0
2015	$ 4.63	$ 4.58	$ 6.56	$ 3.23	143
2025	$ 6.36	$ 6.28	$ 8.90	$ 4.43	197
2035	$ 8.53	$ 8.43	$ 11.94	$ 5.94	264
2045	$ 11.26	$ 11.13	$ 15.77	$ 7.84	349
2055	$ 14.70	$ 14.53	$ 20.58	$ 10.24	455
2058	$ 15.90	$ 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-Marginal-Value Irrigated Crop Acre — Economic Impacts to the Valley

The same process for calculating the economic impacts of the low-marginal-value irrigated crop acre is repeated for the economic impacts of the high-marginal-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-marginal-value composite acre using the same process as discussed in the calculation of converted acres with the low-marginal-value 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 20).

As displayed in Table 22, 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-marginal-value 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 22.

Table 22. 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-Marginal Return Crops, 2009-2058[a]

Year	Change in Gross Revenue ($ million, 2007)	Deflated Change in Gross Revenues ($ million, 2006)	Economic Output ($ million)	Value-Added ($ million)	Employment
2009	$ 0.03	$ 0.03	$ 0.05	$ 0.03	1
2015	$ 9.65	$ 9.54	$ 13.08	$ 8.60	256
2025	$ 13.25	$ 13.09	$ 17.94	$ 11.81	351
2035	$ 17.77	$ 17.56	$ 24.07	$ 15.84	471
2045	$ 23.47	$ 23.19	$ 31.79	$ 20.92	622
2055	$ 30.63	$ 30.27	$ 41.49	$ 27.30	812
2058	$ 33.12	$ 32.73	$ 44.87	$ 29.52	878

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

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-marginal-value crop mix (Table 22). The Valley also realizes an increase in employment, with one new job associated with the increase in gross revenues for 2009, 255 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-marginal-value crops from the additional saved water by the reduction in *Arundo donax*.

Per-Unit Costs of Saved Water

The *Arundo* biological control program costs of $20.0 million (nominal dollars) projected to occur during 2007 to 2016 are inflated at an annual rate of 2.043% for years 2007 and 2008 and discounted at an annual rate of 6.125% for years 2010-2058 to obtain the present value of costs, $16.54 million, in 2009 dollars. Additionally, the annual cumulative amounts of water saved (from 59 acre-feet in 2009 to 58.9 thousand acre-feet in 2058, for a total of 1.6 million nominal acre-feet of water) are discounted by the social discount rate of 4.00% to obtain the present value of water for 2009 of 520 thousand acre-feet of raw water (Table 24).

Annuity equivalents of the respective present values for the cost of the program and the acre-feet of water saved are then obtained 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 (Table 23).

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). Such projects include installing pipelines to prevent water loss from seepage and leaks ($56 per acre-foot), lining irrigation canals ($35 per acre-foot), and installing meters and telemetry to regulate water flow ($83 per acre-foot) (Sturdivant et al. 2007).

Table 23. Baseline Results for the Cost-of-Saving Water with the Beneficial Insect Program in the Rio Grande Basin and the Associated Reduction in *Arundo donax*, 2009 Dollars

Result Item	Units	Nominal Value	Real Value[a]
Initial Program Costs (for 10 years)	2009 dollars	$20,000,000	$16,537,369
Saved Water	ac-ft (lifetime)	1,561,664	520,260
- annuity equivalent	ac-ft per year		24,218
Saved Water	1,000 gal (lifetime)	508,869,773	169,527,086
- annuity equivalent	1,000 gal/yr		7,891,520
NPV of Total Cost Stream[b]	2008 dollars	$20,000,000	$16,537,369
- annuity equivalent	$/year		$1,067,553
Cost-of-Saving Raw Water[c]	$/ac-ft/year		$44.08
Cost-of-Saving Raw Water[c]	$/1000-gal/year		$0.1353

[a] Determined using a 2.043% compound factor for years 2007 and 2008and a 6.125% discount rate for dollars in years 2010 through 1016, and a 4.000% discount rate for water.

[b] These are the total project costs anticipated (nominal and real) relevant to saving raw water over the 50-year planning period. Only the program costs incurred during 2007-2016 of the planning horizon are included, as there are no annual operating and maintenance costs, nor any capital reinvestment costs involved. Further, the value of the water (in terms of delivery revenue for an irrigation district, or residual returns to agriculture) is ignored in these values.

[c] Basis is free-along-side-river-diversion point, Texas Lower Rio Grande Valley; i.e., any diversion costs or irrigation district conveyance-system losses are not considered.

Conclusion

The water saved as a result of the biological control of *Arundo donax* along the Rio Grande occurs primarily between San Ignacio and Del Rio, Texas on the Mexico-Texas, U.S. border. Water flow for this reach of the Rio Grande is controlled by the operation of Falcon and Amistad reservoirs. The reduction in *Arundo* suggests increased flow into Falcon Reservoir. Since Falcon Reservoir has more water losses than Amistad Reservoir, any water saved between the reservoirs will allow more water to be retained at

Amistad Reservoir, thus improving the efficiency of the water management system in the Lower Rio Grande [River] (Rubinstein 2008).

Once *Arundo donax* is controlled, more water is expected to be available for the Rio Grande Valley. Based on agriculture being the residual user of water, it is anticipated to be the beneficiary of any saved water, as dryland crops convert to irrigated crops, resulting in more production of agricultural commodities and hence, increased value of production. Over a 50-year planning horizon, it is estimated that the biological control of *Arundo* will be associated with a market-price-based present value for low-marginal-value crops of $97.80 million, compared to a present value for high-marginal-value crops of $159.87 million. Overall, benefit-cost ratios range from 4.38-8.81:1, suggesting a socially-beneficial project that leads to the creation of jobs and increased economic activity.

The additional water available to the Texas Lower Rio Grande Valley as a result of the USDA–ARS, Weslaco, Texas, *Arundo donax* biological control program is anticipated to increase economic output between $22,000 and $45,000, increase value-added between $11,000 and $29,000, and increase employment by one job for 2009. Over time, the amount of water available to the region will increase as a result of this program, further enhancing the economic impacts to the Valley. By 2058, economic output is projected to increase between $22.26 million and $44.87 million, value-added is projected to increase between $11.07 million and $29.52 million, and employment is expected to increase by between 492 and 898 jobs. These increasing positive impacts to the pre-production processes and farm-gate level of the economy suggest the program provides positive impacts to the Texas Lower Rio Grande Valley and will continue to do so over the 50-year planning horizon.

The estimated per-unit cost of saving water (by reducing giant reed) is $44.08 per acre-foot. This low cost per acre-foot of the *Arundo* biological control program suggests the program is cost-competitive as an effort to increase water supply in the Texas Lower Rio Grande Valley. Not included in this study are potential benefits to the eco-system, environment, Mexico, and improved national security.

DISCUSSION

The many different aspects of this project contribute to the complexity of the research. The central focus of the economic study relates to whether the benefits of the *Arundo* biological control program justify the expenditures of federal (social) resources. While the preliminary calculated results indicate expected positive net benefits 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. Additionally, the enterprise crop budgets' related calculations for the inferred values of irrigation water are greater than those reported in much of the literature.

***Arundo* Considerations**

Several major factors perceived to influence the economics of the *Arundo* biological control program in the Rio Grande Basin are identified in this section. Sensitivity analyses were conducted to examine the stability of the results to variations in each variable.

Only two data estimates of *Arundo* acres infested in the Rio Grande Basin are available, i.e., 15,715 *Arundo* acres in 2002, and 18,072 *Arundo* acres in 2008 (Yang 2008). The assumed linear growth curve over the 50-year planning horizon may not be reflective of the actual biological growth of the plant that will occur in the future, as biological growth typically follows growth curves similar to the logistic growth function, increasing in the beginning, but leveling off over time (Birch 1999).

The water use of *Arundo donax* is a critical factor in estimating the benefits associated with the *Arundo* biological control project. A wide range of water use estimates exist for the plant, however, varying from 3.8 acre-feet (Jackson, Katagi, and Loper 2002) to more than 5.5 acre-feet per acre per year (Watts 2009; Iverson 1994). The 4.37 acre-feet per acre per year estimate of *Arundo* water consumption used in the calculations for this analysis and thesis is between these two estimates.

Research on how the plant uses water relative to size, density, and under different control conditions (e.g., mechanical control, chemical control, or biological control) could not be identified. The assumption of the reduction in acres equaling the reduction in density and height of the plant may or may not accurately represent actual changes in water use occurring after the release of the biological control agents.

Documented water use estimates for the natural vegetation in the Rio Grande Basin (which is expected to replace the mitigated *Arundo* growth) are also unavailable. The native vegetation’s water use estimate of one-third relative to giant reed comes from experts in the region and research performed on California riparian areas (Iverson 1994); however, should the actual water use by these replacement plants be higher, the amount of water to be saved as a result of the biological control program is over-estimated. Such over-estimation would result in higher calculated benefits than the actual benefits realized from the water saved due to reduced *Arundo*. Of course, the opposite is true if natural riparian vegetation uses less water than the estimate assumed in this study.

Another critical variable that impacts benefits is the value of water per crop acre or acre-foot estimated. The calculated annual $190 per acre-foot for low-value crops and $273 per acre-foot for high-value crops are higher than water market prices in the Texas Lower Rio Grande Valley (Sturdivant 2009b; Hinojosa 2008). These results are likely associated with this study’s use of the high crop prices experienced by farmers as commodity prices rose during the 2007 year (the assumed data period for this parameter), while costs of production were relatively low. Another possible explanation for the apparent discrepancy in the value of water could be the typical under-realization of the true value of water by its users (Griffin 2006).

The discount rate used in this thesis research is important in determining the present value of water, and the related estimates of direct benefits and the benefit-cost ratio. The discount rate on dollars assumed for water savings occurring throughout the 50-year study period also affects the estimated value for water. The lower the discount rate, the greater the weight assigned to future values relative to current values, and vice versa. Differences in opinion exist among economists in regard to the value of the discount rate, with some arguing for a negative discount rate, as they expect water to be worth dramatically more in the future, especially when viewed as a depleting resource (Michelsen 2008; Segarra 2008).

The early involvement of economists has provided opportunities for their participation during the research project. This involvement has been helpful in ensuring the appropriate (e.g., type and required accuracy) data are identified and collected for the economic analyses. However, 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.

The use of the biological control agents is anticipated to result in additional water being available for use in the Texas Lower Rio Grande Valley. With the rapid population growth (U.S. Census Bureau 2000) and increased concerns over water supply in the Valley, the *Arundo* biological control program is expected to be beneficial to the region. The amount of water saved, and the value thereof, from the control of giant reed is still an estimate at this date (i.e., May 2009).

Other *Arundo* Considerations

Arundo donax, although considered an invasive weed, has many other uses and is of interest to different companies around the nation. Some of these uses include potential for bio-fuel production, use for woodwind reed, and production of a “paperless” paper (i.e., alternative to wood pulp).

Previous studies have suggested *Arundo* as a candidate for producing bio-fuel, due to its rapid growth rate and biomass production (Angelini, Ceccarini, and Bonari 2005). Biomass Investment Group (BIG) Corporation in the United States is attempting to obtain permits to grow *Arundo donax*, or “e-grass,” in mass for bio-fuel production (Burnham 2008). The company plans to market e-grass along the Gulf Coast of the United States, from south Florida to south Texas (Biomass Investment Group 2007). While *Arundo* appears ideal as a bio-fuel candidate, because of its invasiveness, it is classified as a noxious plant nationally and in Texas (USDA–NRCS 2009); thus, permits to grow it are difficult to obtain.

Historians and researchers initially thought *Arundo* was brought to the United States for use as roof-thatching (Hoshovsky 1986; Dudley 1998). While this situation may have been the case initially, the design and construction of roofs have changed from the plant’s original introduction until now, and *Arundo* is no longer used for this purpose. Further records show the use of *Arundo* as a form of erosion control along rivers and streams (Dudley 1998), which likely contributed to the plant’s invasion. Currently, however, *Arundo donax* is a popular plant used for making reeds for woodwind instruments (Perdue 1958). While this is another possible use for the plant in the Valley, enough reeds are currently in production to meet the needs of musicians. Certainly, current and projected stands of *Arundo* far surpass the amount of giant reed required to meet the produce the quantity of woodwind reeds necessary to meet the music industry's demand.

The Nile Group was founded in 1996 and is also interested in *Arundo donax* as a means to meet the demands of the wood industry. The fibers of *Arundo* can be bleached (Shatalov and Pereira 2005) to obtain a non-wood substitute. This company has received patents in China, Taiwan, and India for their products. Additionally, the group's website shows stands of *Arundo* in the United States that withstood the wind forces of Hurricane Ivan in September of 2004 (The Nile Group 2006).

These alternatives might be considered opportunity costs (i.e., foregone revenue streams) to the research presented in this thesis. Due to the location of the giant reed (Rio Grande [River] Basin), however, harvesting may be difficult and problematic; thus, these opportunity costs are not included in this research.

Limitations

While many issues were addressed in this research, certain areas were not considered. Specifically, potential benefits to the Department of Homeland Security and recreational use and environmental values were not evaluated. The Department of Homeland Security clearly anticipates benefits associated with the reduction of giant reed along the Rio Grande (Goolsby 2009a). The Department has provided financial support to the USDA–ARS for the project; meanwhile, an article in the *Houston Chronicle* newspaper noted on March 24, 2009 that the Border Patrol is also investing another $2.1 million along a 1.1-mile stretch at Laredo to investigate alternative control approaches for controlling giant reed[33] (Schiller 2009). Increased control of *Arundo* means heightened border protection and improved safety for the Border Patrol agents.

The Rio Grande also has many opportunities for recreation, particularly in the vicinity of Amistad Reservoir. Reduced *Arundo* infestations would lead to both increased water access and more water being available for recreation behind the dam and throughout the river stream. The riparian of the Rio Grande would no longer be filled with dense reed, but rather native vegetation, which is considered more suitable for recreation. Additionally, many benefits are expected to accrue to the environment from the reduction of *Arundo*. Growth of giant reed often leads to faster, narrower streams, altering the water stream and source for native animals (Dudley 1998) residing in and around the Rio Grande. The dense growth of the plant and the lack of ecological diversity also do not provide favorable conditions for the native animal inhabitants (Bell 1993a). The Rio Grande Basin is home to the endangered Ocelot. Removing or

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[33] The majority of the research for this thesis was conducted prior to March 25, 2009 and consequently, does not include contemporary data regarding the additional control effects on *Arundo* provided by the Department of Homeland Security funding.

reducing *Arundo* would restore the natural habitation for this species, as well as others (Dudley et al. 2007).

The calculation of the benefits mentioned above would involve alternative methods of analysis, such as contingent valuation through surveys, travel cost analysis, and others. These results often yield a wide range of results, vary wildly, and are prone to uncertainty of accurate results due to population biases and characteristics (Tietenberg 2006). While it is certain these values exist, security, environmental and recreational values are not included in the calculation of the benefits for this project.

Due to funding constraints, this study only examines the economics associated with the biological control of giant reed and does not consider benefits or costs associated with mechanical or chemical (i.e., herbicides) control methods. Other methods of control, including the cut-stump method and grazing of goats on the reed are currently under investigation by the Laredo Community College and the Department of Homeland Security (Vaughn 2009). Additional study is needed on the economics of using these different methods of control to determine the most cost-effective method.

Additionally, since the wasp is mobile and Mexico will receive 50% of the net water saved (Rubinstein 2008), benefits of the USDA–ARS, Weslaco, Texas program are expected to occur in Mexico as well (Goolsby 2008b). This study estimates a reduction in giant reed from both sides of the Rio Grande, but only accounts for benefits accruing to the United States from the release of the biological control agents; thus, benefits are underestimated.

Agencies in Mexico are also investigating using these same insects as biological control agents for giant reed. This study does not account for any releases of the insects by the Mexican government, or benefits accruing to Mexico from the U.S. release of the biological control agents. That is, only the USDA–ARS program and U.S. benefits received from the control of *Arundo donax* in the limited project study area (i.e., 170 river miles between San Ignacio and Del Rio, Texas) are accounted for in this thesis.

Expected benefits accruing to the U.S. only from the release of *Tetramesa romana* and *Rhizaspidiotus donacis* (the wasp and scale, respectively) are considered. The impact on controlling giant reed from *Cryptonevra spp. (i.e.*, the fly) and *Lasioptera donacis* (i.e., the leafminer) are not yet known and thus, are not included in the calculation of the U.S. benefits.

Furthermore, this study only includes the acres of *Arundo* in the Rio Grande riparian and does not include the *Arundo* acres or reduction in *Arundo* acres from tributary streams of the Rio Grande Basin due to the use of the biological control program. Finally, the early phases of the overall project require several assumptions to facilitate the economic analysis.

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-marginal 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 (Table 9) 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 (Table 11). 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 within a range of $22,000-$45,000 in 2009, $11.94 million to $24.07 million in 2035, and $22.26 million to $44.87 million in 2058, (b) value-added within a range of $11.01 to $29.37 thousand in 2009, $5.94 million to $15.84 million in 2035, and $11.07 million to $29.52 million in 2058, and (c) employment within a range of 0 to 1 job in 2009, 264 to 471 jobs in 2035, and 492 to

878 in 2058 (Tables 22 and 23). These results indicate a positive economic impact to the Texas Lower Rio Grande Valley.

The per-unit cost of water saved as a result of the USDA–ARS *Arundo* biological control program are $44.08 per acre-foot, or $0.1353 per 1,000 gallons (Table 23). These results are comparable to the per-acre-foot costs of current programs in use or under consideration for increasing water supply. Subsequently, the comparable costs of the program indicate that should similar results be realized, biological control is a viable option for increasing water supply to the Texas Lower Rio Grande Valley.

As of May 2009, the data results 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 thesis, 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 and (b) creates a positive impact both at the farm level and for the regional economy. Thus, the null hypothesis that “the USDA–ARS biological control program for *Arundo donax* is not economically feasible” is rejected, and the alternative hypothesis that “the USDA–ARS biological control program for *Arundo donax* is economically feasible” is accepted.

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APPENDIX A

COLLABORATORS ON THE USDA–ARS, WESLACO, TEXAS *ARUNDO DONAX* PROGRAM

The *Arundo donax* biological control program encompasses many different fields of study. Several researchers from various entities are collaborating in an effort to become more knowledgeable about the plant and the invasive situation in the Rio Grande Basin. The project is spearheaded by Dr. John A. Goolsby of the USDA–ARS. Below is a list of collaborators for the project, obtained from a poster presentation titled, "*Arundo donax*-Giant Reed; an Invasive Weed of the Rio Grande Basin," by Goolsby et al. (2008) and from personal communication with Dr. Goolsby (2009c).

Primary Investigator
USDA–ARS, Kika de la Garza Subtropical Agricultural Research Center, Weslaco, TX
John A. Goolsby

Collaborators
USDA–ARS, Kika de la Garza Subtropical Agricultural Research Center, Weslaco, TX
John Adamczyk
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Chenghai Yang

USDA–ARS, European Biological Control Laboratory, Montpelier, France
Walker Jones
Alan Kirk

USDA–ARS, Bushland, TX
Prasana Gowda

USDA–ARS, Invasive & Exotic Research Unit, Davis, California
David Spencer

USDA–APHIS, Edinburg, Texas
Ken Jones
Paul Parker
Ray Penk
Tim Roland
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Texas A&M University, Department of Biology, College Station, Texas
Jim Manhart
Alan Pepper
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David Watts

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Ronald D. Lacewell
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M. Edward Rister
Emily K. Seawright

Texas AgriLife Extension Service, Department of Agricultural Economics, Weslaco, Texas
Allen W. Sturdivant

Pronatura Norestre, Monterréy, Mexico
Beto Contreras Arquieta

Instituto Mexicano de Tecnología del Agua, Jiutepec, Mexico
Maricela Martinez Jiménez

Universidad de Alicante, Spain
Eduardo Galante, Professor of Zoology
Maria Angeles Marcos, Biogeography and Ecology
Elena Cortés Mendoza, Institute of Biodiversity

Texas Parks & Wildlife, Austin, Texas
Earl Chilton

University of Texas, School of Biological Sciences, Section of Integrative Biology, Austin, Texas
Lawrence Gilbert

Texas A&M International, Department of Biology, Laredo, Texas
Amede Rubio
Tom Vaughn

Insect Diet Research, Raleigh, North Carolina
Al Cohen

Bureau of Reclamation, Denver, Colorado
Fred Nibling

Algiers, Algieria-Field Collection
Abida Zeddam

The Hebrew University of Jerusalem, Department of Evolution, Systematics, and Ecology, Jerusalem, Israel
Avinoam Danin

Tel Aviv University, Tel Aviv, Israel
Dan Gerling, Department of Zoology

APPENDIX B

CROP ENTERPRISE BUDGETS

The 2007 Texas AgriLife Extension Service Crop Budgets for Region 12 (i.e., the counties of Atascosa, Brooks, Cameron, Dimmitt, Duval, Jim Hogg, Frio, Hidalgo, Jim Hogg, Jim Wells, Kenedy, Kleberg, La Salle, Live Oak, Maverick, McMullen, Starr, Webb, Willacy, Zapata, and Zavala) are used in the determination of price and water use for the low- and high-marginal-value composite acres. The following pages contain the budgets used for this research, including:

Texas AgriLife Extension Service, Region 12 Crop Budget for Corn, Reduced Tillage, Furrow Irrigation, 2007.

Texas AgriLife Extension Service, Region 12 Crop Budget for Corn, Conventional Tillage, Furrow Irrigation, 2007.

Texas AgriLife Extension Service, Region 12 Crop Budget for Cotton, Reduced Tillage, Roundup-Ready, Furrow Irrigation, 2007.

Texas AgriLife Extension Service, Region 12 Crop Budget for Grain Sorghum, Conventional Tillage, Furrow Irrigation, 2007.

Texas AgriLife Extension Service, Region 12 Crop Budget for Grain Sorghum, Reduced Tillage, Furrow Irrigation, 2007.

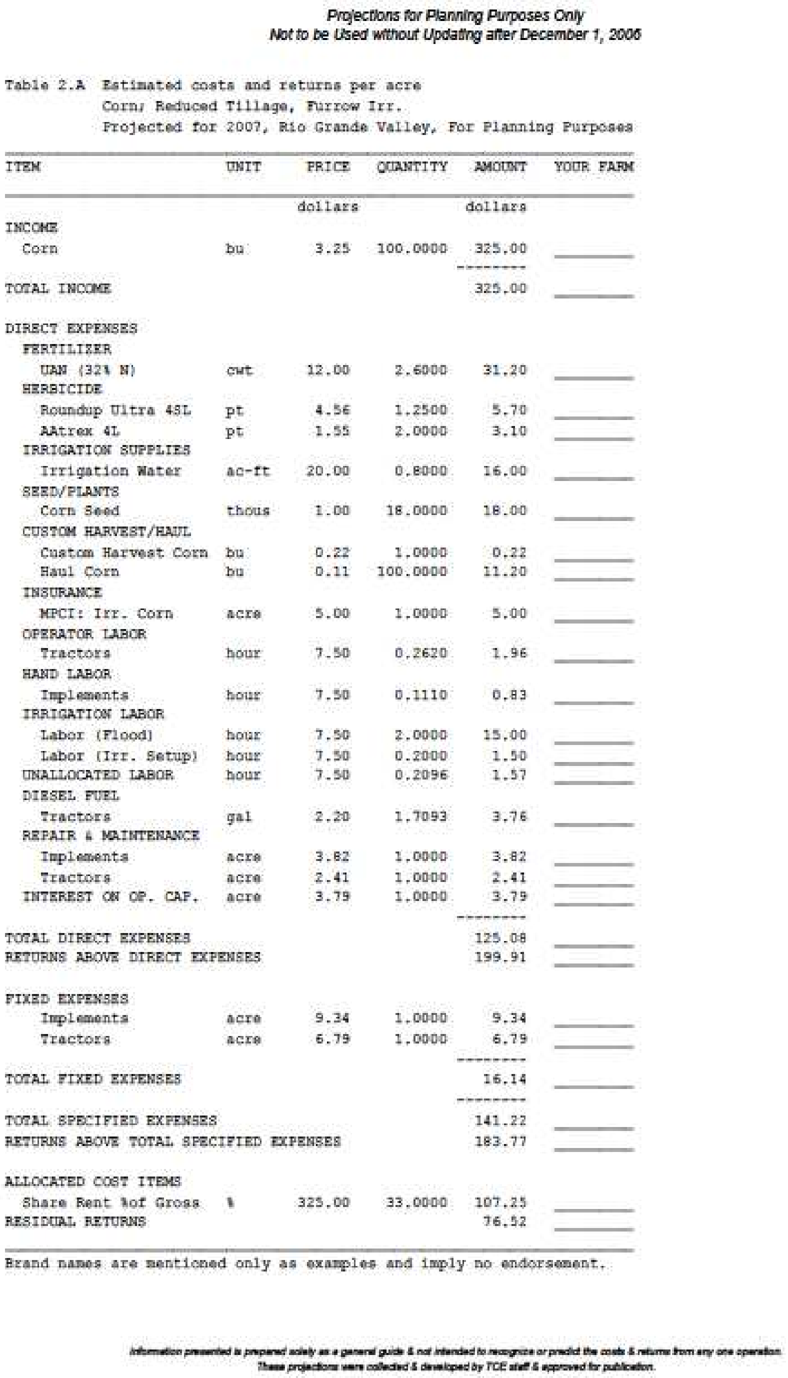
Texas AgriLife Extension Service, Region 12 Crop Budget for Grain Sorghum, Conventional Tillage, Dryland 2007.

Texas AgriLife Extension Service, Region 12 Crop Budget for Sugar Cane, Plant Cane, Furrow Irrigation, 2007.

Texas AgriLife Extension Service, Region 12 Crop Budget for Sugar Cane, Ratoon Cane, Furrow Irrigation, 2007.

Texas AgriLife Extension Service, Region 12 Crop Budget for Onion, Hybrid Yellow Varieties, Furrow Irrigation, 2007.

Texas AgriLife Extension Service, Region 12 Crop Budget for Grapefruits, Years 8+ Mature Orchard, Flood Irrigation, 2007.



Projections for Planning Purposes Only
Not to be Used without Updating after December 1, 2006

B-1241 (C12)

Table 2.A Estimated costs and returns per acre
Corn; Reduced Tillage, Furrow Irr.
Projected for 2007, Rio Grande Valley, For Planning Purposes

ITEM	UNIT	PRICE	QUANTITY	AMOUNT	YOUR FARM
		dollars		dollars	
INCOME					
Corn	bu	3.25	100.0000	325.00	

TOTAL INCOME				325.00	
DIRECT EXPENSES					
FERTILIZER					
UAN (32% N)	cwt	12.00	2.6000	31.20	
HERBICIDE					
Roundup Ultra 4SL	pt	4.56	1.2500	5.70	
AAtrex 4L	pt	1.55	2.0000	3.10	
IRRIGATION SUPPLIES					
Irrigation Water	ac-ft	20.00	0.8000	16.00	
SEED/PLANTS					
Corn Seed	thous	1.00	18.0000	18.00	
CUSTOM HARVEST/HAUL					
Custom Harvest Corn	bu	0.22	1.0000	0.22	
Haul Corn	bu	0.11	100.0000	11.20	
INSURANCE					
MPCI: Irr. Corn	acre	5.00	1.0000	5.00	
OPERATOR LABOR					
Tractors	hour	7.50	0.2620	1.96	
HAND LABOR					
Implements	hour	7.50	0.1110	0.83	
IRRIGATION LABOR					
Labor (Flood)	hour	7.50	2.0000	15.00	
Labor (Irr. Setup)	hour	7.50	0.2000	1.50	
UNALLOCATED LABOR	hour	7.50	0.2096	1.57	
DIESEL FUEL					
Tractors	gal	2.20	1.7093	3.76	
REPAIR & MAINTENANCE					
Implements	acre	3.82	1.0000	3.82	
Tractors	acre	2.41	1.0000	2.41	
INTEREST ON OP. CAP.	acre	3.79	1.0000	3.79	

TOTAL DIRECT EXPENSES				125.08	
RETURNS ABOVE DIRECT EXPENSES				199.91	
FIXED EXPENSES					
Implements	acre	9.34	1.0000	9.34	
Tractors	acre	6.79	1.0000	6.79	

TOTAL FIXED EXPENSES				16.14	

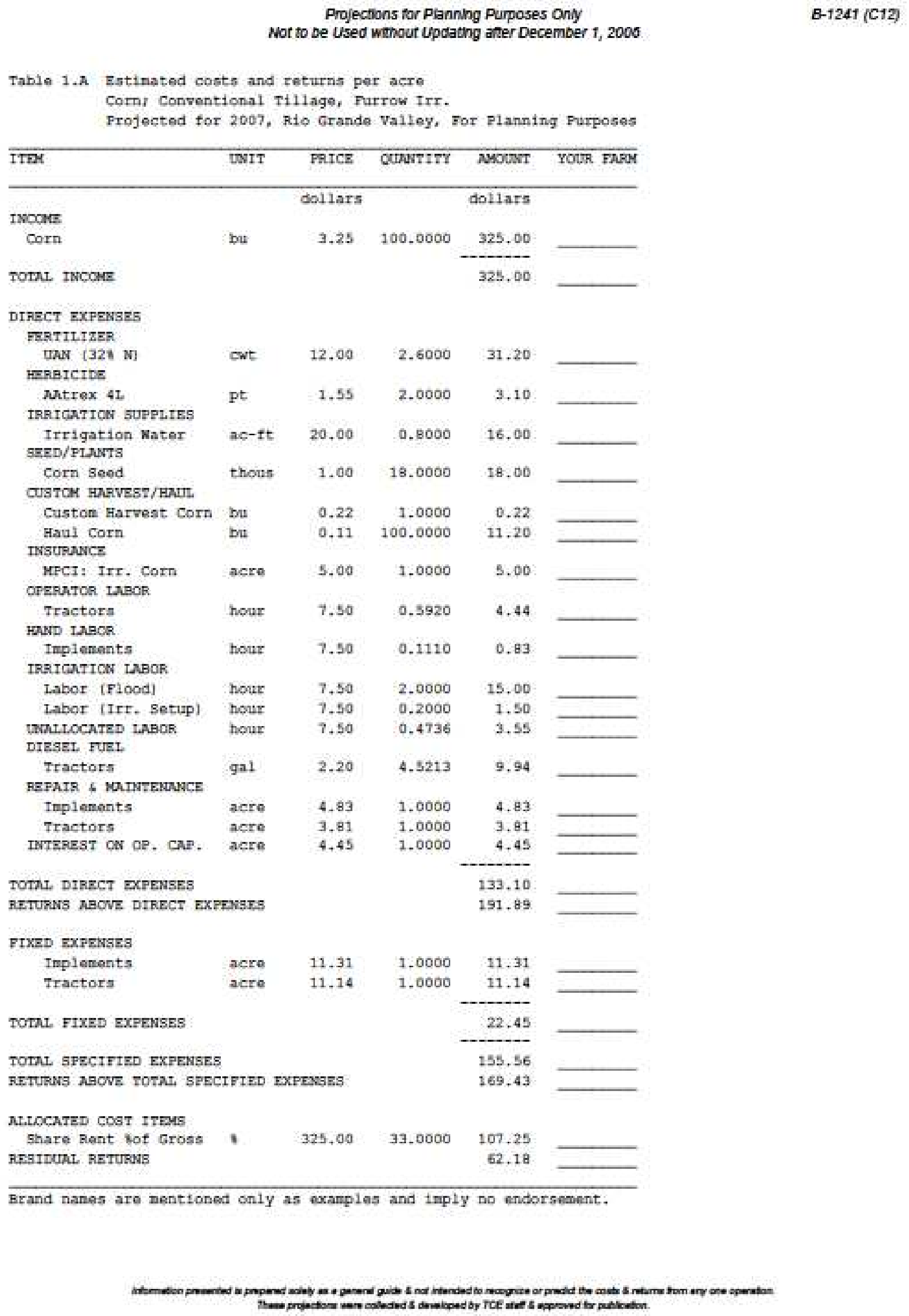
TOTAL SPECIFIED EXPENSES				141.22	
RETURNS ABOVE TOTAL SPECIFIED EXPENSES				183.77	
ALLOCATED COST ITEMS					
Share Rent %of Gross	%	325.00	33.0000	107.25	
RESIDUAL RETURNS				76.52	

Brand names are mentioned only as examples and imply no endorsement.

Information presented is prepared solely as a general guide & not intended to recognize or predict the costs & returns from any one operation.
These projections were collected & developed by TCE staff & approved for publication.

Source: Texas AgriLife Extension Service 2007.

Exhibit B-1. Texas AgriLife Extension Service, Region 12 Crop Budget for Corn, Reduced Tillage, Furrow Irrigation, 2007



Projections for Planning Purposes Only
Not to be Used without Updating after December 1, 2006

B-1241 (C12)

Table 1.A Estimated costs and returns per acre
Corn; Conventional Tillage, Furrow Irr.
Projected for 2007, Rio Grande Valley, For Planning Purposes

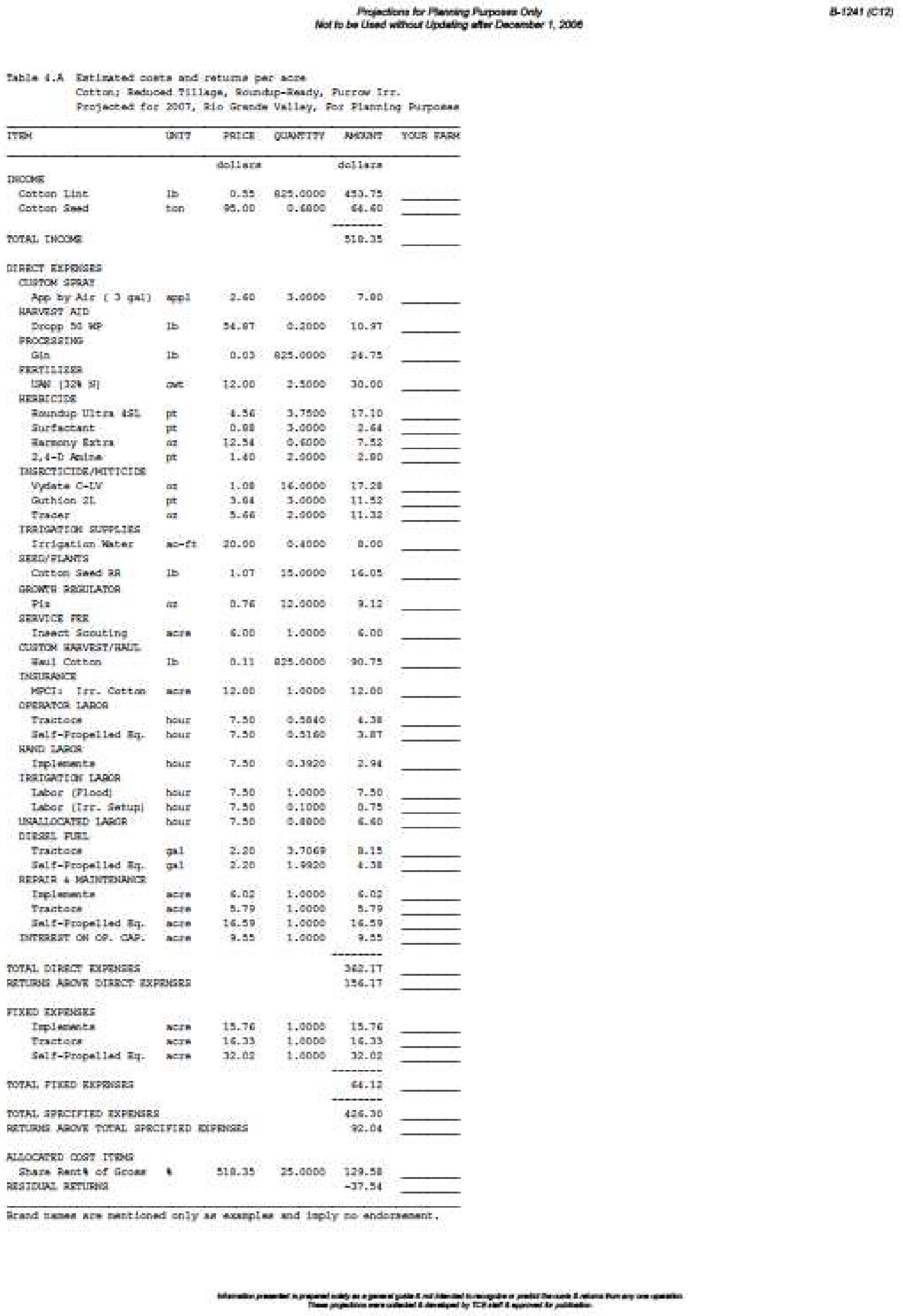
ITEM	UNIT	PRICE	QUANTITY	AMOUNT	YOUR FARM
		dollars		dollars	
INCOME					
Corn	bu	3.25	100.0000	325.00	
TOTAL INCOME				325.00	
DIRECT EXPENSES					
FERTILIZER					
UAN (32% N)	cwt	12.00	2.6000	31.20	
HERBICIDE					
AAtrex 4L	pt	1.55	2.0000	3.10	
IRRIGATION SUPPLIES					
Irrigation Water	ac-ft	20.00	0.8000	16.00	
SEED/PLANTS					
Corn Seed	thous	1.00	18.0000	18.00	
CUSTOM HARVEST/HAUL					
Custom Harvest Corn	bu	0.22	1.0000	0.22	
Haul Corn	bu	0.11	100.0000	11.20	
INSURANCE					
MPCI: Irr. Corn	acre	5.00	1.0000	5.00	
OPERATOR LABOR					
Tractors	hour	7.50	0.5920	4.44	
HAND LABOR					
Implements	hour	7.50	0.1110	0.83	
IRRIGATION LABOR					
Labor (Flood)	hour	7.50	2.0000	15.00	
Labor (Irr. Setup)	hour	7.50	0.2000	1.50	
UNALLOCATED LABOR	hour	7.50	0.4736	3.55	
DIESEL FUEL					
Tractors	gal	2.20	4.5213	9.94	
REPAIR & MAINTENANCE					
Implements	acre	4.83	1.0000	4.83	
Tractors	acre	3.81	1.0000	3.81	
INTEREST ON OP. CAP.	acre	4.45	1.0000	4.45	
TOTAL DIRECT EXPENSES				133.10	
RETURNS ABOVE DIRECT EXPENSES				191.89	
FIXED EXPENSES					
Implements	acre	11.31	1.0000	11.31	
Tractors	acre	11.14	1.0000	11.14	
TOTAL FIXED EXPENSES				22.45	
TOTAL SPECIFIED EXPENSES				155.56	
RETURNS ABOVE TOTAL SPECIFIED EXPENSES				169.43	
ALLOCATED COST ITEMS					
Share Rent %of Gross	%	325.00	33.0000	107.25	
RESIDUAL RETURNS				62.18	

Brand names are mentioned only as examples and imply no endorsement.

Information presented is prepared solely as a general guide & not intended to recognize or predict the costs & returns from any one operation.
These projections were collected & developed by TCE staff & approved for publication.

Source: Texas AgriLife Extension Service 2007.

Exhibit B-2. Texas AgriLife Extension Service, Region 12 Crop Budget for Corn, Conventional Tillage, Furrow Irrigation, 2007



Projections for Planning Purposes Only
Not to be Used without Updating after December 1, 2006

B-1241 (C12)

Table 4.A Estimated costs and returns per acre
Cotton; Reduced Tillage, Roundup-Ready, Furrow Irr.
Projected for 2007, Rio Grande Valley, For Planning Purposes

ITEM	UNIT	PRICE	QUANTITY	AMOUNT	YOUR FARM
		dollars		dollars	
INCOME					
Cotton Lint	lb	0.55	825.0000	453.75	
Cotton Seed	ton	95.00	0.6800	64.60	

TOTAL INCOME				518.35	
DIRECT EXPENSES					
CUSTOM SPRAY					
App by Air (3 gal)	appl	2.60	3.0000	7.80	
HARVEST AID					
Dropp 50 WP	lb	54.87	0.2000	10.97	
PROCESSING					
Gin	lb	0.03	825.0000	24.75	
FERTILIZER					
UAN (32% N)	cwt	12.00	2.5000	30.00	
HERBICIDE					
Roundup Ultra 4SL	pt	4.56	3.7500	17.10	
Surfactant	pt	0.88	3.0000	2.64	
Harmony Extra	oz	12.54	0.6000	7.52	
2,4-D Amine	pt	1.40	2.0000	2.80	
INSECTICIDE/MITICIDE					
Vydate C-LV	oz	1.08	16.0000	17.28	
Guthion 2L	pt	3.84	3.0000	11.52	
Tracer	oz	5.66	2.0000	11.32	
IRRIGATION SUPPLIES					
Irrigation Water	ac-ft	20.00	0.4000	8.00	
SEED/PLANTS					
Cotton Seed RR	lb	1.07	15.0000	16.05	
GROWTH REGULATOR					
Pix	oz	0.76	12.0000	9.12	
SERVICE FEE					
Insect Scouting	acre	6.00	1.0000	6.00	
CUSTOM HARVEST/HAUL					
Haul Cotton	lb	0.11	825.0000	90.75	
INSURANCE					
MPCI: Irr. Cotton	acre	12.00	1.0000	12.00	
OPERATOR LABOR					
Tractors	hour	7.50	0.5840	4.38	
Self-Propelled Eq.	hour	7.50	0.5160	3.87	
HAND LABOR					
Implements	hour	7.50	0.3920	2.94	
IRRIGATION LABOR					
Labor (Flood)	hour	7.50	1.0000	7.50	
Labor (Irr. Setup)	hour	7.50	0.1000	0.75	
UNALLOCATED LABOR	hour	7.50	0.8800	6.60	
DIESEL FUEL					
Tractors	gal	2.20	3.7069	8.15	
Self-Propelled Eq.	gal	2.20	1.9920	4.38	
REPAIR & MAINTENANCE					
Implements	acre	6.02	1.0000	6.02	
Tractors	acre	5.79	1.0000	5.79	
Self-Propelled Eq.	acre	16.59	1.0000	16.59	
INTEREST ON OP. CAP.	acre	9.55	1.0000	9.55	

TOTAL DIRECT EXPENSES				362.17	
RETURNS ABOVE DIRECT EXPENSES				156.17	
FIXED EXPENSES					
Implements	acre	15.76	1.0000	15.76	
Tractors	acre	16.33	1.0000	16.33	
Self-Propelled Eq.	acre	32.02	1.0000	32.02	

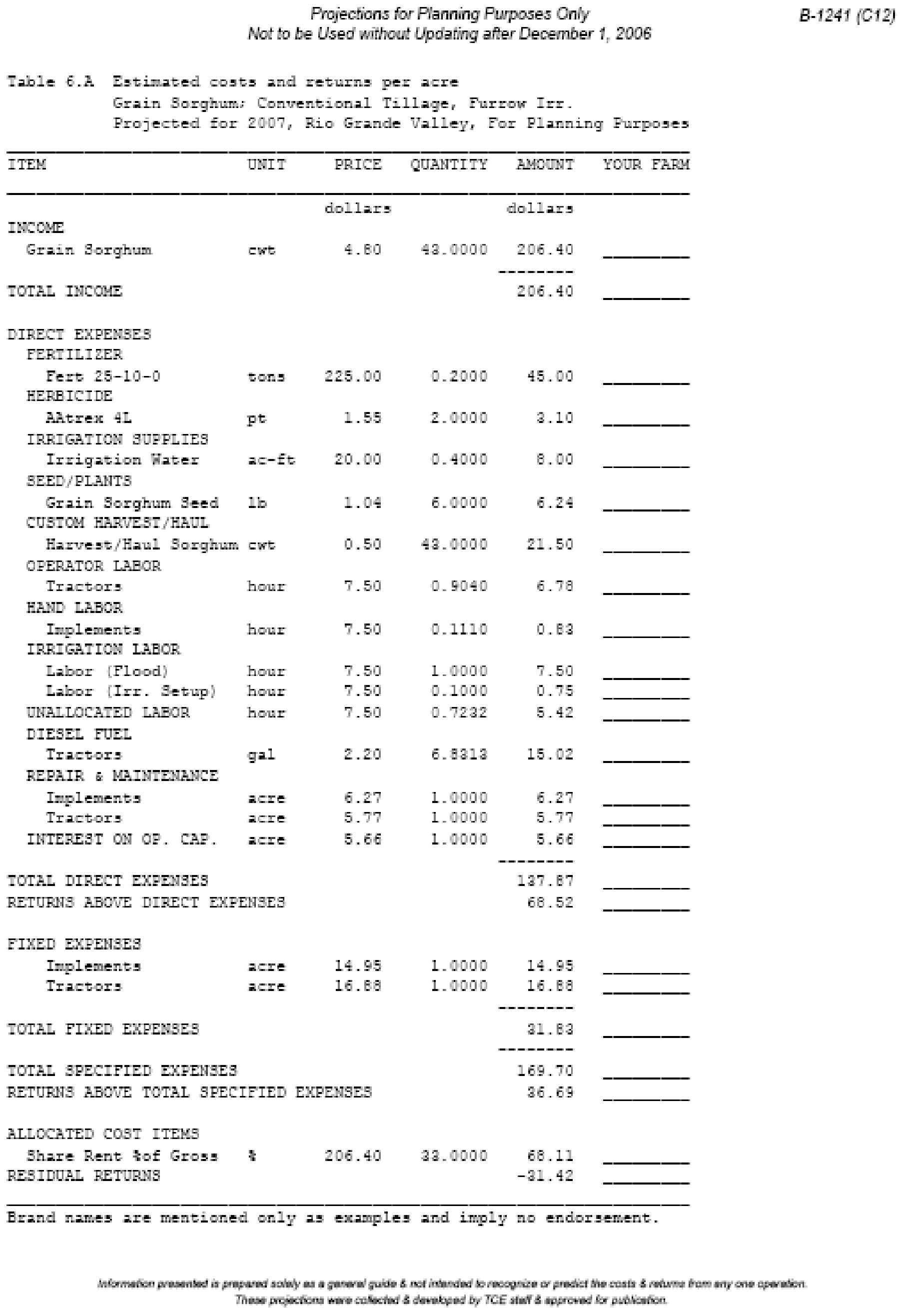
TOTAL FIXED EXPENSES				64.12	

TOTAL SPECIFIED EXPENSES				426.30	
RETURNS ABOVE TOTAL SPECIFIED EXPENSES				92.04	
ALLOCATED COST ITEMS					
Share Rent% of Gross	%	518.35	25.0000	129.58	
RESIDUAL RETURNS				-37.54	

Brand names are mentioned only as examples and imply no endorsement.

Source: Texas AgriLife Extension Service 2007.

Exhibit B-3. Texas AgriLife Extension Service, Region 12 Crop Budget for Cotton, Reduced Tillage, Roundup-Ready, Furrow Irrigation, 2007



Projections for Planning Purposes Only
Not to be Used without Updating after December 1, 2006

B-1241 (C12)

Table 6.A Estimated costs and returns per acre
Grain Sorghum; Conventional Tillage, Furrow Irr.
Projected for 2007, Rio Grande Valley, For Planning Purposes

ITEM	UNIT	PRICE	QUANTITY	AMOUNT	YOUR FARM
		dollars		dollars	
INCOME					
Grain Sorghum	cwt	4.80	43.0000	206.40	________

TOTAL INCOME				206.40	________
DIRECT EXPENSES					
FERTILIZER					
Fert 25-10-0	tons	225.00	0.2000	45.00	________
HERBICIDE					
AAtrex 4L	pt	1.55	2.0000	3.10	________
IRRIGATION SUPPLIES					
Irrigation Water	ac-ft	20.00	0.4000	8.00	________
SEED/PLANTS					
Grain Sorghum Seed	lb	1.04	6.0000	6.24	________
CUSTOM HARVEST/HAUL					
Harvest/Haul Sorghum	cwt	0.50	43.0000	21.50	________
OPERATOR LABOR					
Tractors	hour	7.50	0.9040	6.78	________
HAND LABOR					
Implements	hour	7.50	0.1110	0.83	________
IRRIGATION LABOR					
Labor (Flood)	hour	7.50	1.0000	7.50	________
Labor (Irr. Setup)	hour	7.50	0.1000	0.75	________
UNALLOCATED LABOR	hour	7.50	0.7232	5.42	________
DIESEL FUEL					
Tractors	gal	2.20	6.8313	15.02	________
REPAIR & MAINTENANCE					
Implements	acre	6.27	1.0000	6.27	________
Tractors	acre	5.77	1.0000	5.77	________
INTEREST ON OP. CAP.	acre	5.66	1.0000	5.66	________

TOTAL DIRECT EXPENSES				137.87	________
RETURNS ABOVE DIRECT EXPENSES				68.52	________
FIXED EXPENSES					
Implements	acre	14.95	1.0000	14.95	________
Tractors	acre	16.88	1.0000	16.88	________

TOTAL FIXED EXPENSES				31.83	________

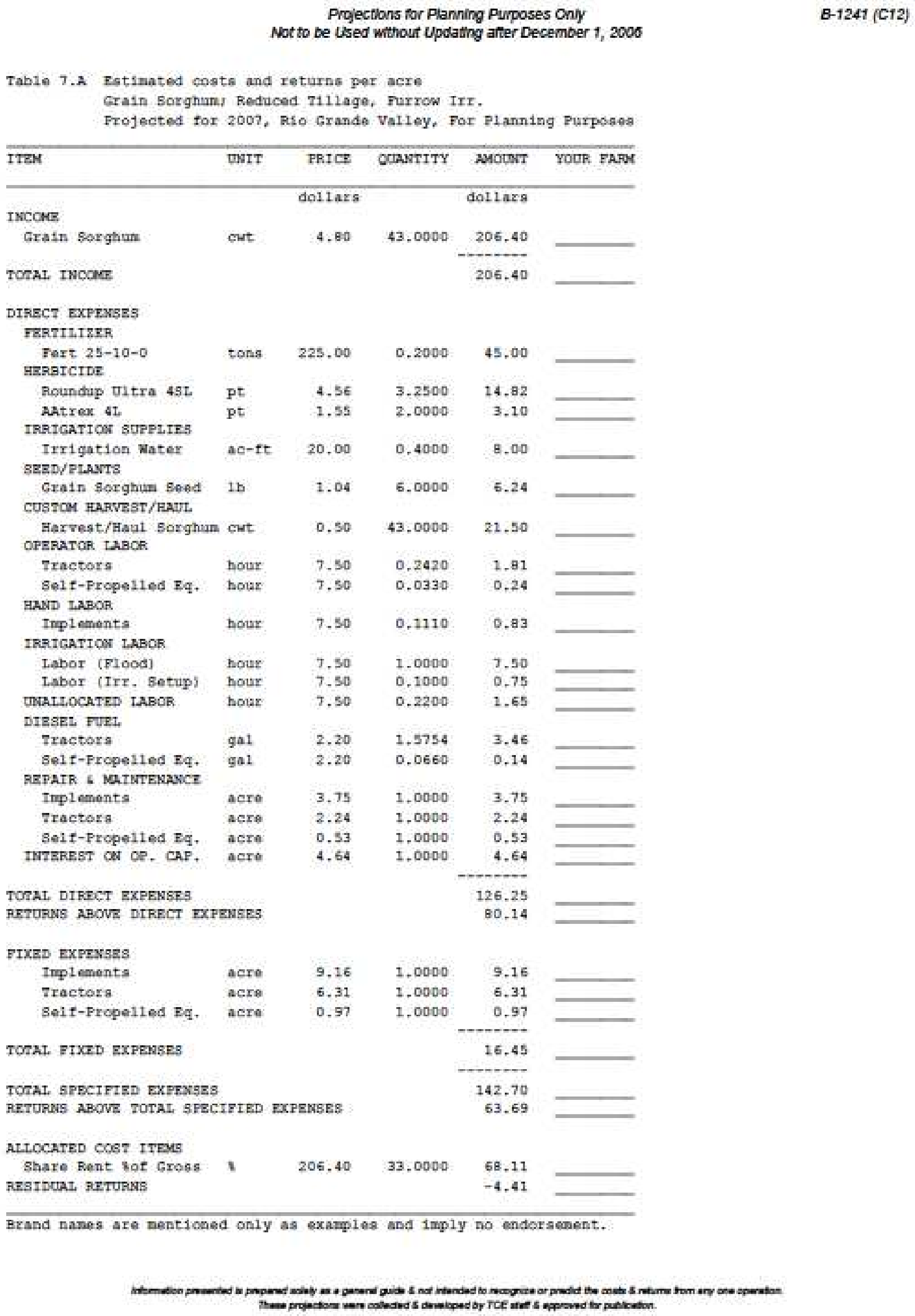
TOTAL SPECIFIED EXPENSES				169.70	________
RETURNS ABOVE TOTAL SPECIFIED EXPENSES				36.69	________
ALLOCATED COST ITEMS					
Share Rent %of Gross	%	206.40	33.0000	68.11	________
RESIDUAL RETURNS				-31.42	________

Brand names are mentioned only as examples and imply no endorsement.

Information presented is prepared solely as a general guide & not intended to recognize or predict the costs & returns from any one operation.
These projections were collected & developed by TCE staff & approved for publication.

Source: Texas AgriLife Extension Service 2007.

Exhibit B-4. Texas AgriLife Extension Service, Region 12 Crop Budget for Grain Sorghum, Conventional Tillage, Furrow Irrigation, 2007



Projections for Planning Purposes Only
Not to be Used without Updating after December 1, 2006

B-1241 (C12)

Table 7.A Estimated costs and returns per acre
Grain Sorghum; Reduced Tillage, Furrow Irr.
Projected for 2007, Rio Grande Valley, For Planning Purposes

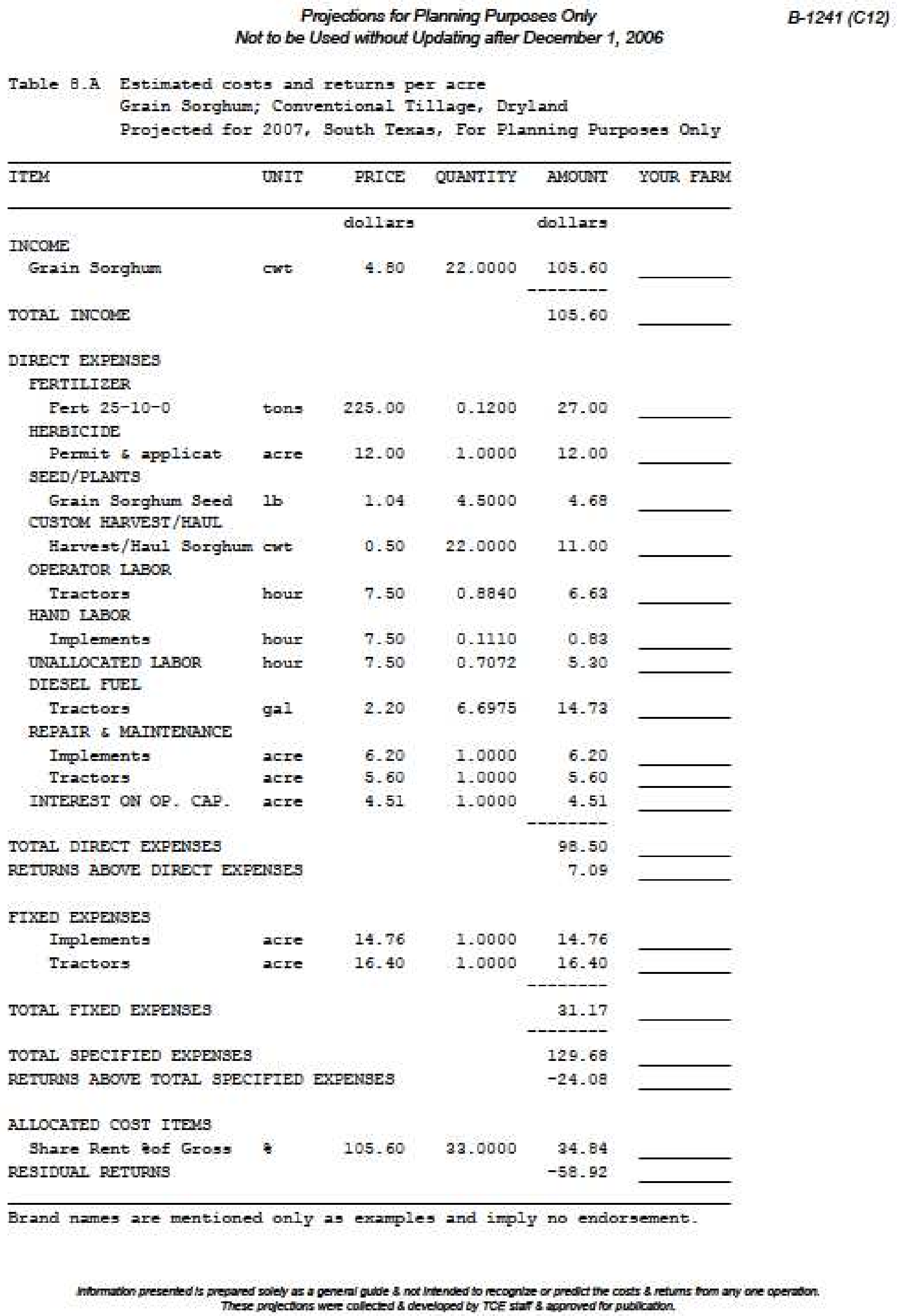
ITEM	UNIT	PRICE	QUANTITY	AMOUNT	YOUR FARM
		dollars		dollars	
INCOME					
Grain Sorghum	cwt	4.80	43.0000	206.40	
TOTAL INCOME				206.40	
DIRECT EXPENSES					
FERTILIZER					
Fert 25-10-0	tons	225.00	0.2000	45.00	
HERBICIDE					
Roundup Ultra 4SL	pt	4.56	3.2500	14.82	
AAtrex 4L	pt	1.55	2.0000	3.10	
IRRIGATION SUPPLIES					
Irrigation Water	ac-ft	20.00	0.4000	8.00	
SEED/PLANTS					
Grain Sorghum Seed	lb	1.04	6.0000	6.24	
CUSTOM HARVEST/HAUL					
Harvest/Haul Sorghum	cwt	0.50	43.0000	21.50	
OPERATOR LABOR					
Tractors	hour	7.50	0.2420	1.81	
Self-Propelled Eq.	hour	7.50	0.0330	0.24	
HAND LABOR					
Implements	hour	7.50	0.1110	0.83	
IRRIGATION LABOR					
Labor (Flood)	hour	7.50	1.0000	7.50	
Labor (Irr. Setup)	hour	7.50	0.1000	0.75	
UNALLOCATED LABOR	hour	7.50	0.2200	1.65	
DIESEL FUEL					
Tractors	gal	2.20	1.5754	3.46	
Self-Propelled Eq.	gal	2.20	0.0660	0.14	
REPAIR & MAINTENANCE					
Implements	acre	3.75	1.0000	3.75	
Tractors	acre	2.24	1.0000	2.24	
Self-Propelled Eq.	acre	0.53	1.0000	0.53	
INTEREST ON OP. CAP.	acre	4.64	1.0000	4.64	
TOTAL DIRECT EXPENSES				126.25	
RETURNS ABOVE DIRECT EXPENSES				80.14	
FIXED EXPENSES					
Implements	acre	9.16	1.0000	9.16	
Tractors	acre	6.31	1.0000	6.31	
Self-Propelled Eq.	acre	0.97	1.0000	0.97	
TOTAL FIXED EXPENSES				16.45	
TOTAL SPECIFIED EXPENSES				142.70	
RETURNS ABOVE TOTAL SPECIFIED EXPENSES				63.69	
ALLOCATED COST ITEMS					
Share Rent %of Gross	%	206.40	33.0000	68.11	
RESIDUAL RETURNS				-4.41	

Brand names are mentioned only as examples and imply no endorsement.

Information presented is prepared solely as a general guide & not intended to recognize or predict the costs & returns from any one operation.
These projections were collected & developed by TCE staff & approved for publication.

Source: Texas AgriLife Extension Service 2007.

Exhibit B-5. Texas AgriLife Extension Service, Region 12 Crop Budget for Grain Sorghum, Reduced Tillage, Furrow Irrigation, 2007



Projections for Planning Purposes Only
Not to be Used without Updating after December 1, 2006

B-1241 (C12)

Table 8.A Estimated costs and returns per acre
Grain Sorghum; Conventional Tillage, Dryland
Projected for 2007, South Texas, For Planning Purposes Only

ITEM	UNIT	PRICE	QUANTITY	AMOUNT	YOUR FARM
		dollars		dollars	
INCOME					
Grain Sorghum	cwt	4.80	22.0000	105.60	

TOTAL INCOME				105.60	
DIRECT EXPENSES					
FERTILIZER					
Fert 25-10-0	tons	225.00	0.1200	27.00	
HERBICIDE					
Permit & applicat	acre	12.00	1.0000	12.00	
SEED/PLANTS					
Grain Sorghum Seed	lb	1.04	4.5000	4.68	
CUSTOM HARVEST/HAUL					
Harvest/Haul Sorghum	cwt	0.50	22.0000	11.00	
OPERATOR LABOR					
Tractors	hour	7.50	0.8840	6.63	
HAND LABOR					
Implements	hour	7.50	0.1110	0.83	
UNALLOCATED LABOR	hour	7.50	0.7072	5.30	
DIESEL FUEL					
Tractors	gal	2.20	6.6975	14.73	
REPAIR & MAINTENANCE					
Implements	acre	6.20	1.0000	6.20	
Tractors	acre	5.60	1.0000	5.60	
INTEREST ON OP. CAP.	acre	4.51	1.0000	4.51	

TOTAL DIRECT EXPENSES				98.50	
RETURNS ABOVE DIRECT EXPENSES				7.09	
FIXED EXPENSES					
Implements	acre	14.76	1.0000	14.76	
Tractors	acre	16.40	1.0000	16.40	

TOTAL FIXED EXPENSES				31.17	

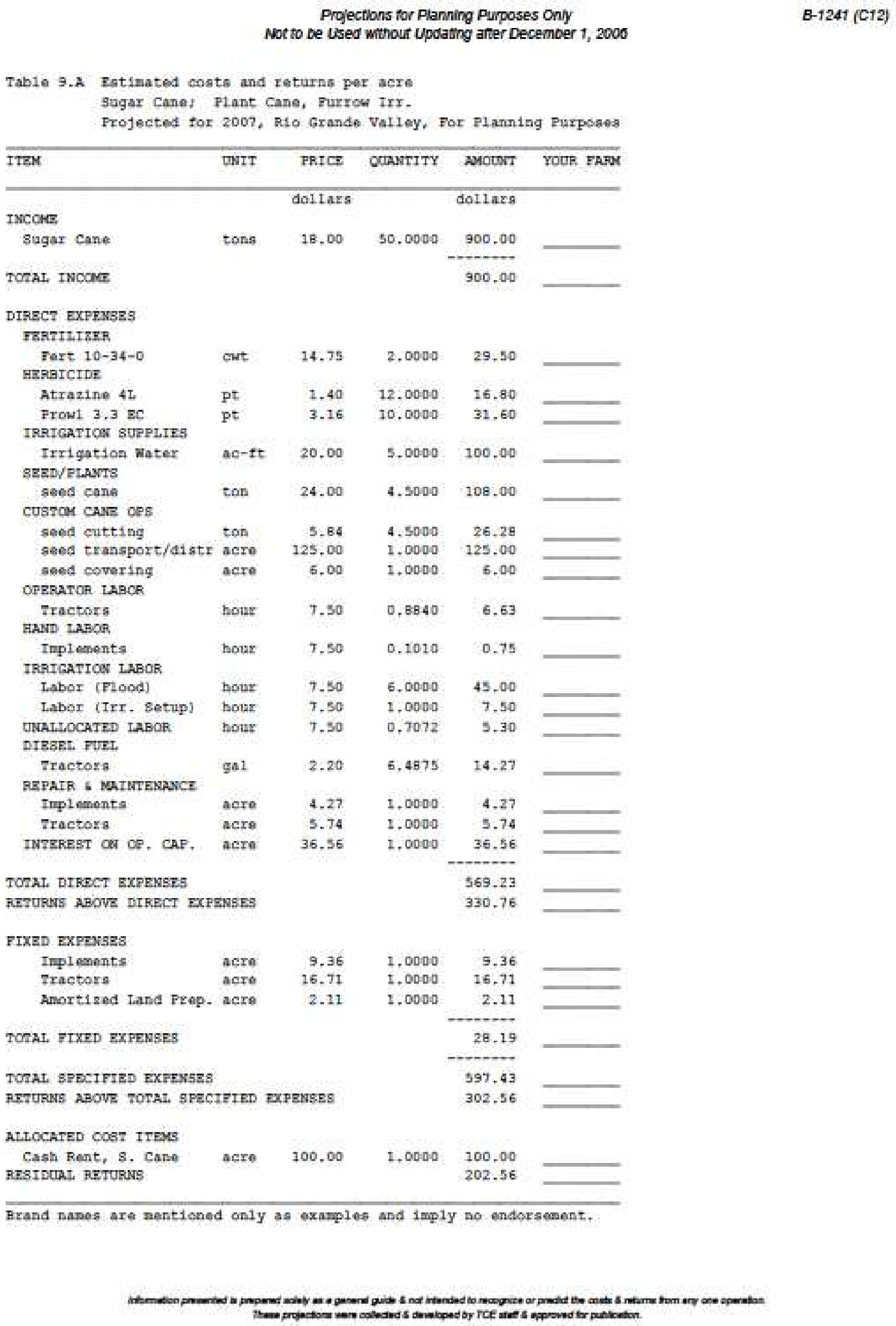
TOTAL SPECIFIED EXPENSES				129.68	
RETURNS ABOVE TOTAL SPECIFIED EXPENSES				-24.08	
ALLOCATED COST ITEMS					
Share Rent %of Gross	%	105.60	33.0000	34.84	
RESIDUAL RETURNS				-58.92	

Brand names are mentioned only as examples and imply no endorsement.

Information presented is prepared solely as a general guide & not intended to recognize or predict the costs & returns from any one operation.
These projections were collected & developed by TCE staff & approved for publication.

Source: Texas AgriLife Extension Service 2007.

Exhibit B-6. Texas AgriLife Extension Service, Region 12 Crop Budget for Grain Sorghum, Conventional Tillage, Dryland, 2007



Projections for Planning Purposes Only
Not to be Used without Updating after December 1, 2006

B-1241 (C12)

Table 9.A Estimated costs and returns per acre
Sugar Cane; Plant Cane, Furrow Irr.
Projected for 2007, Rio Grande Valley, For Planning Purposes

ITEM	UNIT	PRICE	QUANTITY	AMOUNT	YOUR FARM
		dollars		dollars	
INCOME					
Sugar Cane	tons	18.00	50.0000	900.00	

TOTAL INCOME				900.00	
DIRECT EXPENSES					
FERTILIZER					
Fert 10-34-0	cwt	14.75	2.0000	29.50	
HERBICIDE					
Atrazine 4L	pt	1.40	12.0000	16.80	
Prowl 3.3 EC	pt	3.16	10.0000	31.60	
IRRIGATION SUPPLIES					
Irrigation Water	ac-ft	20.00	5.0000	100.00	
SEED/PLANTS					
seed cane	ton	24.00	4.5000	108.00	
CUSTOM CANE OPS					
seed cutting	ton	5.84	4.5000	26.28	
seed transport/distr	acre	125.00	1.0000	125.00	
seed covering	acre	6.00	1.0000	6.00	
OPERATOR LABOR					
Tractors	hour	7.50	0.8840	6.63	
HAND LABOR					
Implements	hour	7.50	0.1010	0.75	
IRRIGATION LABOR					
Labor (Flood)	hour	7.50	6.0000	45.00	
Labor (Irr. Setup)	hour	7.50	1.0000	7.50	
UNALLOCATED LABOR	hour	7.50	0.7072	5.30	
DIESEL FUEL					
Tractors	gal	2.20	6.4875	14.27	
REPAIR & MAINTENANCE					
Implements	acre	4.27	1.0000	4.27	
Tractors	acre	5.74	1.0000	5.74	
INTEREST ON OP. CAP.	acre	36.56	1.0000	36.56	

TOTAL DIRECT EXPENSES				569.23	
RETURNS ABOVE DIRECT EXPENSES				330.76	
FIXED EXPENSES					
Implements	acre	9.36	1.0000	9.36	
Tractors	acre	16.71	1.0000	16.71	
Amortized Land Prep.	acre	2.11	1.0000	2.11	

TOTAL FIXED EXPENSES				28.19	

TOTAL SPECIFIED EXPENSES				597.43	
RETURNS ABOVE TOTAL SPECIFIED EXPENSES				302.56	
ALLOCATED COST ITEMS					
Cash Rent, S. Cane	acre	100.00	1.0000	100.00	
RESIDUAL RETURNS				202.56	

Brand names are mentioned only as examples and imply no endorsement.

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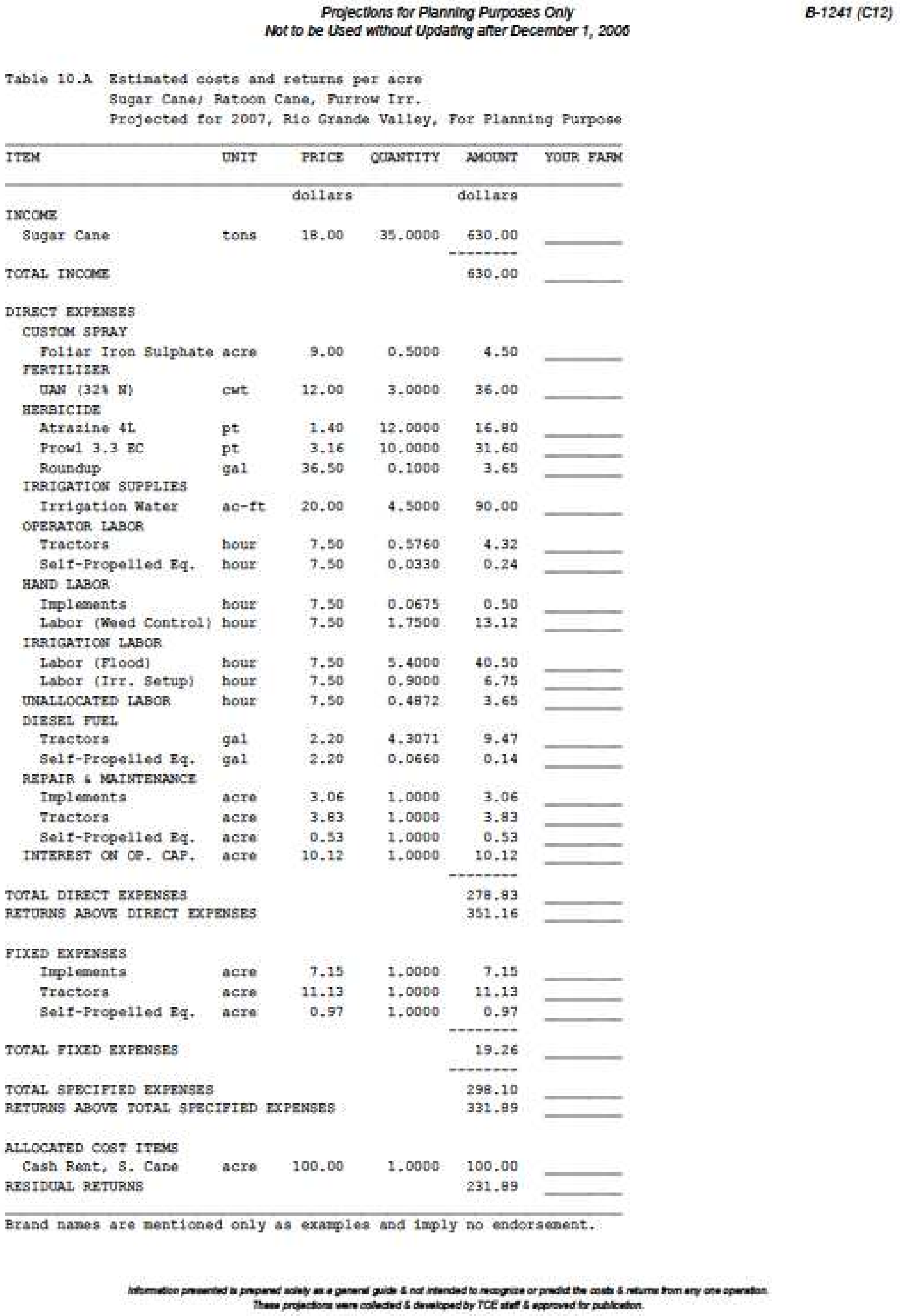
These projections were collected & developed by TCE staff & approved for publication.

Source: Texas AgriLife Extension Service 2007.

Exhibit B-7. Texas AgriLife Extension Service, Region 12 Crop Budget for Sugar Cane, Plant Cane, Furrow Irrigation, 2007



Projections for Planning Purposes Only
Not to be Used without Updating after December 1, 2006

B-1241 (C12)

Table 10.A Estimated costs and returns per acre
Sugar Cane; Ratoon Cane, Furrow Irr.
Projected for 2007, Rio Grande Valley, For Planning Purpose

ITEM	UNIT	PRICE	QUANTITY	AMOUNT	YOUR FARM
		dollars		dollars	
INCOME					
Sugar Cane	tons	18.00	35.0000	630.00	

TOTAL INCOME				630.00	
DIRECT EXPENSES					
CUSTOM SPRAY					
Foliar Iron Sulphate	acre	9.00	0.5000	4.50	
FERTILIZER					
UAN (32% N)	cwt	12.00	3.0000	36.00	
HERBICIDE					
Atrazine 4L	pt	1.40	12.0000	16.80	
Prowl 3.3 EC	pt	3.16	10.0000	31.60	
Roundup	gal	36.50	0.1000	3.65	
IRRIGATION SUPPLIES					
Irrigation Water	ac-ft	20.00	4.5000	90.00	
OPERATOR LABOR					
Tractors	hour	7.50	0.5760	4.32	
Self-Propelled Eq.	hour	7.50	0.0330	0.24	
HAND LABOR					
Implements	hour	7.50	0.0675	0.50	
Labor (Weed Control)	hour	7.50	1.7500	13.12	
IRRIGATION LABOR					
Labor (Flood)	hour	7.50	5.4000	40.50	
Labor (Irr. Setup)	hour	7.50	0.9000	6.75	
UNALLOCATED LABOR	hour	7.50	0.4872	3.65	
DIESEL FUEL					
Tractors	gal	2.20	4.3071	9.47	
Self-Propelled Eq.	gal	2.20	0.0660	0.14	
REPAIR & MAINTENANCE					
Implements	acre	3.06	1.0000	3.06	
Tractors	acre	3.83	1.0000	3.83	
Self-Propelled Eq.	acre	0.53	1.0000	0.53	
INTEREST ON OP. CAP.	acre	10.12	1.0000	10.12	

TOTAL DIRECT EXPENSES				278.83	
RETURNS ABOVE DIRECT EXPENSES				351.16	
FIXED EXPENSES					
Implements	acre	7.15	1.0000	7.15	
Tractors	acre	11.13	1.0000	11.13	
Self-Propelled Eq.	acre	0.97	1.0000	0.97	

TOTAL FIXED EXPENSES				19.26	

TOTAL SPECIFIED EXPENSES				298.10	
RETURNS ABOVE TOTAL SPECIFIED EXPENSES				331.89	
ALLOCATED COST ITEMS					
Cash Rent, S. Cane	acre	100.00	1.0000	100.00	
RESIDUAL RETURNS				231.89	

Brand names are mentioned only as examples and imply no endorsement.

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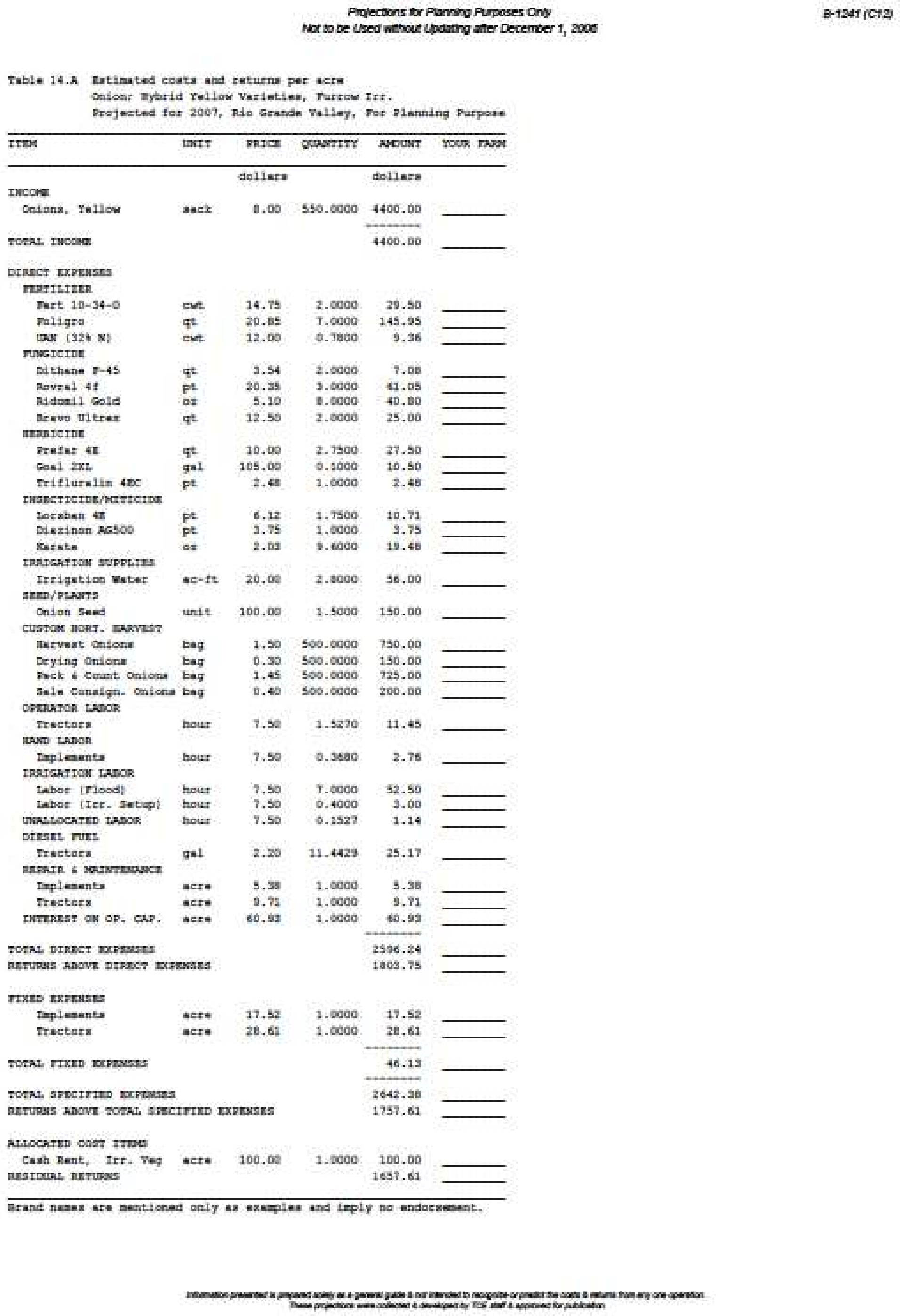
These projections were collected & developed by TCE staff & approved for publication.

Source: Texas AgriLife Extension Service 2007.

Exhibit B-8. Texas AgriLife Extension Service, Region 12 Crop Budget for Sugar Cane, Ratoon Cane, Furrow Irrigation, 2007



Projections for Planning Purposes Only
Not to be Used without Updating after December 1, 2006

B-1241 (C12)

Table 14.A Estimated costs and returns per acre
Onion; Hybrid Yellow Varieties, Furrow Irr.
Projected for 2007, Rio Grande Valley, For Planning Purpose

ITEM	UNIT	PRICE	QUANTITY	AMOUNT	YOUR FARM
		dollars		dollars	
INCOME					
Onions, Yellow	sack	8.00	550.0000	4400.00	
TOTAL INCOME				4400.00	
DIRECT EXPENSES					
FERTILIZER					
Fert 10-34-0	cwt	14.75	2.0000	29.50	
Foligro	qt	20.85	7.0000	145.95	
UAN (32% N)	cwt	12.00	0.7800	9.36	
FUNGICIDE					
Dithane F-45	qt	3.54	2.0000	7.08	
Rovral 4f	pt	20.35	3.0000	61.05	
Ridomil Gold	oz	5.10	8.0000	40.80	
Bravo Ultrex	qt	12.50	2.0000	25.00	
HERBICIDE					
Prefar 4E	qt	10.00	2.7500	27.50	
Goal 2XL	gal	105.00	0.1000	10.50	
Trifluralin 4EC	pt	2.48	1.0000	2.48	
INSECTICIDE/MITICIDE					
Lorsban 4E	pt	6.12	1.7500	10.71	
Diazinon AG500	pt	3.75	1.0000	3.75	
Karate	oz	2.03	9.6000	19.48	
IRRIGATION SUPPLIES					
Irrigation Water	ac-ft	20.00	2.8000	56.00	
SEED/PLANTS					
Onion Seed	unit	100.00	1.5000	150.00	
CUSTOM HORT. HARVEST					
Harvest Onions	bag	1.50	500.0000	750.00	
Drying Onions	bag	0.30	500.0000	150.00	
Pack & Count Onions	bag	1.45	500.0000	725.00	
Sale Consign. Onions	bag	0.40	500.0000	200.00	
OPERATOR LABOR					
Tractors	hour	7.50	1.5270	11.45	
HAND LABOR					
Implements	hour	7.50	0.3680	2.76	
IRRIGATION LABOR					
Labor (Flood)	hour	7.50	7.0000	52.50	
Labor (Irr. Setup)	hour	7.50	0.4000	3.00	
UNALLOCATED LABOR	hour	7.50	0.1527	1.14	
DIESEL FUEL					
Tractors	gal	2.20	11.4429	25.17	
REPAIR & MAINTENANCE					
Implements	acre	5.38	1.0000	5.38	
Tractors	acre	9.71	1.0000	9.71	
INTEREST ON OP. CAP.	acre	60.93	1.0000	60.93	
TOTAL DIRECT EXPENSES				2596.24	
RETURNS ABOVE DIRECT EXPENSES				1803.75	
FIXED EXPENSES					
Implements	acre	17.52	1.0000	17.52	
Tractors	acre	28.61	1.0000	28.61	
TOTAL FIXED EXPENSES				46.13	
TOTAL SPECIFIED EXPENSES				2642.38	
RETURNS ABOVE TOTAL SPECIFIED EXPENSES				1757.61	
ALLOCATED COST ITEMS					
Cash Rent, Irr. Veg	acre	100.00	1.0000	100.00	
RESIDUAL RETURNS				1657.61	

Brand names are mentioned only as examples and imply no endorsement.

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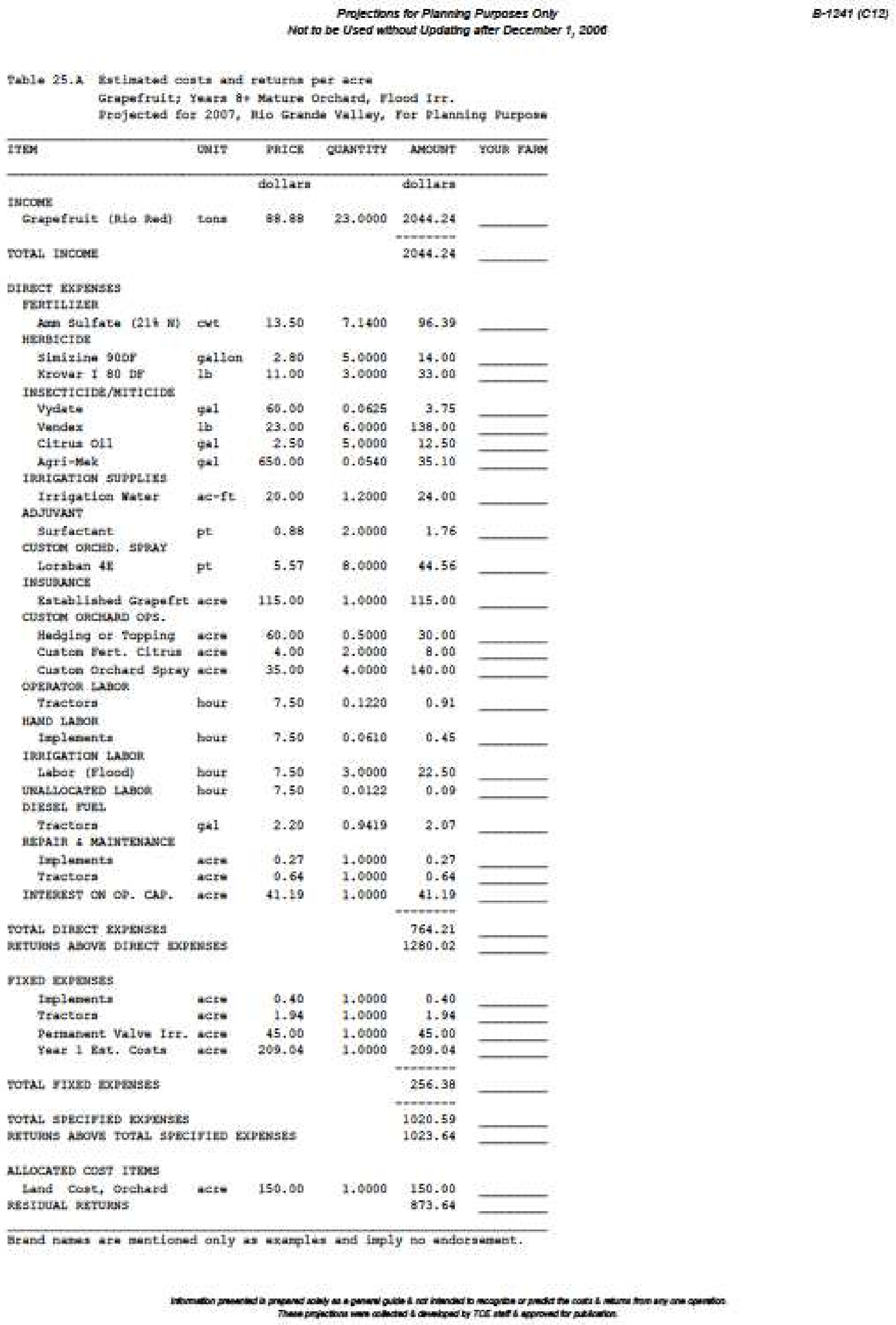
These projections were collected & developed by TCE staff & approved for publication.

Source: Texas AgriLife Extension Service 2007.

Exhibit B-9. Texas AgriLife Extension Service, Region 12 Crop Budget for Onion, Hybrid Yellow Varieties, Furrow Irrigation, 2007



Projections for Planning Purposes Only
Not to be Used without Updating after December 1, 2006

B-1241 (C12)

Table 25.A Estimated costs and returns per acre
Grapefruit; Years 8+ Mature Orchard, Flood Irr.
Projected for 2007, Rio Grande Valley, For Planning Purpose

ITEM	UNIT	PRICE	QUANTITY	AMOUNT	YOUR FARM
		dollars		dollars	
INCOME					
Grapefruit (Rio Red)	tons	88.88	23.0000	2044.24	
TOTAL INCOME				2044.24	
DIRECT EXPENSES					
FERTILIZER					
Amm Sulfate (21% N)	cwt	13.50	7.1400	96.39	
HERBICIDE					
Simizine 90DF	gallon	2.80	5.0000	14.00	
Krovar I 80 DF	lb	11.00	3.0000	33.00	
INSECTICIDE/MITICIDE					
Vydate	gal	60.00	0.0625	3.75	
Vendex	lb	23.00	6.0000	138.00	
Citrus Oil	gal	2.50	5.0000	12.50	
Agri-Mek	gal	650.00	0.0540	35.10	
IRRIGATION SUPPLIES					
Irrigation Water	ac-ft	20.00	1.2000	24.00	
ADJUVANT					
Surfactant	pt	0.88	2.0000	1.76	
CUSTOM ORCHD. SPRAY					
Lorsban 4E	pt	5.57	8.0000	44.56	
INSURANCE					
Established Grapefrt	acre	115.00	1.0000	115.00	
CUSTOM ORCHARD OPS.					
Hedging or Topping	acre	60.00	0.5000	30.00	
Custom Fert. Citrus	acre	4.00	2.0000	8.00	
Custom Orchard Spray	acre	35.00	4.0000	140.00	
OPERATOR LABOR					
Tractors	hour	7.50	0.1220	0.91	
HAND LABOR					
Implements	hour	7.50	0.0610	0.45	
IRRIGATION LABOR					
Labor (Flood)	hour	7.50	3.0000	22.50	
UNALLOCATED LABOR	hour	7.50	0.0122	0.09	
DIESEL FUEL					
Tractors	gal	2.20	0.9419	2.07	
REPAIR & MAINTENANCE					
Implements	acre	0.27	1.0000	0.27	
Tractors	acre	0.64	1.0000	0.64	
INTEREST ON OP. CAP.	acre	41.19	1.0000	41.19	
TOTAL DIRECT EXPENSES				764.21	
RETURNS ABOVE DIRECT EXPENSES				1280.02	
FIXED EXPENSES					
Implements	acre	0.40	1.0000	0.40	
Tractors	acre	1.94	1.0000	1.94	
Permanent Valve Irr.	acre	45.00	1.0000	45.00	
Year 1 Est. Costs	acre	209.04	1.0000	209.04	
TOTAL FIXED EXPENSES				256.38	
TOTAL SPECIFIED EXPENSES				1020.59	
RETURNS ABOVE TOTAL SPECIFIED EXPENSES				1023.64	
ALLOCATED COST ITEMS					
Land Cost, Orchard	acre	150.00	1.0000	150.00	
RESIDUAL RETURNS				873.64	

Brand names are mentioned only as examples and imply no endorsement.

Information presented is prepared solely as a general guide & not intended to recognize or predict the costs & returns from any one operation.
These projections were collected & developed by TCE staff & approved for publication.

Source: Texas AgriLife Extension Service 2007.

Exhibit B-10. Texas AgriLife Extension Service, Region 12 Crop Budget for Grapefruits, Years 8+ Mature Orchard, Flood Irrigation, 2007

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