

**A Case Study in Efficiency –  
Agriculture and Water Use in the  
Yuma, Arizona Area**

February 2015

Yuma County Agriculture Water Coalition

This case study is available online at [www.agwateryuma.com](http://www.agwateryuma.com)

*Wade Noble, Coordinator  
(928) 343-9447, [wade@noblaw.com](mailto:wade@noblaw.com)*

## **CREDITS**

- Section 1: WATER SUPPLY - THE COLORADO RIVER  
N.W. "Bill" Plummer plummernw@aol.com, 602-376-3029
- Section 2: INFRASTRUCTURE-WATERCONVEYANCES AND DELIVERY SYSTEMS IN YUMA  
N.W. "Bill" Plummer plummernw@aol.com, 602-376-3029
- Section 3: IRRIGATION MANAGEMENT IN YUMA COUNTY  
Dr. Paul W. Brown, University of Arizona College of Agriculture and Life Sciences  
pbrown@ag.arizona.edu, 520-419-2991  
  
Dr. Kurt D. Nolte, University of Arizona College of Agriculture and Life Sciences  
knolte@ag.arizona.edu, 928-503-4956  
  
Dr. Charles A. Sanchez, University of Arizona College of Agriculture and Life Sciences  
sanchez@ag.arizona.edu,
- Section 4: THE ECONOMIC CONTRIBUTION OF AGRICULTURE IN YUMA COUNTY  
Dr. George Frisvold, University of Arizona College of Agriculture and Life Sciences  
frisvold@ag.arizona.edu, 520-621-6269
- Section 5: ENVIRONMENTAL WATER USE IN YUMA COUNTY AND THE LOWER COLORADO RIVER  
Patricia Ware, patwarefarms@yahoo.com, 928-580-6727  
N.W. "Bill" Plummer plummernw@aol.com, 602-376-3029

## **ACKNOWLEDGEMENTS**

### **Yuma County Agriculture Water Coalition**

Wellton-Mohawk Irrigation and Drainage District Patricia Ware, President Elston K. Grubaugh, General Manager	Yuma County Water Users' Association Jim Cuming, President Tom Davis, General Manager
Yuma Mesa Irrigation and Drainage District Mark R. Spencer, President Pat Morgan, General Manager	Yuma Irrigation District Mark R. Smith, President Rex Green, General Manager
North Gila Valley Irrigation and Drainage District Frank Ferguson, President	Unit B Irrigation and Drainage District Connie Beshears, President Bryan Knight, General Manager

### **Arizona Department of Water Resources**

Thomas Buschatzke, Director  
Gerry L. Walker, Deputy Assistant Director for Water Planning

### **University of Arizona College of Agriculture and Life Sciences**

Dr. Jeffery C. Silvertooth, Associate Dean & Director, Extension and Economic Development,  
Associate Director, Arizona Experiment Station College of Agriculture and Life Sciences University  
of Arizona

### **Case Study Committee**

Dr. Paul W. Brown	University of Arizona
Thomas Buschatzke	Arizona Department of Water Resources
Tom Davis	Yuma County Water Users' Association
Dr. George Frisvold	University of Arizona
Elston K. Grubaugh	Wellton-Mohawk Irrigation and Drainage District
Bryan Knight	Unit B Irrigation and Drainage District
Pat Morgan	Yuma Mesa Irrigation and Drainage District
Wade Noble	North Gila Valley Irrigation and Drainage District
Dr. Kurt D. Nolte	University of Arizona
N.W. "Bill" Plummer	Consultant
Dr. Charles A. Sanchez	University of Arizona
Mark R. Smith	Yuma Irrigation District
Gerry L. Walker	Arizona Department of Water Resources
Patricia Ware	Wellton-Mohawk Irrigation and Drainage District

## PREFACE

As the quotes below illustrate, the historical importance of agriculture in the Yuma area cannot be overstated and the economic importance of agriculture in the Yuma area today should not be minimalized.

### **Soils unsurpassed in productive power.**

Los Angeles, California  
Nov. 25<sup>th</sup>, 1901

Dear Sirs:-

. . . I stopped at Yuma on my return from Colorado to examine the conditions under which irrigation has been practiced on the Algodones Grant with a view to determining whether or not gravity canals are likely to prove feasible for the general irrigation of that district, as against pumping. The following report has been prepared to embody my conclusions on the matter.

The territory in question comprises a tract of 50,000 to 60,000 acres of alluvial bottom lands extending some 25 miles south of Yuma to the Mexican boundary, and lying between the Colorado river and the Mesa lands to the east. The lands are extremely fertile and productive, and capable of producing enormous crops when provided with a sufficient supply of water for irrigation. **The inducement offered for a satisfactory solution of the irrigation problem is therefore quite extraordinary as the soil of the region is certainly unsurpassed in productive power by any lands in the United States** (emphasis added). . . .

Jas. D. Schuyler

"Report on Irrigation from the Colorado River Below Yuma, Arizona, by Pumping vs. Gravity Canals - November 25, 1901" from <http://cdm16658.contentdm.oclc.org/cdm/ref/collection/p267501ccp2/id/1923>

### **Myth: "Water is too valuable to use on farms."**

"Although about 80 percent of Colorado River water goes to agriculture, we would be unwise to assume that we can address shortages solely by removing irrigation water from farms. Retiring too much farmland will harm our economy in the Southwest, our food security and our quality of life. Further improving efficiency, judicious switching to less-thirsty crops, and using science to grow more with less water will be essential, but we must be careful not to destabilize rural economies that are the foundation of the basin."

Anne Castle, former Assistant Secretary for Water and Science, U.S. Dept. of the Interior from "Busting myths about water shortage" at <http://www.utsandiego.com/news/2013/sep/26/busting-myths-about-water-shortage/>

### **Model for Efficiency**

"Agribusiness in Yuma has adapted to changing technologies and markets to evolve into a world class venture that is a model for efficiently using water to maximize agricultural production and economic value. It is a driving force for the financial strength of the community in Yuma and is a key component of Arizona's vibrant economy."

Thomas Buschatzke, Director of the Arizona Department of Water Resources – February 2015

**TABLE OF CONTENTS**

CREDITS ..... i

ACKNOWLEDGEMENTS.....ii

PREFACE..... iii

LIST OF FIGURES ..... vii

LIST OF TABLES ..... ix

ACRONYMS AND ABBREVIATIONS..... x

EXECUTIVE SUMMARY..... I

SETTING THE STAGE: THE LAY OF THE LAND..... 1

SECTION 1: WATER SUPPLY – THE COLORADO RIVER ..... 3

    Section Summary..... 3

    Early Water Use..... 3

    The Arizona Priority System ..... 7

    Water Rights for Agriculture in the Yuma Area - Long Standing, Complex, and Unique..... 7

    River Operations..... 7

    References ..... 9

SECTION 2: INFRASTRUCTURE-WATER CONVEYANCES AND DELIVERY SYSTEMS IN YUMA COUNTY ..... 11

    Section Summary.....11

    District Infrastructure Improvements .....12

    On-Farm Infrastructure Improvements .....13

    Return Flows – Unique to Yuma Area .....14

SECTION 3: IRRIGATION MANAGEMENT IN YUMA COUNTY .....17

Section Summary.....	17
Background.....	19
Overview of Yuma Area Agriculture: 2010 vs 1970.....	20
Agricultural Water Use and Irrigation Management.....	22
Components of Irrigation Scheduling.....	35
Water Use Efficiency (WUE).....	47
Conclusion.....	48
References.....	49
<b>SECTION 4: THE ECONOMIC CONTRIBUTION OF AGRICULTURE IN YUMA COUNTY.....</b>	<b>53</b>
Section Summary.....	53
Agricultural Cash Receipts.....	57
Yuma Area Sales and Acreage Rankings.....	58
Yuma County Land Values.....	60
Net Cash Income.....	66
Crop Sales Per Water Withdrawals.....	67
Agriculture is Yuma County’s Single Largest Private Industry.....	71
Contribution Analysis.....	73
References.....	79
<b>SECTION 5: ENVIRONMENTAL WATER USE IN YUMA COUNTY AND THE LOWER COLORADO</b>	
<b>RIVER.....</b>	<b>83</b>
Section Summary.....	83
General Considerations.....	83
National Wildlife Refuges.....	84

The Lower Colorado River Multi-Species Conservation Program.....	85
Environmental Restoration and Enhancement in the Yuma, Arizona area .....	87
Yuma East Wetlands .....	87
The Gila River Channel .....	88
Cross Border Environmental Restoration .....	88
APPENDIX A: THE YUMA AND GILA PROJECTS.....	91
The Yuma Project .....	91
The Gila Project .....	93
APPENDIX B: THE LAW OF THE RIVER .....	99
APPENDIX C: CROPS GROWN IN THE YUMA AREA.....	103
APPENDIX D: DEFINING THE CONTRIBUTION OF AGRICULTURE .....	105

## LIST OF FIGURES

Figure 1.1 Map of the Seven Basin States of the Colorado River Basin .....	5
Figure 2.1 Concrete Lined Canal.....	14
Figure 3.1 Yuma County Crop Production in 1970 and 2010.....	21
Figure 3.2 Irrigable Acres Planted to Vegetable and Multi-crop Production Systems in Yuma County, 1970-201 .....	21
Figure 3.3 Volume of Irrigation Water Delivered to Yuma County Irrigators – 1970-2010 .....	23
Figure 3.4 Estimated Crop Water Use in the Yuma Area. Cross hatched bars represent water use of the vegetable crop. Solid bars above hatched bars represent water use of the rotation crop.....	25
Figure 3.5 Monthly Farm Water Deliveries (AF) for Yuma Valley Irrigation Districts .....	26
Figure 3.6 Infrastructure and Field Management Operations that have Improved Irrigation Management in the Yuma Area .....	30
Figure 3.7 Relationship between Furrow Length, Flow Rate and Application Efficiency for Fine Textured Soils in the Yuma Valley.....	32
Figure 3.8 The Practice of Subbing up has been Replaced by Sprinklers Resulting in a Reduction in the Amount of Water Needed to Establish Vegetable Crops.....	33
Figure 3.9 Relative Yield of Lettuce Irrigated at Different Depletion Percentages .....	36
Figure 3.10 Crop Coefficient Curve for Lettuce that Can be Utilized to Estimate Water Use of Lettuce Crops .....	37
Figure 3.11 Application Efficiency (left) and Low-quarter Distribution Uniformity Expressed as a Function of Furrow Inflow Rate and Cutoff Time for Medium Textured Soils in the Yuma Area.....	39

Figure 3.12 Application Efficiency as a Function of Unit Inflow Rate and Cutoff Distance in Level Basins of the Yuma Mesa for Citrus (left) and Alfalfa (right).....	41
Figure 3.13 On-farm Irrigation Efficiencies for the WMIDD computed from estimates of crop water use – 1970-2010.....	45
Figure 3.14 Drainage Well within the WMIDD .....	46
Figure 3.15 Irrigation Efficiency in WMIDD Estimated from Monthly Leaching Fractions.....	47
Figure 3.16 Water Use Efficiency of Head Lettuce in the Yuma Area – 1970 to 2010.....	49
Figure 4.1 Yuma Case Receipts, Crop and Livestock Sales .....	58
Figure 4.2 2011 Crop Cash Receipts by County.....	61
Figure 4.3 2014 Estimates of Range of Dollar per Acre Cash Rents.....	65

## LIST OF TABLES

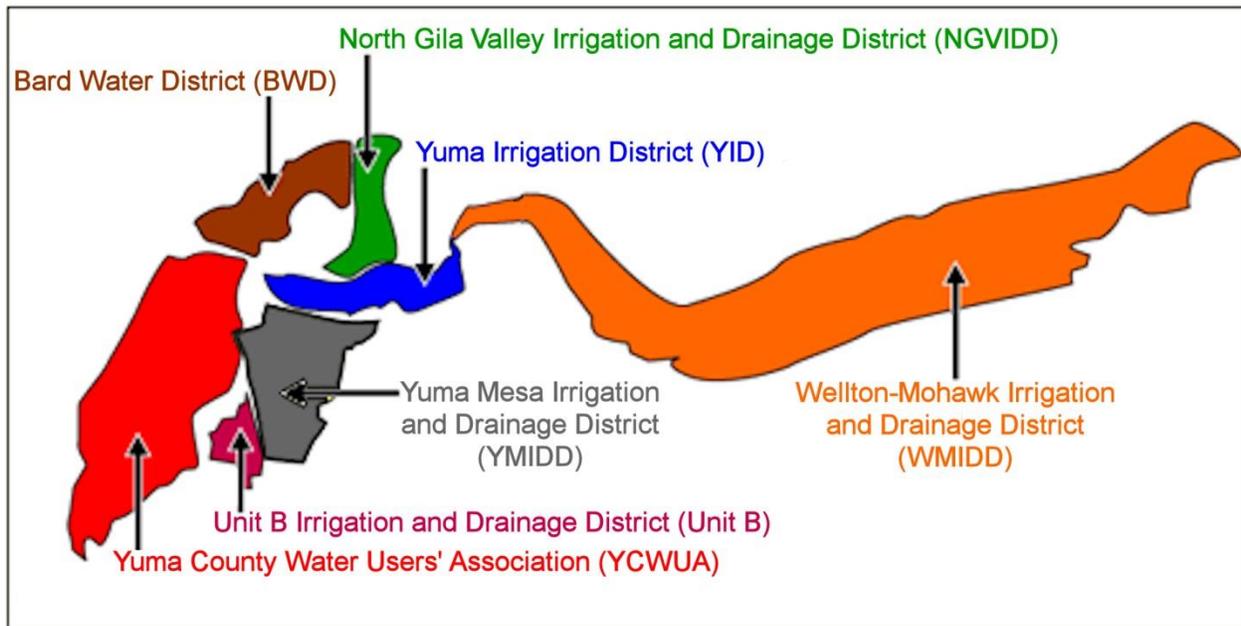
Table 1.1	Yuma Area Mainstem Agricultural Contractors and their Entitlements and Priorities ..	8
Table 1.2	Yuma Area Diversions .....	9
Table 2.1	Yuma Area Irrigation Infrastructure <sup>1</sup> .....	13
Table 2.2	Pumping Plants and Drainage Infrastructure .....	13
Table 4.1	Cash Receipts from Sales Vegetable and Melons: Yuma and Arizona Totals .....	58
Table 4.2	Yuma’s Rank Among All Producing Counties in Crop Sales.....	59
Table 4.3	Yuma’s Rank Among All Producing Counties in Crop Acreage.....	60
Table 4.4	Value of Agricultural Land and Buildings, Yuma, Arizona, and U.S. Averages.....	62
Table 4.5	Cash Rents in Arizona Counties, 2013.....	62
Table 4.6	Comparison of Cash Rents for Irrigated Land Between Yuma County and Crop Reporting Districts in the Colorado River Basin .....	64
Table 4.7	Gross Crop Cash Receipts per Acre-Foot of Water Withdrawn, Arizona Counties Using Colorado River Water, 2010 .....	67
Table 4.8	Ranking of Yuma 3-Digit NAICS Sectors by Location Quotient, 2011 .....	71
Table 4.9	Location Quotients for Selected Yuma Agricultural Sectors .....	72

## ACRONYMS AND ABBREVIATIONS

AF	acre foot or acre feet
AFY	acre foot/year or acre feet/year
Basin States	Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
CAP	Central Arizona Project
CAWCD	Central Arizona Water Conservation District
cfs	Cubic Feet per Second
Compact	Colorado River Compact of 1922
CRD	Crop Reporting District
Cross Border Plan	Plan developed and presented at 2008 Common Ground conference
Decree	United States Supreme Court Decree in <i>Arizona v. California</i> (1964)
DU	Low-quarter Distribution Uniformity
Ea	Application Efficiency
EO	Executive Order
ESA	Endangered Species Act
ETc	Crop Evapotranspiration
ETos	Reference Evapotranspiration
GDP	Gross Domestic Product
HCP	Habitat Conservation Plan
IE	Irrigation Efficiency
LCR MSCP	Lower Colorado River, Multi-Species Conservation Program
Lower Basin	Comprised of the states of Arizona, California and Nevada
LQ	Location Quotient
MAD	Management Allowable Depletion
MAF	Million Acre Feet
MOD	Main Outlet Drain
MODE	Main Outlet Drain Extension
NAICS	North American Industrial Classification System
NASS	National Agricultural Statistical Service
NGVIDD	North Gila Valley Irrigation and Drainage District

PPR	Present Perfected Right
SCADA	Supervisory Control and Data Acquisition
Secretary	Secretary of the Department of the Interior
Siphon Drop	Siphon Drop Hydro-power Plant
UCC	Christiansen's Uniformity Coefficient
Unit B	Unit B Irrigation and Drainage District
Upper Basin	Comprised of the states of Colorado, New Mexico, Utah and Wyoming
U.S.	United States of America
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WCE	Water Conveyance Efficiency
WMD	Wellton-Mohawk Division of the Gila Project - the WMIDD
WMIDD	Wellton-Mohawk Irrigation and Drainage District
WUE	Water Use Efficiency
YCWUA	Yuma County Water Users' Association
YEW Project	Yuma East Wetlands Project
YID	Yuma Irrigation District
YMD	Yuma Mesa Division of the Gila Project - YMIDD, YID and NGVIDD
YMIDD	Yuma Mesa Irrigation and Drainage District

## Yuma, Arizona Area Irrigation Districts and Water Users' Association



## **EXECUTIVE SUMMARY**

The Yuma area is not unique with respect to the fact that settlement of the area and economic progress are tied to the development of water resources from the Colorado River. The Yuma area is unique because a combination of factors, including geographic location, fertile soils, agricultural efficiency, technological innovation, high priority use water, an available workforce and environmental stewardship have transformed the Yuma area into one of the most productive agricultural centers in the United States. This case study draws on both qualitative and quantitative data to tell the story of agricultural water use in the Yuma area.

### **Water Supply – The Colorado River**

Agricultural water use efficiency has improved over time. The Yuma and Gila Projects were authorized to provide irrigation diversion and water delivery systems.

Competition for water resources within the Colorado River Basin resulted in the Colorado River Compact of 1922 (Compact), and the many laws, court decrees and decisions, policies, contracts and treaties that govern the operation of the Colorado River, collectively known as the Law of the River.

Agricultural water rights in the Yuma area are, in general, among the oldest and best water rights on the Lower Colorado River. The water rights held by the six entities are described herein.

Water management in the Lower Colorado River Basin is unique due to the USBR acting under the authority of the Secretary of the Interior (Secretary) as watermaster. All water releases from Glen Canyon Dam and Hoover Dam and Lower Basin water uses are under the purview of the USBR.

Due to the operational structure of the Lower Colorado River Basin, there is an emphasis in the Yuma area on accuracy when placing water orders because water ordered but not used can result in deliveries to Mexico above their water orders and shortages at Imperial Dam result in irrigators receiving less water than they had ordered.

## **Infrastructure – Water Conveyances and Delivery Systems in Yuma County**

The productivity of farmland in Yuma, Arizona has long been recognized.

Infrastructure improvements in the Yuma area were largely driven by the transition to winter vegetable production. Most of the many miles of canals, laterals and farm ditches within the Yuma irrigation districts are lined with concrete and laser and GPS land leveling is practiced within Yuma County.

Return flows are an important concept to understand when considering water use efficiency within Yuma County. It is described in the section.

## **Irrigation Management in Yuma County**

Agriculture has flourished due to the long, nearly frost-free growing season, fertile soils and the availability of quality and dependable irrigation water.

Agricultural production in the Yuma area has shifted from perennial and summer-centric crop production systems (alfalfa, citrus, cotton) to winter-centric, multi-crop systems focused on the production of high-value vegetable crops.

The number of acres planted to vegetables has increased nearly six-fold over the past 40 years while acreage committed to the perennial and full season crops such as citrus, cotton, sorghum and alfalfa has declined 43 percent.

Nearly 70 percent of the irrigable acres now support multi-crop production systems that include a winter vegetable crop followed by durum wheat, melons, short season cotton or sudangrass. The water requirements of these multi-crop systems are typically less than the perennial and full season crops they replaced.

Irrigation water diverted to farms has decreased 15 percent since 1990 (0.8 acre foot (AF)/acre) and nearly 18 percent since 1975 (1.0 AF/acre). Factors contributing to this reduction in water use include a reduction in irrigable acres, expanded use of multi-crop production systems that require less water and significant improvements in crop and irrigation management and infrastructure.

Use of irrigation water during the hot, summer months has declined precipitously over the past 30 years, reflecting the decline in perennial and full season crop production. Today, the only months with higher water deliveries relative to the 1970s are October, November and December, the establishment months for winter vegetables.

Improvements in on-farm irrigation infrastructure, including construction of concrete lined irrigation ditches and high flow turnouts, shortened irrigation runs and sprinkler irrigation systems have improved on-farm irrigation efficiencies, resulting in a reduction in water use.

Yuma area farm fields are leveled each year using precision laser leveling systems and growers utilize press wheels ("bolas") and other management operations to improve water flow across fields. Most Yuma growers use highly efficient level furrow or level basin surface irrigation systems with average application efficiencies in the 80-85 percent range.

Procedures for optimizing the application efficiencies of area irrigation systems have been developed from local research studies. Application efficiencies can approach 90 percent in finer textured valley soils and 55 to 60 percent on coarse textured mesa soils using these procedures.

Data sufficient to evaluate district or regional irrigation efficiency is limited. However, an analysis performed for the Wellton-Mohawk Irrigation and Drainage District (WMIDD) indicates district-wide irrigation efficiencies have increased in recent years and approach 75 percent. Such efficiency levels are quite high, given that leaching fractions approaching 15 percent are required to maintain soil salinity at optimal levels for vegetable production.

Buried drip or trickle irrigation is not widely used in the Yuma area for reasons other than high installation costs. Among the challenges associated with using drip irrigation in vegetable production are non-uniform emergence caused by variation in soil moisture, inability to leach salts that accumulate near the soil surface and the industry need to adjust row orientation and spacing to optimize production efficiencies.

Crop water use efficiency, computed as the ratio of harvestable yield to crop evapotranspiration, continues to increase for most crops in the region and has nearly doubled for head lettuce over the past 40 years.

### **The Economic Contribution of Agriculture in Yuma County**

Yuma is a national center of agricultural production in the U.S. The county ranks at the very top of U.S. counties in several measures of agricultural sales, acreage and production.

Farm-level production only reflects a portion of agriculture's contribution to the Yuma County economy, however. Agricultural production creates demands for goods and services in agricultural input and service sectors. It also creates demands for inputs from sectors not directly related to agriculture. Farm proprietors and employees also spend earnings and wages in local businesses in the county. Both spending on inputs and spending of earnings and wages generates additional demands for goods and services – and jobs – in the Yuma economy. These "multiplier effects" mean that the contribution of agriculture to the Yuma economy stretches beyond the farm gate.

In order to determine the contribution of agriculture to the Yuma economy, one must take a comprehensive look at the industry, incorporating the economic activities of industries directly and indirectly related to agriculture.

Yuma ranks in the top 0.1 percent among U.S. counties in vegetable and melon sales, the top 0.5 percent in sales of all crops, in the top 1 percent in sales of all crop and livestock products combined. In terms of acreage, Yuma ranks in the top 0.1 percent among U.S. counties in vegetable acreage, the top 0.2 percent in lettuce acreage, the top 9 percent in durum wheat acreage, and the top 9 percent in forage crop acreage.

The total market value of on-farm capital assets (land, buildings, and farm machinery) in Yuma was nearly \$1.8 billion. Yuma's average value of land and buildings of \$3.9 million *per farm* is nearly four times the national average. More than 14 percent of Yuma operations had land and buildings valued at more than \$5 million. Only about 2.5 percent of operations in the rest of Arizona had land and buildings valued at more than \$5 million.

Economists frequently use cash rents to measure the productivity and profitability of current agricultural production. This study compared Yuma cash rents to other areas using two different data sources: (a) survey estimates of average cash rents collected by the United States Department of Agriculture (USDA), National Agricultural Statistical Service (NASS) and (b) reports of ranges (low to high) of cash rents reported to the Arizona Chapter of the American Society of Farm Managers and Rural Appraisers. Both data sources indicate that Yuma cash rents are significantly higher than in other Arizona counties and in other areas of the Colorado River Basin.

As one measure of water productivity, this study estimated the dollar value of crop sales per AF of water withdrawn. Gross crop receipts were \$681 per AF of water in Yuma County, while receipts ranged from \$162-\$520 per AF in the five other Arizona counties that utilize Colorado River water.

Yuma is to U.S. agriculture what Silicon Valley is to U.S. computer and electronics production, what Detroit is to U.S. automobile production, and what Napa is to U.S. wine sales. A widely used measure of the relative importance of an industry to a local economy is its Location Quotient (LQ). The LQ measures a local industry's share of local employment relative to the national industry's share of national employment. One can also use LQs to identify national centers of production. The higher the LQ, the more specialized a region is in a particular industry. Based on recent data, the LQ for Wine and Spirit Merchant Wholesalers in Napa County, California was 13.3. The LQ for Computer and Electronic Equipment Manufacturing in Santa Clara County, California (Silicon Valley) was 13.6. The LQ for Motor Vehicle Manufacturing in Wayne County, Michigan (Detroit) was 16.3. For Yuma County, the LQ for agricultural production and support services was 24.5.

Agriculture and supporting services is the single largest private sector contributor to Yuma's Gross Domestic Product (GDP). GDP measures the value of an economy's production of final goods and services. With a GDP of nearly \$5.4 billion, Yuma County's economy would rank 151<sup>st</sup> out of 192 countries, globally. Agriculture is not only Yuma County's single largest private sector industry (as measured by GDP); it is nearly as big as the next two industries (health care and all retail trade) combined.

Valued at 2014 dollars, agriculture and related industries contributed \$2.8 billion in output to the Yuma economy. This included \$2.26 billion in direct sales effects from agricultural and related industries and an additional \$540 million in sales by other Yuma industries.

Agriculture and related industries contributed to one in four jobs in Yuma County. Agriculture and related industries (such as agricultural inputs and services, food and fiber processing) directly account for one in five jobs. Agriculture creates additional jobs in non-agricultural sectors when it purchases goods and services from those sectors. When farming households and employees spend their incomes and paychecks at local businesses, this creates demand for even more jobs.

Every 100 jobs in agriculture and agribusiness industries supported an additional 26 jobs in other industries throughout Yuma's economy. Agricultural and agribusiness spending created demand for jobs in transportation, warehousing, real estate, banking, retailing, and wholesale trade, among many industries. Spending of agricultural paychecks and proprietors' income on local goods and services created demand for jobs in health care, food and beverage service, retailing, banking, and auto repair among other industries.

Data from various sources were analyzed to evaluate the role of agriculture and related industries in Yuma's economy. Data sources included the USDA NASS *Census of Agriculture* and *Arizona Agricultural Statistical Bulletin* (and other data products of the Arizona NASS Field Office), the Bureau of Labor Statistics' (BLS) *Quarterly Census of Employment and Wages*, the U.S. Department of Commerce, Bureau of Economic Analysis, *Regional Economic Accounts*, and the U.S. Census Bureau's *Economic Census* and *County Business Patterns*, and the U.S. Geological Survey's (USGS) *Water Use in the United States*.

The importance of agricultural and related industries was determined by conducting an economic base analysis. This analysis allows for the identification of industries that serve as part of the economic base as well as highlights whether the industry employs more people in the region than the national average.

The economic contribution of agriculture to Yuma County's economy was estimated using input-output modeling and the premiere modeling software for this type of analysis, IMPLAN. Agriculture's contribution to total output, value added (GDP), employment, and employee compensation was estimated.

## **Environmental Considerations**

The Lower Colorado River Basin has been the subject of many actions to mitigate river operations by the USBR from Hoover Dam to the Mexican border. The National Wildlife refuges along the river were created for the purpose of conservation of fish and wildlife in association with mitigating effects of operation of the federal water projects.

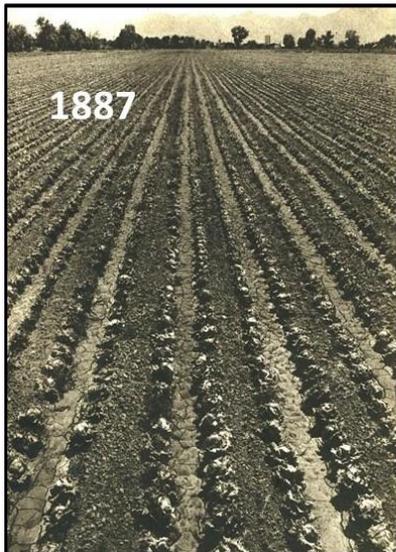
The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) was implemented in 2005 to mitigate the effects of the discretionary operations of the dams by balancing the use of

the Colorado River resources with the conservation of native species and habitats. Both agricultural water users and hydropower users in the Yuma area contribute substantially to Arizona's share of the program costs each year.

Other environmental efforts in the Yuma area include the Yuma East Wetlands, activities within the Gila River channel and cross border environmental efforts.



**125 Years of Yuma  
Agriculture**



## **SETTING THE STAGE: THE LAY OF THE LAND**

The availability and distribution of water are the primary character determinants of all natural ecosystems and modern economies because society is dependent upon an adequate supply of water for municipal, recreational, agricultural, environmental and industrial uses. Like other regions within the western states of the U.S., the majority of settlements in and around Yuma, Arizona and their subsequent economic progress were made possible through the development of water resources from the Colorado River. The early settlements were generally contingent on the availability and management of water to irrigate crops and maintain livestock and the residents that lived there. Early irrigation projects in the region were usually the cooperative efforts of pioneer farmers, but by the early twentieth century, they largely reflected federal intentions. The Reclamation Act of 1902 was passed to provide water storage and irrigation projects to allow the creation of new farms out of the western public domain lands. This case study illustrates how one small but significant portion of the nation's western frontier became the example of agricultural efficiency, technological innovation and environmental stewardship and transformed the Yuma area into one of the most productive farming regions in the nation.

The issues of water availability and water scarcity can be considered in a variety of ways, including identifying areas of water availability, areas of water stress, the impacts of water use and projections of water scarcity. Typically, studies evaluating these issues have evaluated water consumption with respect to generic or state-level measures of crop production.

However, a number of recent research works have highlighted the wide variability in crop yields and have linked agricultural water consumption data with detailed yield data. These efforts have provided key information regarding specific ways to improve yields and reduce water use.

Regional-scale analyses are also beneficial because they facilitate learning between systems such as those in the Yuma area and others that are geographically and culturally diverse.

When water is scarce, understanding the magnitude of water consumption and the efficiency of water use is important. In most cases, however, evaluation for decision-making requires information about both on-farm and system efficiency – when water is being used, is it being used wisely? In this case study, water efficiency is quantitatively assessed in the context of recent water consumption and crop production data provided by Yuma area irrigation water users. It is set within the context of the historical and legal development of water use in the Yuma area coupled with the physical components of the irrigation water user's infrastructure, and it reflects the significant environmental benefit seen as a result of agricultural activity. The final element of importance in the evaluation is economics. As economic benefits increase, there is an increasing commitment on behalf of water users to even more improved efficiencies.

This case study draws on both qualitative and quantitative data to empirically model and analyze the agricultural water use for the Yuma area. It is anticipated that by telling the story of how the Yuma area has evolved into a highly productive and water efficient agricultural center, it will be recognized that there is, in reality, very little room for additional water savings in this sector. It is the intent of the Yuma County Agriculture Water Coalition that this study be included as a case study in the Agricultural Conservation, Productivity and Transfers Working Group's assessment of the Colorado River Basin Water Supply and Demand Study as it relates to agriculture within Yuma County, Arizona.

## **SECTION 1: WATER SUPPLY – THE COLORADO RIVER**

### **Section Summary**

- Agricultural water use efficiency has improved over time. The Yuma and Gila Projects provided irrigation diversion and water delivery systems.
- Competition for water resources within the Colorado River Basin resulted in the Compact, and the many laws, court decrees and decisions, policies, contracts and treaties that govern the operation of the Colorado River, collectively known as the Law of the River.
- Agricultural water rights in the Yuma area are, in general, among the oldest and best water rights on the Lower Colorado River.
- Water management in the Lower Colorado River Basin is unique due to the USBR acting under the authority of the Secretary as watermaster. All water releases from Glen Canyon Dam and Hoover Dam and Lower Basin water uses are under the purview of USBR.
- Due to the operational structure of the Lower Colorado River Basin, there is an emphasis in the Yuma area on accuracy when placing water orders because water ordered but not used can result in deliveries to Mexico above their water orders and shortages at Imperial Dam result in irrigators receiving less water than they had ordered.

### **Early Water Use**

The Colorado River was first diverted for farming in the Yuma area in the late 1800s. At that time, flows in the river were sufficient to serve irrigation needs but the variability and

inconsistency of flows created a challenge. There were no diversion structures to serve the Yuma area.

The Yuma Project was authorized on May 10, 1904, and resulted in development of an irrigation diversion and water delivery system for tens of thousands of acres of rich agricultural farmland, unsurpassed by any in the United States (Schuyler, 1901). Floods and river meandering after construction of the Yuma Project damaged agricultural land and flooded homes and businesses in the Yuma area. As a result, the levee system was constructed in the Valley Division. For additional information regarding the Yuma Project, see Appendix A.

Basin-wide competition for the river increased and users recognized the need for an agreement to fairly share the river. This was partly due to the perception California was over-appropriating river water. The seven Basin States and the United States met and developed the Compact that divided the Colorado River into the Upper Basin and the Lower Basin and allocated water to each basin. Lee Ferry, just downstream of where Glen Canyon Dam was later constructed, separates the Upper Basin from the Lower Basin (See Figure 1.1).

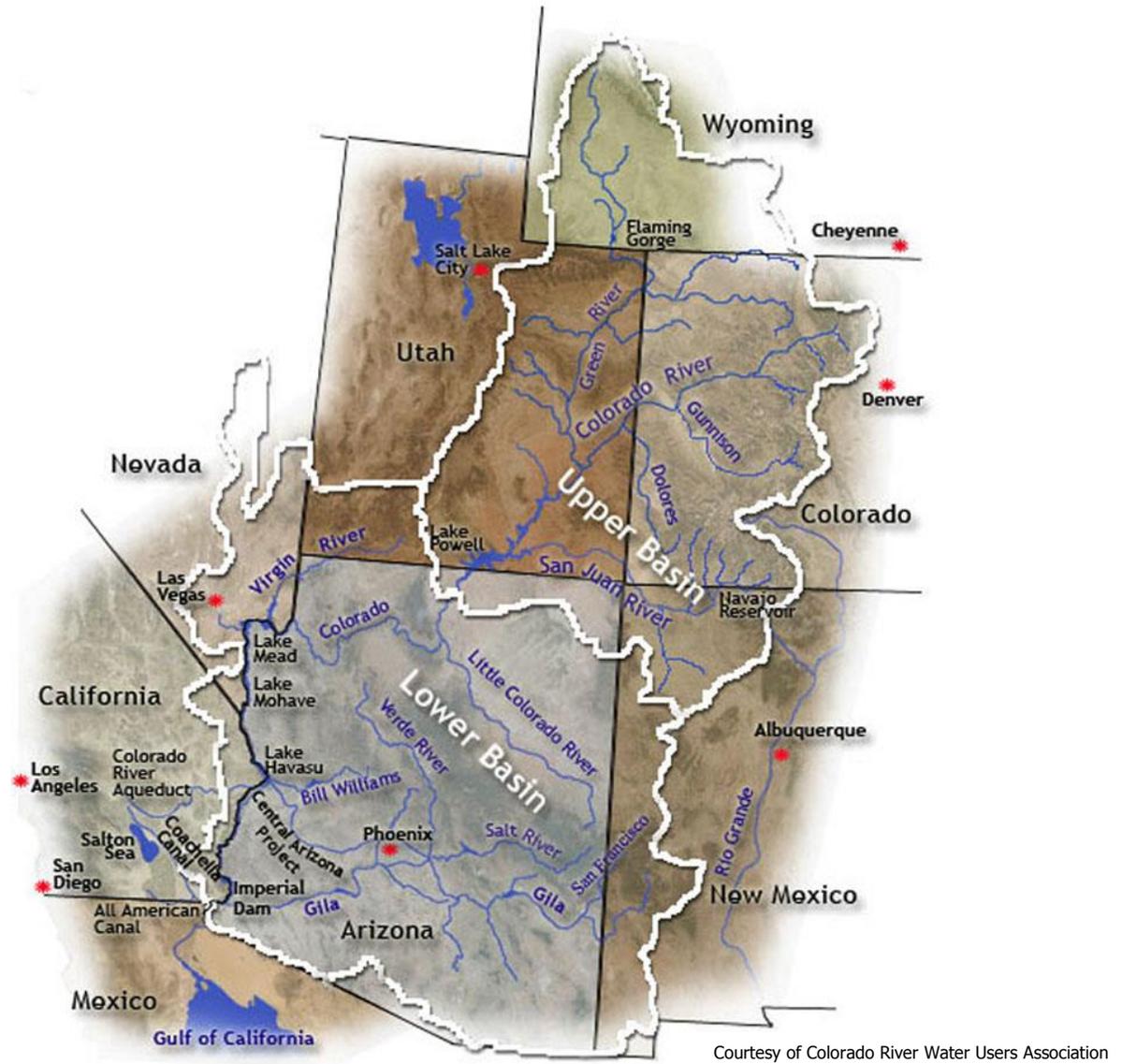


Figure 1.1 Map of the Seven Basin States of the Colorado River Basin

Even with the Compact, there were concerns about the volume of California’s water use. A provision in the Boulder Canyon Project Act of 1928 authorized an agreement among the Lower Basin states to allocate the water as follows: California received 4.4 million AF (MAF);

Arizona received 2.8 MAF and Nevada received 0.3 MAF. The provision also authorized the Secretary to enter into contracts with the states for those volumes of water. The Lower Basin States never entered into an agreement but the volumes were later reflected in contracts with the Secretary. The Compact, the Boulder Canyon Project Act, and the contracts are components of the Law of the River. The Law of the River is the term used to describe the collective assembly of the many laws, court decrees and decisions, policies, contracts and treaties that govern the operation of the Colorado River from the headwaters in Colorado to the international border with Mexico. For additional information on the Law of the River, see Appendix B. The Boulder Canyon Project Act also authorized the initiation of investigation of the Parker-Gila Project, now known as the Gila Project. For detailed information regarding the Gila Project, see Appendix A.

For many years, Arizona and Nevada did not divert their full entitlements which enabled California to divert its 4.4 MAF plus a portion of Arizona's and Nevada's unused entitlement. Arizona sued California to protect its allocation and for a final determination of the allocations. The Supreme Court of the United States decided the case in 1963. The decision was followed with a decree in 1964 (Decree) confirming the Boulder Canyon Project Act allocations. Pursuant to the Boulder Canyon Project Act and the Decree, Colorado River water can only be used in the Lower Basin if authorized by the Decree, a Secretarial reservation or pursuant to a contract with the Secretary. In addition, the Decree identified water rights existing as of June 25, 1929 as Present Perfected Rights (PPR) with the highest priority.

## **The Arizona Priority System**

Arizona applies a priority system to its apportionment of Colorado River water. PPRs as described in the Decree have first priority as the most senior rights. Federal Reservations and Perfected Rights established before September 30, 1968 are second priority. Third priority water rights are held by water users that executed contracts with the United States on or before September 30, 1968. Second and third priority rights are coequal. Fourth priority rights are held by water users with contracts, Secretarial reservations or other rights established after September 30, 1968. This priority includes the Central Arizona Water Conservation District (CAWCD) contract, and all subcontracts for Central Arizona Project (CAP) water. All fourth priority entitlements are coequal. Fifth priority water users have contracts for unused Arizona entitlement and sixth priority water users have contracts for surplus Colorado River water.

## **Water Rights for Agriculture in the Yuma Area - Long Standing, Complex, and Unique**

Water rights vary among the water users in the Yuma area with a combination of PPRs and contractual rights. Table 1.1 summarizes the entitlements of the Yuma area irrigators. Yuma County Water Users' Association (YCWUA), North Gila Valley Irrigation and Drainage District (NGVIDD), and Yuma Auxiliary Project, Unit B (Unit B) have PPRs in addition to contractual rights. PPRs are the oldest and best water rights on the lower Colorado River.

## **River Operations**

Management of the Colorado River in the Lower Basin is unique due to the USBR acting under the authority of the Secretary as watermaster. All water releases from Glen Canyon Dam and

Hoover Dam and water uses within the lower basin are pursuant to the Law of the River. For additional information regarding the Law of the River, see Appendix B. Releases from Hoover Dam provide water for the following purposes, in priority order: (1) river regulation and improvement of navigation and flood control; (2) irrigation and domestic uses; and (3) power. The USBR schedules water releases only on advance water orders for downstream users.

Table 1.1 Yuma Area Mainstem Agricultural Contractors and their Entitlements and Priorities

Entity	Contract Entitlements <sup>1</sup>	Quantity (in AF)	Priority
WMIDD	Consumptive use	278,000	3rd
YCWUA	Beneficial Use-Diversion Right	254,200	1st
YMIDD <sup>2</sup>	Consumptive use	YMD Apportionment	3rd
YID <sup>2</sup>	Consumptive use	YMD Apportionment	3rd
NGVIDD <sup>2</sup>	Beneficial Use-Diversion Right		1st
	Consumptive use	YMD Apportionment	3rd
Unit B	Beneficial Use-Diversion Right	6,800	1st

<sup>1</sup>Two terms - Beneficial Use and Consumptive Use are used. The older contracts, particularly those with PPRs are Beneficial Use Contracts meaning that the diversions to those lands shall be sufficient to irrigate a certain number of acres with beneficial use being the only limitation. Consumptive Use contracts subtract return flows from diversions to calculate contract use.

<sup>2</sup>YMIDD, YID and NGVIDD comprise the Yuma Mesa Division of the Gila Project. A single Consumptive Use water right is assigned to the Division rather than to each District. Consequently, each District, by contract, has "an appropriate and equitable share of the quantity of water available (250,000 AF) for the Division".

Parker Dam is the last facility on the lower Colorado River used by USBR to control downstream releases. Water users are required to carefully assess their water needs to minimize extra releases or shortages at Imperial Dam near Yuma, Arizona. Extra water at the dam can result in additional Colorado River water being delivered to Mexico above their water order.

Shortages at Imperial Dam results in each water user taking delivery from the dam being

required to take a pro rata reduction in their deliveries to accommodate the shortage. The USBR prepared an analysis in 1961 to evaluate the incidence of over-delivery to Mexico and the incidence of shortages. As a result of the study, Senator Dam Wash and Reservoir were constructed for regulatory purposes. The William H. Brock Reservoir, another regulating reservoir, was constructed in 2010 to conserve water ordered and released but not taken by water users in the United States.

Colorado River water delivered to Imperial Dam is diverted to the water users in the Yuma area and the Imperial Valley of California. Table 1.2 identifies the two diversion locations and water recipients.

Table 1.2 Yuma Area Diversions

All-American Canal Diverters	Gila Gravity Main Canal Diverters
YCWUA	WMIDD YMIDD YID NGVIDD Unit B IDD

**References**

Schuyler, J. (1901). "Report on Irrigation from the Colorado River Below Yuma, Arizona, by Pumping vs. Gravity Canals - November 25, 1901" from <http://cdm16658.contentdm.oclc.org/cdm/ref/collection/p267501ccp2/id/1923>



## **SECTION 2: INFRASTRUCTURE-WATER CONVEYANCES AND DELIVERY SYSTEMS IN YUMA COUNTY**

### **Section Summary**

- The productivity of farmland in Yuma, Arizona has long been recognized.
- Infrastructure improvements in the Yuma area were largely driven by the transition to winter vegetable production. Most of the many miles of canals, laterals and farm ditches within the Yuma irrigation districts are lined with concrete and laser and GPS land leveling is practiced within Yuma County.
- Return flows are an important concept to understand when considering water use efficiency within Yuma County.

Early on, it was recognized that the Yuma area had some of the most productive farm land in the United States. Beginning in the late 1800's and early 1900's, the construction of infrastructure in the Yuma area began and the first water was delivered to Yuma Valley fields in 1910. The North Gila received water deliveries shortly thereafter. Early agricultural practices were less efficient, at both the district level and on-farm. Generally, districts utilized earth ditches and delivered water to farms that furrow irrigated crudely leveled fields.

The story began to change in the latter part of the 20<sup>th</sup> century. In the 1960's and 1970's, issues with the salinity of the Colorado River began to influence the infrastructure within the Yuma area. For more information regarding distribution systems and individual district infrastructure, see Tables 2.1 and 2.2 and Appendix A.

The largest changes came about as a result of the beginning of consolidation within the food industry. Arizona farmers adapted readily to consolidated production processes and there was a shift to the Yuma area as a center for vegetable production. As Yuma transitioned into a major national production hub, greater demands in quality, size, uniformity and yield were placed on area growers, prompting a cultural transition to the precision management of Yuma grown crops. This prompted a need for greater irrigation consistency and efficiency, both at the district and on-farm levels and the Yuma area farmers responded.

### **District Infrastructure Improvements**

#### *Lining Canals, Ditches and Laterals or Using Closed Conduits*

The volume of system losses to evaporation, seepage and phreatophytes in main canals, laterals and ditches are highly dependent on whether structures are lined or unlined or within closed conduits. Within the Yuma area, there is a very large number of lined canals, laterals and ditches. Tables 2.1 and 2.2 summarize the infrastructure of the Yuma area. Although the numbers vary by district, over 70 percent of the main canal miles are lined while nearly 90 percent of the lateral miles are lined and over 80 percent of the on-farm ditches are lined. See Figure 2.1 for an example of a concrete lined canal.

#### *Other District Improvements*

There have been numerous other changes within the districts to improve water use efficiency. They include modifications of conveyance systems and turnouts to allow high volume deliveries, implementation of improved scheduling and delivery practices including the use of Supervisory

Control and Data Acquisition (SCADA) systems for gate control and the use of electronic metering devices.

Table 2.1 Yuma Area Irrigation Infrastructure<sup>1</sup>

Entity	Canals (miles)		Laterals (miles)		Farm Ditches (miles)	
	Lined	Unlined	Lined or Pipe	Unlined	Lined	Unlined
WMIDD	103	0	275	0	294	0
YCWUA <sup>2</sup>	9	52	81	53	130	120
YMIDD	23	0	41	0	96	0
YID	8	0	27	0	78	0
NGVIDD	2	8	5	10	28	21
Unit B	4	0	42	2	3	0
<b>TOTAL</b>	<b>149</b>	<b>60</b>	<b>471</b>	<b>63</b>	<b>629</b>	<b>141</b>

<sup>1</sup>Historically, USBR canals were lined with relatively impervious soil material. Some seepage occurs in these earth lined canals. There is little seepage in concrete lined canals. Unlined canals were rarely constructed due to seepage losses. Most unlined canals were later lined with concrete.

<sup>2</sup>Miles of lined and unlined farm ditches for YCWUA are estimated.

Table 2.2 Pumping Plants and Drainage Infrastructure

Entity	Surface Water Pumping Plants	Drainage Pumping Plants	Drainage Wells	Drainage Channels/Pipe (miles)
WMIDD	3	0	90	65
YCWUA	0	1	65	70
YMIDD	1	0	0	0
YID	0	0	24	17
NGVIDD	0	0	0	20

### **On-Farm Infrastructure Improvements**

Mechanical land-leveling has resulted in improved water distribution and increased water conservation. Precision field leveling using lasers is the most current technology. In conjunction

with leveled fields, water is also applied using alternate delivery methods, including sprinkler and drip irrigation. Growers may irrigate the same crop using more than one irrigation method to insure that the volume of water needed to optimize production is delivered to the plant. For additional discussion regarding these improvements, see Section 3.



Figure 2.1 Concrete Lined Canal

### **Return Flows – Unique to Yuma Area**

The concept of return flows must be included in any discussion regarding infrastructure improvements and water efficiency in the Yuma area. As previously discussed, there is an extensive amount of canal and ditch lining in the region and this large amount is somewhat counter-intuitive when you factor return flows into the analysis. In the Yuma area, the majority of contracts with the USBR are consumptive use contracts meaning that the USBR measures both deliveries and return flows to the system. The consumptive use is then determined by subtracting return flows from diversions. When a district's delivery system is less efficient, there is a greater amount of return flows entering the system. This allows the district to divert additional water and still stay within their contract entitlement. This system is unique to the

Yuma area where return flows are available for consumptive use in the U.S. or in satisfaction of the Mexican treaty obligation. By lining a canal, lateral or ditch, the district actually decreases their return flows to the river. Lining enhances system operations but does not necessarily result in increased water in the Colorado River.



## **SECTION 3: IRRIGATION MANAGEMENT IN YUMA COUNTY**

### **Section Summary**

Crop production systems in the Yuma area have changed dramatically over the past 40 years as the region developed into the premier location for winter vegetable production in the U.S. The conversion of Yuma agriculture from a system based on perennial and full season crop production to one dominated by multi-crop systems focused on high-value, shallow-rooted vegetable crops resulted in significant challenges, particularly with respect to management of irrigation water. Yuma area growers have been quick to adapt to new, innovative production and irrigation technologies that have improved crop productivity while lowering the amount of water used for irrigation. Key findings of this section are as follows:

- The number of acres planted to vegetables has increased nearly six-fold over the past 40 years while acreage committed to the perennial and full season crops such as citrus, cotton, sorghum and alfalfa has declined 43 percent.
- Nearly 70 percent of the irrigable acres now support multi-crop production systems that include a winter vegetable crop followed by durum wheat, melons, short season cotton or sudangrass. The water requirements of these multi-crop systems are typically less than the perennial and full season crops they replaced.
- Irrigation water diverted to farms has decreased 15 percent since 1990 (0.8 AF/acre) and nearly 18 percent since 1975 (1.0 AF/acre). Factors contributing to this reduction in water use include a reduction in irrigable acres, expanded use of multi-crop production systems that require less water and significant improvements in crop and irrigation management and infrastructure.

- Use of irrigation water during the hot, summer months has declined precipitously over the past 30 years, reflecting the decline in perennial and full season crop production. Today, the only months with higher water deliveries relative to the 1970s are October, November and December, the establishment months for winter vegetables.
- Improvements in on-farm irrigation infrastructure, including construction of concrete lined irrigation ditches and high flow turnouts, shortened irrigation runs and sprinkler irrigation systems have improved on-farm irrigation efficiencies, resulting in a reduction in water use.
- Yuma area farm fields are leveled each year using precision laser leveling systems and growers utilize press wheels (“bolas”) and other management operations to improve water flow across fields. Most Yuma growers use highly efficient level furrow or level basin surface irrigation systems with average application efficiencies in the 80-85 percent range.
- Procedures for optimizing the application efficiencies of area irrigation systems have been developed from local research studies. Application efficiencies can approach 90 percent in finer textured valley soils and 55 to 60 percent on coarse textured mesa soils using these procedures.
- Data sufficient to evaluate district or regional irrigation efficiency is limited. However, an analysis performed for the WMIDD indicates district-wide irrigation efficiencies have increased in recent years and approach 75 percent. Such efficiency levels are quite high, given that leaching fractions approaching 15 percent are required to maintain soil salinity at optimal levels for vegetable production.

- Buried drip or trickle irrigation is not widely used in the Yuma area for reasons other than high installation costs. Among the challenges associated with using drip irrigation in vegetable production are non-uniform emergence caused by variation in soil moisture, inability to leach salts that accumulate near the soil surface and the industry need to adjust row orientation and spacing to optimize production efficiencies.
- Crop water use efficiency, computed as the ratio of harvestable yield to crop evapotranspiration, continues to increase for most crops in the region and has nearly doubled for head lettuce over the past 40 years.

### **Background**

Agriculture is a fundamental component of the economic and social fabric of Yuma County. Irrigated crop production was initiated in the late 1800s and has flourished for more than 100 years due to a combination of factors that include a long, nearly frost-free growing season, fertile soils and the availability of quality and dependable irrigation water. During the past 40 years crop production systems have changed dramatically as the Yuma area developed into the premier and primary location for U.S. winter vegetable production. This change in production emphasis has resulted in a shift from perennial and summer-centric crop production systems to winter-centric, multi-crop systems focused on the production of high-value vegetable crops. Such rapid conversion of the Yuma agricultural landscape was not without significant challenges, particularly in relation to irrigation management. Growers quickly realized that traditional approaches to crop irrigation had to be modified to address the challenges of irrigating large acreages of shallow-rooted vegetables. Yuma area growers responded to this challenge by adopting a number of improved irrigation practices that collectively have resulted

in a significant decrease in water used for irrigation. This section of the case study examines the changes in production and irrigation practices that have contributed to the reduction in overall water use by agriculture in the Yuma area. For a list of crops grown in the Yuma area, see Appendix C.

### **Overview of Yuma Area Agriculture: 2010 vs 1970**

The Yuma area is an exceptionally productive agricultural region when compared to the rest of the United States. Weather conditions are conducive to year round crop production which allows for the production of a wide range of cool and warm season crops, and the alluvial soils that reside along the Colorado and Lower Gila Rivers produce exceptionally high yields provided irrigation water is readily available. Crop yields in Yuma County are typically higher than yields for equivalent crops in the rest of Arizona and nearly always higher than the national average yields for equivalent crops.

Agricultural production has changed significantly in the Yuma area over the past four decades. The production systems of the 1970s focused on perennial crops such as alfalfa and citrus, or warm season crops such as cotton and sorghum (See Figure 3.1). The dominant winter crop was wheat which served as the transition crop for growers rotating from cotton to alfalfa, or the second crop in multi-crop production systems that included vegetables or melons. Less than 17 percent of the irrigable land was planted to vegetables in 1970 and just 10 percent of the land was dedicated to multi-crop production systems.

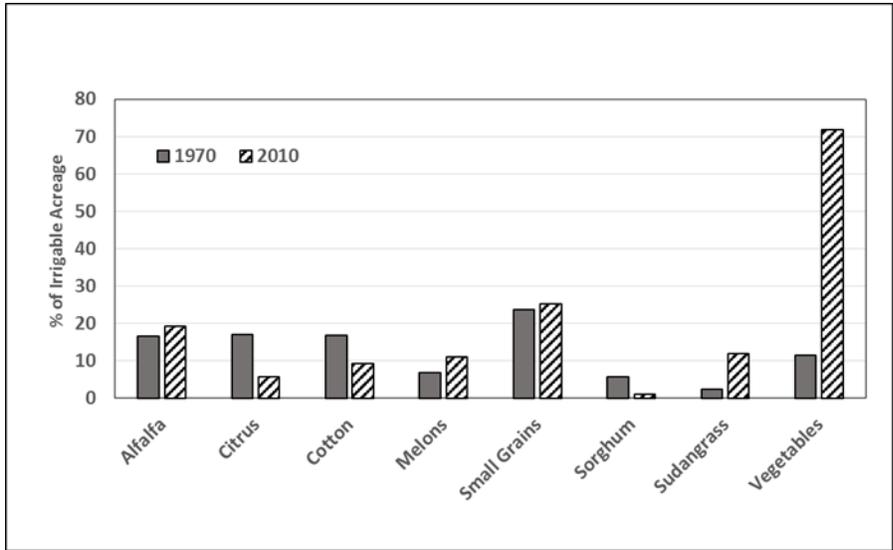


Figure 3.1 Yuma County Crop Production in 1970 and 2010

The rapid development of Yuma as the premier and dominant winter source for cool season vegetables has significantly altered agricultural production systems over the past four decades. The nearly 6-fold increase in vegetable production since 1970 has led to a rapid increase in multi-cropped acreage and a reduction in perennial and full summer crop production (See Figure 3.2).

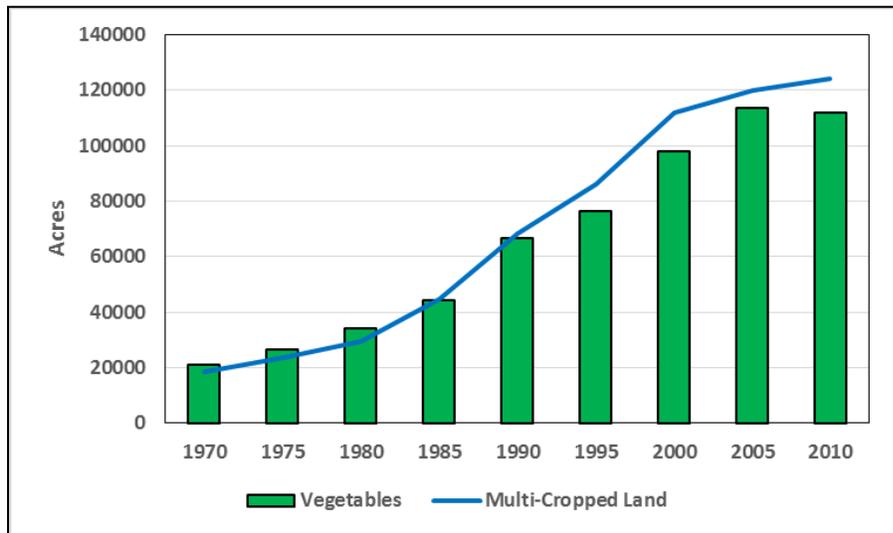


Figure 3.2 Irrigable Acres Planted to Vegetable and Multi-crop Production Systems in Yuma County, 1970-2010

Acreage dedicated to vegetable production is now three times greater than that of any other crop, and in excess of 70 percent of the irrigable acres now support multi-crop production systems each year. Land planted to citrus, cotton and sorghum has decreased by 70 percent, 50 percent, and 85 percent, respectively and the production seasons for summer annual forages (sudangrass) and cotton have been shortened to facilitate the transition of land back to fall and winter vegetable production. Land dedicated to the traditional crops (alfalfa, cotton, citrus and sorghum) has decreased 43 percent since 1970. Production of alfalfa fluctuates with market conditions and crop rotation requirements, but has remained a relatively stable component (15-20 percent of irrigable acres) of Yuma area agriculture over the past 40 years due in large part to regional population growth and the growing demand for dairy products. Wheat continues to serve as an excellent rotation crop with vegetables and remains the second largest acreage crop in Yuma County. The Yuma area is well known for producing high quality durum wheat, much of which is exported to overseas pasta companies.

### **Agricultural Water Use and Irrigation Management**

Water deliveries to Yuma area farms reflect both changes in the management of the Colorado River and the changing dynamics of Yuma agriculture (Figure 3.3). Farm deliveries declined substantially between 1975 and 1985 in response to growing concerns regarding the salinity of Colorado River water. The Salinity Control Act of 1974 was passed to address this issue and required two changes that impacted water deliveries to farms in the WMIDD. One of the changes was retirement of 10,000 acres of sandy, high infiltration rate soils from the WMIDD. The second was a program designed to improve irrigation management and involved leveling of 44,000 acres of district land, lining of 263 miles of farm canals and construction of 10,600 on-

farm water control structures (Bureau of Reclamation, 2005). Another feature of the WMIDD program was the USBR Irrigation Management Services Program that provided irrigation scheduling assistance to growers. The impacts of the Salinity Control Act requirements were significant for the WMIDD and reduced on-farm water deliveries by approximately 145,000 AF annually between 1975 and 1985 and increased district-wide irrigation efficiencies from 56 percent to 72 percent (Bureau of Reclamation, 2005).

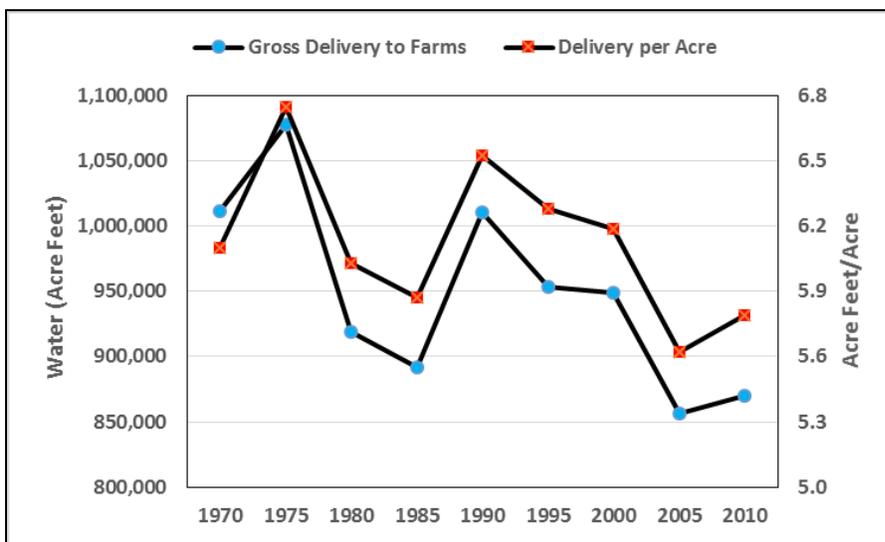


Figure 3.3 Volume of Irrigation Water Delivered to Yuma County Irrigators – 1970-2010

Delivery of water to farms reversed course and increased by approximately 120,000 AF in the late 1980s (Figure 3.3). Much of this increased water delivery occurred in the valley districts where acreage dedicated to vegetable production was increasing at a fast pace. The standard practice at the time was to germinate newly planted vegetable fields using subbing which consisted of filling the furrows with water for seven to 10 days to facilitate uniform germination and early season crop development. A more detailed discussion regarding subbing appears later in this section. While subbing was an effective means of germinating vegetable crops, the

technique greatly increased demand for water from September through November when the bulk of the vegetable crops were being established, and considerable water was lost to percolation below the root zone which reduced irrigation efficiencies and led to problems with high water tables.

Water deliveries to Yuma area farms have declined since 1990 and are now at their lowest levels since 1970 (Figure 3.3). Several factors have contributed to this 15 percent decline in water deliveries since 1990. One factor is urbanization which has reduced the number of irrigable acres by approximately three percent. Nearly half (46 percent) of the acreage reduction has occurred on the Yuma Mesa with the remaining 54 percent occurring in the valley districts. However, a 3 percent reduction in irrigable acres cannot by itself drive a 15 percent reduction in water use. This becomes evident when the gross farm water delivery data are divided by the number of irrigable acres (Figure 3.3). When viewed in this manner, farm water deliveries on a per acre basis have declined by approximately 0.8 AF per acre since 1990.

The development of the Yuma vegetable industry is also responsible for the reduction in water use through its impact on crop production seasons and the industry's unending search for improved production practices. While multi-crop production systems now dominate Yuma area agriculture, the total water requirement of these systems is often less than the perennial and full season production systems of the past. Crop evapotranspiration (ETc) rates of leafy green vegetables, broccoli and cauliflower typically range from 12 to 18 inches and when combined with ETc from the second crop such as durum wheat (ETc approximately 20"), spring melons (ETc approximately 19"), sudangrass (ETc approximately 36"), or short season cotton (ETc

approximately 34”) the combined ETc of multi-cropped production systems is often less than the traditional cropping systems of the 1970s (See Figure 3.4).

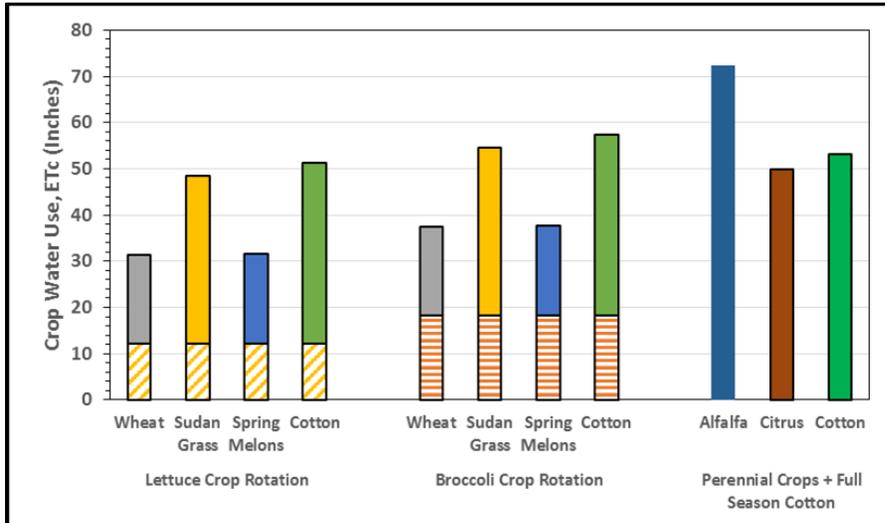


Figure 3.4 Estimated Crop Water Use in the Yuma Area. Cross hatched bars represent water use of the vegetable crop. Solid bars above hatched bars represent water use of the rotation crop.

The reason multi-cropped systems use less water is that the crop following vegetables matures in late spring (wheat and melons) or mid-summer (cotton and sudangrass), thus eliminating the need for irrigation during latter half of the summer – a period with high evaporative demand. This impact is clearly evident when comparing farm water delivery on a monthly basis in 1970s and during the most recent decade (See Figure 3.5). Farm water deliveries in valley irrigation districts supporting vegetable production have decreased substantially during the months of July through September. During the past decade, the only months with increased water deliveries (relative to 1970s) are October through December, the primary establishment months for winter vegetables.

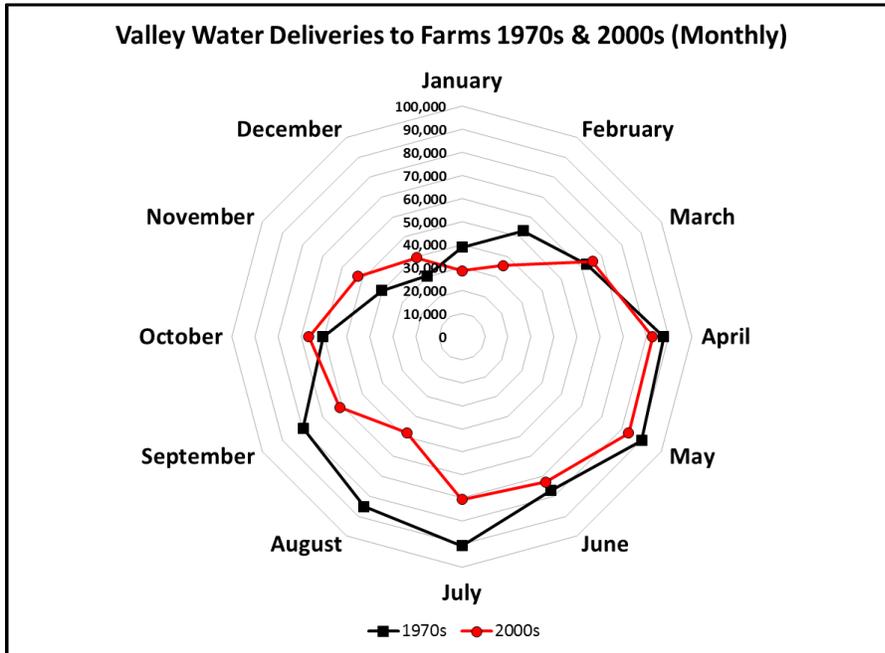


Figure 3.5 Monthly Farm Water Deliveries (AF) for Yuma Valley Irrigation Districts

The other important factor driving the reduction in water use is improved irrigation management. As indicated earlier in this report, vegetable acreage in Yuma County has increased substantially over the past four decades while regional water use has declined. This is a notable accomplishment considering vegetable crops are shallow rooted, and irrigation water that infiltrates more than 12 to 18 inches below the surface cannot be accessed by the crop and moves to the water table where it is recovered and returned to the river. Economic concerns, specifically crop yield and quality, have provided an incentive for improved irrigation management. Vegetable crops are very sensitive to water management, and over-irrigation as much as under-irrigation adversely impacts crop yield and quality. Over-irrigation adversely affects root respiration and plant energetics, makes mobile nutrients such as nitrogen difficult to manage, and increases the incidence of disease. Yuma producers have adopted a number of new and/or improved technologies and cultural practices to improve irrigation management and

efficiency, and a number of these practices are described in the paragraphs below. Prior to discussing these practices it is appropriate to define some concepts and ideas relative to water and agricultural production because there are several ways to examine the efficiency of water utilization in irrigated agriculture and the terminology has changed over time. The terms below are utilized within this study as defined:

- Irrigation Efficiency (IE). IE is often defined as the water used by the crop consumptively (ETc) relative to that applied to the crop. This expression can have local (field level) or global (district-wide) ramifications. More recently, "water used beneficially" has replaced ETc in the definition of IE (see below).
- Water Conveyance Efficiency (WCE). WCE is the volume of water that reaches the farm relative to that diverted from the source. This water may or may not be accounted for in a district wide assessment of irrigation efficiency but would be excluded from the estimate of farm level irrigation efficiency.
- Application Efficiency (Ea). Ea specifically refers to the depth of water required relative to the amount of water applied in a single irrigation event. The required depth is typically the amount of water required to offset soil water depletion resulting from ETc, but may also include a leaching fraction for salt management. It is important to note that Ea usually needs to be discussed concurrently with distribution uniformity which refers to how uniformly irrigation water is applied to a field. For example, field wide Ea may be high but if distribution uniformity is low, large parts of the field will be under-irrigated and/or over-irrigated, thereby compromising production.
- Water Use Efficiency (WUE). WUE is defined as marketable yield relative to ETc (Viets, 1962).

Beyond these simple considerations of efficiency, there are beneficial uses of water that may or may not be imbedded into these expressions of efficiency. For example, land that is fallow a portion of the summer is frequently pre-irrigated before the produce season to leach salts that accumulate during the summer. Atmospheric evaporative demand is high in summer and water moves by capillarity from the underlying moist soil to the dry soil surface in the fine textured soils of the valley. Water that evaporates from the surface leaves behind soluble salts that must be leached below the crop root zone to preclude salt damage to sensitive vegetable crops such as lettuce. Pre-irrigation also hastens residue decomposition (such as wheat or cotton stubble) and provides moisture for seed bed preparation. This pre-irrigation water would be considered in a calculation of district wide efficiency but would generally not be considered in a calculation of individual crop water use efficiency.

Another beneficial use is water used for microclimate modification. For example, thermodormancy inhibits germination of lettuce and other vegetable crops. Appreciable amounts of water are often used during stand establishment to moisten seed beds and reduce near surface soil temperatures in an effort to combat thermodormancy during late summer and early fall. This water used for stand establishment would reduce water use efficiency relative to  $ET_c$ , but is required for successful stand establishment barring some future innovation in technology. Water is also occasionally used for frost control. Irrigation immediately before a forecasted frost will increase the heat capacity and thermal conductivity of near surface soils and increase the dew point within the crop canopy, providing some protection from frost damage. Use of water for frost control has decreased with the decline of the citrus industry in Yuma County.

Recognition that not all water beneficially used is ET<sub>c</sub> prompted Burt et al. (1979) to define irrigation efficiency as the ratio of water beneficially used to the volume of irrigation water applied. Beneficial uses include salt removal (leaching), climate control, soil preparation and water harvested in the crop (e.g., water contained in harvested melons, produce, etc.). Burt et al. (1979) went on to identify another performance indicator known as irrigation sagacity which is the water used for both beneficial and reasonable uses relative to water applied. Some examples of reasonable uses include sprinkler and reservoir evaporation and some percolation losses due to irrigation non-uniformity.

Any discussion related to improved irrigation management in the Yuma area must begin with the on-farm infrastructure used for the delivery of irrigation water. Today, most farm irrigation ditches are lined with concrete to reduce seepage loss and thereby provide more predictable inlet flow volumes onto fields (See Figure 3.6a). Efficient water application requires predictable, constant, and manageable inlet flows. High flow concrete turnouts have been installed in many areas that allow large volumes of water to be applied to basin and border irrigated field crops (See Figure 3.6b). The more quickly that water can be transported downstream across fields, the lower the opportunity time for water to infiltrate below the root zone toward the inlet end of the fields.



Figure 3.6a Concrete Lined Ditch



Figure 3.6b High Flow Irrigation Turnouts



Figure 3.6c GPS-based Laser Leveling



Figure 3.6d Use of Bolas to Reduce Resistance to Water Flow in Furrows

Figure 3.6 Infrastructure and Field Management Operations that have Improved Irrigation Management in the Yuma Area

Along with high flow turnouts, border width is often manipulated to optimize inlet flow per unit border width, thereby reducing irrigation time and losses due to water infiltrating below the root zone.

Laser leveling represents another irrigation management technology that has been adopted by Yuma area growers (See Figure 3.6c). The efficient overland flow of water depends on land

grade, and smooth grades reduce friction or hydraulic resistance. Laser leveling was introduced into the region over three decades ago, and currently all fields used for crop production are laser leveled at minimum once a year. All vegetable crops in the Yuma area utilize impounded level furrows with zero slope and do not allow for runoff (Erie and Dedrick, 1979), and most field crops use impounded level basins. Level furrow and level basin systems represent the most efficient means of surface irrigation with application efficiencies averaging 80 to 85 percent (Howell, 2003). In some instances some subtle slope is desirable. However, excess slope results in poor water distribution uniformity caused by water ponding at the downstream end and insufficient time for infiltration at the inlet end of the field (Sanchez et al., 2008a).

Furrow geometry is another management practice that has been employed to improve water management. During the first cultivation after stand establishment, grower's press the furrows into a tight trapezoidal configuration using an implement known as a press wheel or bola. This trapezoidal configuration reduces friction and enables rapid movement of water down furrows (See Figure 3.6d).

Field length along the irrigation run is another factor affecting water application efficiency and uniformity. Over the past three decades irrigation runs have been reduced to take advantage of this reality. While irrigation runs of 0.5 to 0.25 miles were not uncommon in the past, present day irrigation runs for vegetable crops seldom exceed 600 feet (0.125 miles less the ditches and field roads). Short runs coupled with zero slope and proper inlet flows allow for highly efficient distribution uniformities and application efficiencies (See Figure 3.7 adapted from Sanchez et al., 2008b).

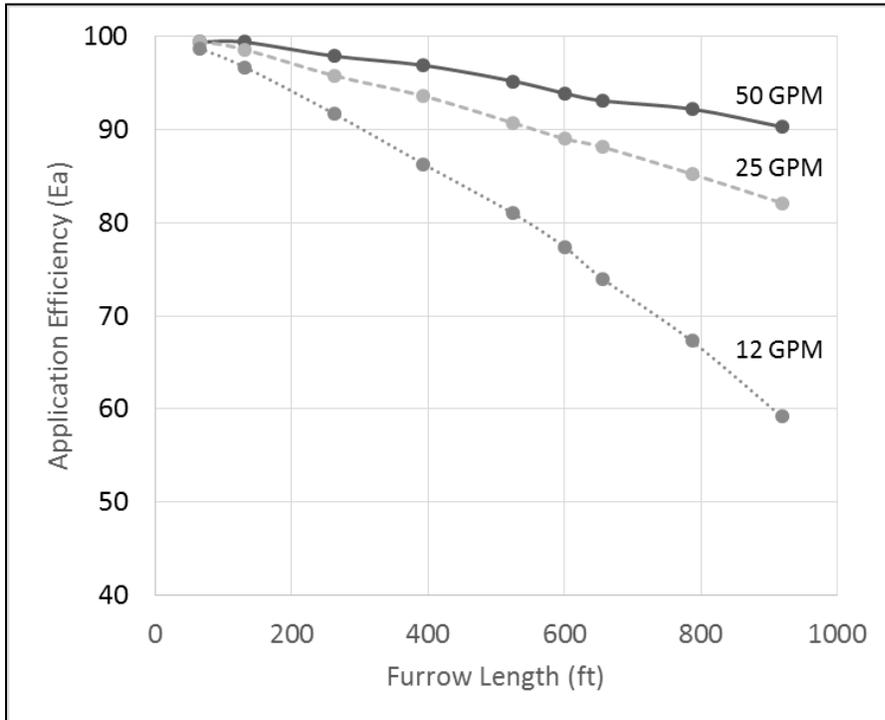


Figure 3.7 Relationship between Furrow Length, Flow Rate and Application Efficiency for Fine Textured Soils in the Yuma Valley

Clean cultivation represents another cultural practice that has improved irrigation application efficiencies in citrus groves located on the Yuma Mesa. In the past, most citrus groves were routinely disked to control weeds. Over time, increased friction and hydraulic resistance from these roughened surface soils increased the time required to move water across the field, thus lowering application efficiency. Weeds are now routinely controlled with herbicides, or less disruptive cultivators resulting in smoother surfaces and faster water advance times. Clean cultivation was initially introduced as part of a regional gnat abatement program but it has had a positive impact on irrigation efficiency as well.

The use of sprinklers has been a significant factor contributing to improved irrigation efficiency. Two decades ago, vegetable crops were principally established by subbing. This practice involved running water in furrows until crop emergence, which typically took seven to 10 days (See Figure 3.8a). Given that typical valley soils have a water intake rate of three to five inches per day, estimates for the amount of water used for subbing range from 18 to 37 inches. Conversely, sprinklers used for crop establishment are typically run for 36 hours continuously, and thereafter, four to six hours per day as needed to keep the soil surface moist (See Figure 3.8b). The typical solid set sprinkler system used in the region delivers about 0.125 inches of water per hour. Given that a typical sprinkler system is operated for approximately 68 hours during crop establishment, the water required for crop establishment is reduced to approximately 8.5 inches, with three inches of establishment water remaining in the top foot of soil and available for use by the crop.



Figure 3.8 The Practice of Subbing up has been Replaced by Sprinklers Resulting in a Reduction in the Amount of Water Needed to Establish Vegetable Crops

More recently, sprinklers have been used for season-long vegetable production. This is due to an increase in vegetables produced on 84 inch beds, including spring mix lettuce and brassica crops, spinach, and romaine hearts, where furrow irrigation is not possible. Sprinklers also are now routinely used to establish stands in wheat resulting in additional water savings.

The use of sprinklers potentially enables growers to apply amounts of water nearly equal to water lost to ETc. The solid set systems used in the Yuma area are generally well designed, however, it is of utmost importance that sprinkler systems be operated and maintained for the uniform delivery of water. Poor distribution uniformities lead to poor efficiencies because growers adjust system run times to ensure that drier portions of the field (areas receiving lower water deliveries) receive adequate water. This results in over-irrigation of part of the field.

Two measures of uniformity are typically used in the field: Christiansen's uniformity coefficient (UCC), which is good measure of spatially distributed non-uniformity and low-quarter distribution uniformity ( $DU_{lq}$ ), which is a good measure of localized significant negative deviations from the average. Recent research studies conducted by the University of Arizona show the potential for high distribution uniformities for sprinkler systems operated in the Yuma area (  $UCC \& DU_{lq} > 80$ ) (Zerihun et al., 2014; Zerihun and Sanchez, 2014). The lowest uniformities ( $UCC$  or  $DU_{lq} < 50$ ) are obtained under conditions of high winds. However, uniformity values less than 80 can be attributed to poor system maintenance and operation.

A prerequisite to obtaining high uniformities and efficiencies of water application with sprinklers is system maintenance and limiting system operations to periods when wind speeds are less than three miles per hour. Unfortunately, daytime winds in the Yuma area commonly exceed

this three mile per hour threshold which means the evening and night hours are the preferred periods of operation to obtain high application uniformity (Brown et al., 1995). Future research that better integrates current and forecasted weather conditions into sprinkler system operations could improve distribution uniformities and may further reduce the quantity of water required to establish vegetable crops. In reality, however, there are times when producers must operate sprinklers under less than ideal conditions. These situations would include windy days during the critical stages of crop germination and emergence.

### **Components of Irrigation Scheduling**

Irrigation scheduling represents another aspect of irrigation management that has improved with time in the Yuma area. There are three principal questions that must be addressed to effectively manage irrigation. These are when should irrigation water be applied (irrigation timing); how much water should be applied (required depth), and how should an irrigation system be managed to apply this required depth? Answers to these questions are provided below in the context of the technological improvements discussed above.

#### *Timing of Water Application*

For most crops, irrigation water must be applied before available soil water is depleted to some critical level at which a further decrease would result in irreversible yield and quality losses. This threshold, which is characteristic for each crop, is known as the management allowable depletion (MAD). Field crops often can handle higher levels of soil water depletion. For example, cotton will tolerate up to 60 percent depletion of available water without yield loss. Vegetable crops are more sensitive to soil water depletion and generally have lower MAD

values. Using lettuce as an example, irrigation must be applied before 40 percent of the available water is depleted (See Figure 3.9).

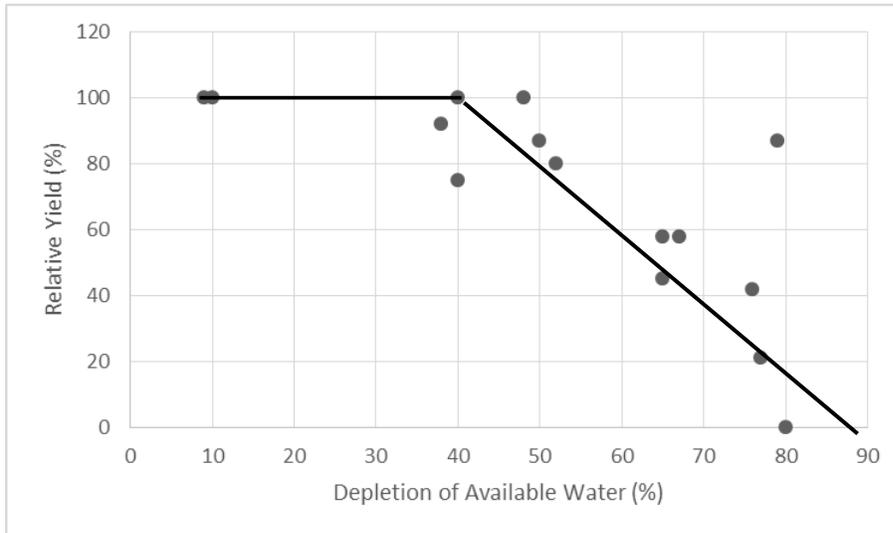


Figure 3.9 Relative Yield of Lettuce Irrigated at Different Depletion Percentages

Rooting depth for cool season vegetables averages about 18 inches and a typical medium to heavy textured soil in the lower Colorado River Valley holds 4 to 6 inches of total water per foot of soil. However, only about 50 percent of this water is available for uptake by the crop. Irrigations must occur when just 40 percent of available soil moisture or 1.2 to 1.8 inches of water have been used by the crop. This determination can be made by direct measurements of soil moisture or indirect estimates derived from weather-based estimates of environmental evaporative demand know as reference evapotranspiration (ET<sub>o</sub>) (ASCE, 2005; Brown, 2005). These values are used with experimentally determined crop coefficients to estimate ET<sub>c</sub> (See Figure 3.10, unpublished data of Sanchez and Brown). In practice, most growers make this

determination using the shovel method (the ease with which they can turn soil with a shovel) which with experience is a fairly accurate means of assessing soil moisture depletion.

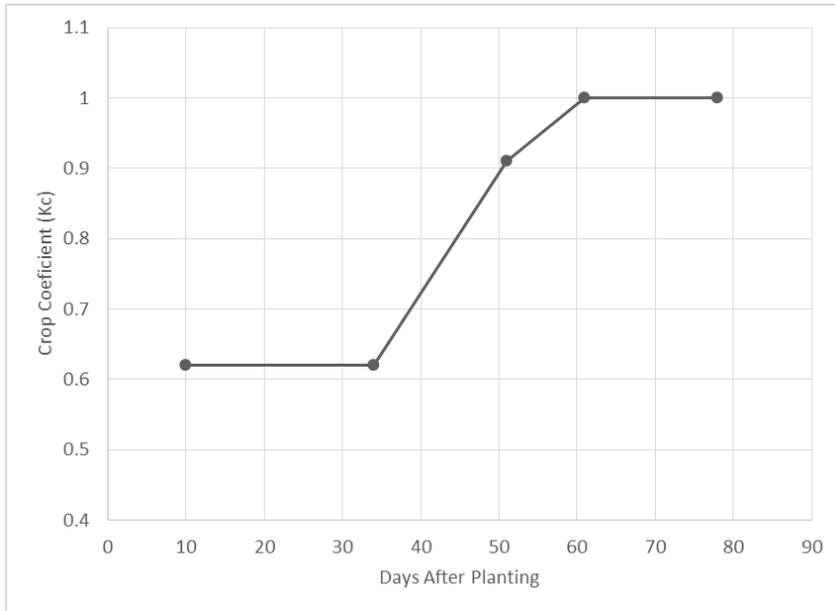


Figure 3.10 Crop Coefficient Curve for Lettuce that Can be Utilized to Estimate Water Use of Lettuce Crops

### *Depth of Water Application*

The minimum required depth of water to apply is equal to the amount depleted since the last irrigation with a possible adjustment for leaching required for salt management. For loam to clay loam soils, the required depth would be approximately 1.2 and 1.8 inches, respectively for lettuce. For many other Yuma area crops the required depth of water would be greater and would depend on rooting depth, MAD and soil type. Lighter, sandy soils hold less water and would require water application more often than heavier textured soils but would require less water to re-fill the rooting zone each irrigation.

For lettuce irrigated with Colorado River water, the required leaching is typically 15 percent. However, it is important to note that the required leaching does not have to occur every irrigation, but over the growing season to avoid detrimental salt build-up and osmotic stress. Required leaching volumes can be restricted to certain irrigations where management of mobile nutrients, such as nitrogen, are less critical. In practice much of the required leaching can be achieved with the pre-irrigation and water used during stand establishment.

#### *Operation of an Irrigation System to Achieve the Required Depth of Water*

The answer to this question depends on operational infrastructure. For pressurized irrigation infrastructure like sprinkler and drip systems, application of water to offset ET<sub>c</sub> or ET<sub>c</sub> plus a required leaching fraction, is a relatively simple task if the conveyance system is well maintained and operated. The frequency of application is largely a logistical consideration because low volume deliveries can be achieved. However, for surface irrigation, water application should occur when the MAD is reached because maximum soil storage capacity is needed to avoid deep percolation losses. Optimum operation of surface irrigation systems requires careful manipulation of flows, cutoff time or distance, and knowledge of field hydraulic characteristics such as bed slope, friction slope, and infiltration parameters.

Because it is impossible to gain such data on every field, generalized approximations have been developed through hydraulic modeling. If the resulting model is calibrated using field data and validated with independent field data sets, criteria for system operations can be developed for various irrigation scenarios (Sanchez et al., 2008a; 2008b), and provided to growers through generalized operation manuals (Sanchez and Zerihun, 2004a; 2004b). With proper adjustment

of the aforementioned factors high water application efficiencies can be obtained for furrow irrigation scenarios in the valley soils in the Yuma area (See Figure 3.11, adapted from Sanchez et al., 2008b). For a clay loam soil with a field length of 600 feet, trapezoidal furrows, inlet flow rates of 25 gallons per furrow per minute, and cutoff time of 80 minutes we can easily achieve application efficiencies and distribution uniformities approaching 90 percent. For furrows, a cutoff time is used instead of distance (of water advance) because of non-uniform movement of water along furrows (water advances faster in furrows with wheel tracks). Nevertheless, application uniformity is high because of the zero slope and border impoundment at the downstream end forces the water from the faster furrows back up the slower ones.

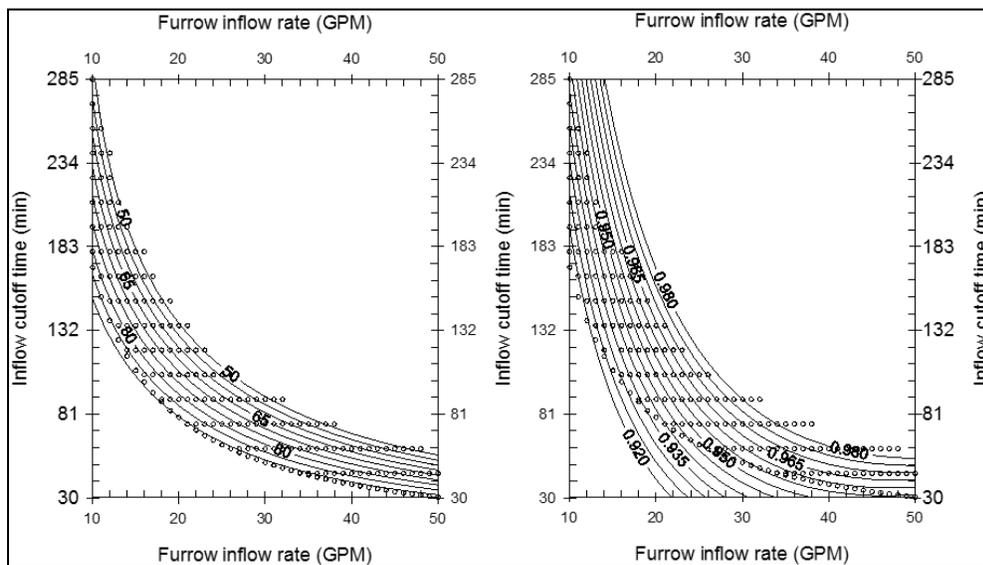


Figure 3.11 Application Efficiency (left) and Low-quarter Distribution Uniformity Expressed as a Function of Furrow Inflow Rate and Cutoff Time for Medium Textured Soils in the Yuma Area

Ancillary Extension programs were implemented to provide growers with the tools and training to use this approach. Perhaps the greatest limitation to these resulting operation manuals, is

uncertainties in spatial (among fields), and to a lesser extent temporal (changes with time) field infiltration characteristics. This variation was partially addressed by grouping soil textural classes, but in practice some minor adjustments in cutoff distance or time, and flow, need to be made by the grower in the field after some trial runs and experience.

The sandy soils on the Yuma Mesa present a special challenge with respect to surface irrigation. Infiltration rates range from three to four inches per hour and soil water holding capacities run approximately 3.5 inches per foot. Assuming 50 percent of the soil water is available for plant uptake, a MAD of 50 percent, and a rooting depth of two feet for citrus, it takes only 1.8 inches to refill the rooting zone. This is difficult to achieve at infiltration rates of four inches per hour, and irrigation efficiencies for the Mesa districts have historically averaged less than 40 percent. However, using many of the technologies noted above, including laser leveling, clean cultivation, narrow borders, high flow turnouts, and water cutoff before the water reaches the end of field, irrigation efficiencies approaching 65 percent for citrus and 55 percent for alfalfa have been attained (See Figure 3.12, adapted from Sanchez et al., 2008a). The thick stands of alfalfa have more friction and result in more hydraulic resistance than citrus fields, thereby resulting in longer irrigation times and lower application efficiency.

It should be noted that even with all the aforementioned improvements, if growers terminate irrigation when water arrives at end of field, application efficiencies remain below 50 percent. Irrigation efficiencies approaching 60 percent require flow cutoff when water has advanced across 70 percent of the field in Mesa soils. The momentum of the water usually allows completion of irrigation to end of the field after cutoff. Due to uncertainties in infiltration

characteristics among fields and with time, growers can make small changes in cutoff distance with experience to ensure the entire field is adequately irrigated.

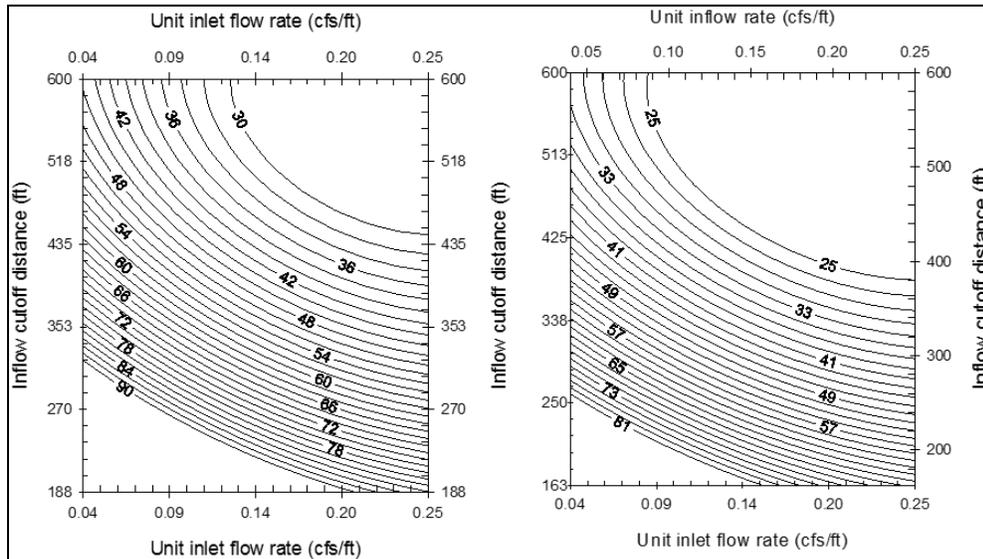


Figure 3.12 Application Efficiency as a Function of Unit Inflow Rate and Cutoff Distance in Level Basins of the Yuma Mesa for Citrus (left) and Alfalfa (right)

Further improvements in irrigation efficiency on the Yuma Mesa will likely require some conversion from surface to pressurized irrigation. Because of the high installation costs of pressurized systems, some cost support incentive would be required. It is noteworthy that most of the drainage from the Mesa irrigation districts is captured by drainage wells in the adjacent valleys and conveyed to Mexico where most of this water is accounted for as part of the treaty obligated delivery to Mexico.

One proposed technique for improving irrigation efficiencies in the Yuma area is drip or trickle irrigation. Research has shown that drip irrigation can be used for vegetable crops in Arizona (Pier and Doerge, 1995; Thompson and Doerge 1995; 1996). However, less than two percent of

the vegetable acreage in Yuma is irrigated by drip. Drip is generally only used where production advantages compared to surface irrigation are evident, as with watermelon, and to some extent cantaloupes.

There are a number of factors besides low cost water and high installation costs that discourage the use of drip irrigation in the Yuma area. There is no production advantage for cool season lettuce and brassica crops because wetting is insufficiently uniform to establish the crop. Sprinklers are therefore needed for crop establishment. Secondly, the need to leach salts remains. Use of buried drip irrigation leads to the accumulation of salts near the soil surface, salts that can only be removed through periodic leaching using flood irrigation, which significantly reduces the potential water savings. A third factor discouraging drip irrigation is the variable ways crops are planted or configured in fields. For example, two-row bed lettuce and brassica crops are planted on beds oriented in a north-south direction so that one row does not shade the other. Spring melons are typically planted on the south side of beds oriented in an east-west direction to capitalize on solar warming. Many crops such as wheat and sudangrass are planted in basins. In addition, row widths can vary. Most two row vegetable crops are planted on 42 inch raised beds, but single row cauliflower is planted on 38 inch beds. In many cases two row romaine hearts are planted on 34 inch beds, and most of the spring mix is planted on 84 inch beds. A buried drip system once installed will restrict crop rotations and planting configurations. One area where pressurized irrigation might be given further consideration is citrus production on the Yuma Mesa (Roth et al., 1995). Both drip and micro-sprinklers are possibilities.

Information pertaining to irrigation efficiency on a district-wide basis is limited in the Yuma area (Bureau of Reclamation, 2005). One means of addressing this issue is to relate ET<sub>c</sub> to the total amount water diverted to farms. This procedure restricts beneficial use of water to ET<sub>c</sub> and does not account for other beneficial uses of water such as leaching, microclimate modification and water for tillage. Well established procedures for estimating ET<sub>c</sub> have been developed over the past two decades (Allen et al., 1998; ASCE, 2005) and consist of using crop-specific adjustment factors (crop coefficients: K<sub>c</sub>) to convert meteorological estimates of environmental evaporative demand, known as reference evapotranspiration (ET<sub>o</sub>), into accurate estimates of ET<sub>c</sub>:

$$ET_c = K_c * ET_o$$

The procedure on a district-wide basis first requires that ET<sub>c</sub> be calculated for each crop in inches or feet. Next, the ET<sub>c</sub> value for each crop is multiplied by the planted area to determine the total volume of water used by each crop. District-wide ET<sub>c</sub> is then obtained by summing the water used by each crop with irrigation efficiency computed by dividing the district-wide ET<sub>c</sub> value by the volume of water diverted to farms.

This methodology was used to assess irrigation efficiency of the WMIDD in five year increments from 1970 through 2010. Reference ET data sets dating back to 1970 were developed by using the ET<sub>o</sub> data available from the Arizona Meteorological Network (AZMET: <http://ag.arizona.edu/azmet>) to calibrate the temperature-based Hargreaves Equation (Hargreaves and Samani, 1982). The Hargreaves Equation was used to estimate ET<sub>o</sub> in this study because AZMET data sets extend back just 27 years to 1987. Crop coefficient curves

were developed for each crop grown in the WMIDD using the procedures recommended by Allen, et al., (1998) with adjustments made for the length of the cropping season and the aridity of the local climate.

Crop acreage estimation proved to be the most challenging and potentially limiting factor in efforts to estimate district-wide irrigation efficiency using ETc. Acreage estimates provided by the NASS did not agree with the acreage reported by the irrigation districts and the USBR. The reason the WMIDD was chosen for the efficiency assessment was the district maintained a better crop database than other districts in the Yuma area, and the district through direct measurement of drainage provided a second means of assessing irrigation efficiency. However, even with the better records provided by WMIDD the sum of the crop specific acreage values provided by the district were less than the total number of farmed acres, taking into consideration multiple crop fields. Acreage estimates that are biased low will transfer that bias to the estimate of irrigation efficiency because the computation divides district wide ETc by the volume of water diverted to farms. A correction factor was developed to adjust for the low acreage estimate and a second, adjusted irrigation efficiency was computed. Unadjusted irrigation efficiencies have increased from the upper 40 percent range in the 1970s to current values in the low to mid 60 percent range in recent years (See Figure 3.13).

The peak unadjusted irrigation efficiency was 69 percent in 1985. The acreage adjustment increased irrigation efficiency from 5 to 14 percent. Adjusted efficiencies ranged from 52 percent in 1975 to a peak value of 77 percent in 2010 and have exceeded 70 percent since 1985 with the exception of 2000 (See Figure 3.13).

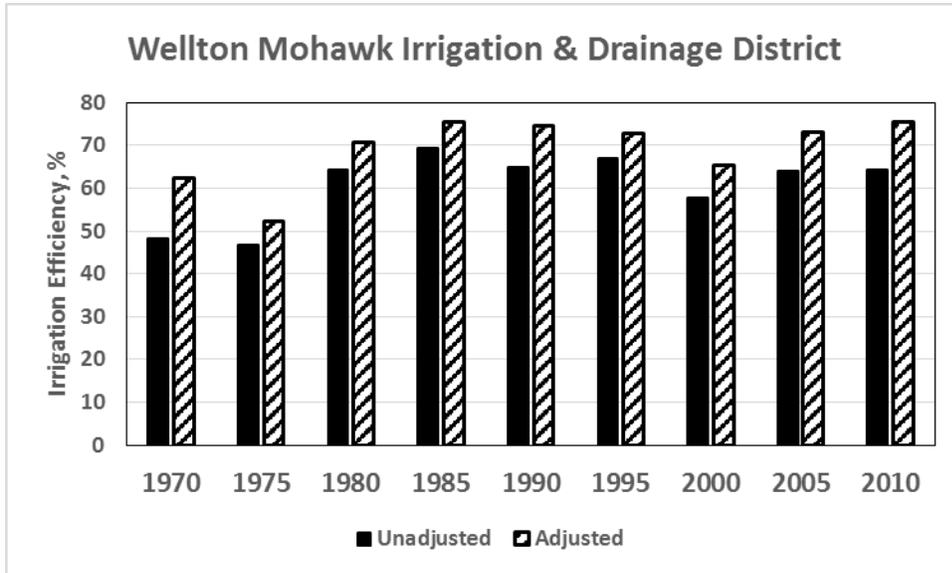


Figure 3.13 On-farm Irrigation Efficiencies for the WMIDD computed from estimates of crop water use – 1970-2010.

The adjustment for under reported acreage could in itself be biased and provide incorrect estimates of irrigation efficiency. Fortunately, alternative procedures were available and were utilized to assess irrigation efficiency in the WMIDD. For the management of salt and water tables in the WMIDD, drainage wells are operated and the water is pumped into a drain for transport to the Santa Clara slough north of the Sea of Cortez (See Figure 3.14). Using data obtained for salt concentrations measured in the irrigation water diverted into the WMIDD and that of the drainage water transported out of this district (data courtesy of the USBR), the drainage or leaching fraction (L) can be estimated. This computation is based on a salt balance where under steady state assumptions:

$$L = D_{dw} / D_{iw} = C_{iw} / C_{dw}$$

where D=volume of water, C=concentration of salt, iw=irrigation water, and dw=drainage water (ASCE, 1990).



Figure 3.14 Drainage Well within the WMIDD

Irrigation efficiency can be estimated from this computation by subtracting the resulting leaching fractions from 1.0 and multiplying by 100 to convert the value to a percentage. Irrigation efficiencies obtained in this manner agree quite closely with the adjusted values presented in Figure 3.13 and indicate district-wide values approach 75 percent on an annual basis (See Figure 3.15). The efficiency values obtained from both computation methods are trending higher in recent years which indicates improved irrigation management. It is interesting to note the decrease in irrigation efficiency that appears each fall which presumably reflects increased drainage associated with establishment of vegetable crops. The efficiency value computed using L should provide a better overall assessment of district-wide irrigation efficiency because the computation includes all water entering the district as compared to the ETC-based computation that is based on water diverted to farm fields. A district-wide irrigation efficiency approaching 75 percent would be considered an excellent value given the fact that

growers must always apply water in excess of growing season ETc to leach soluble salts and keep soils productive.

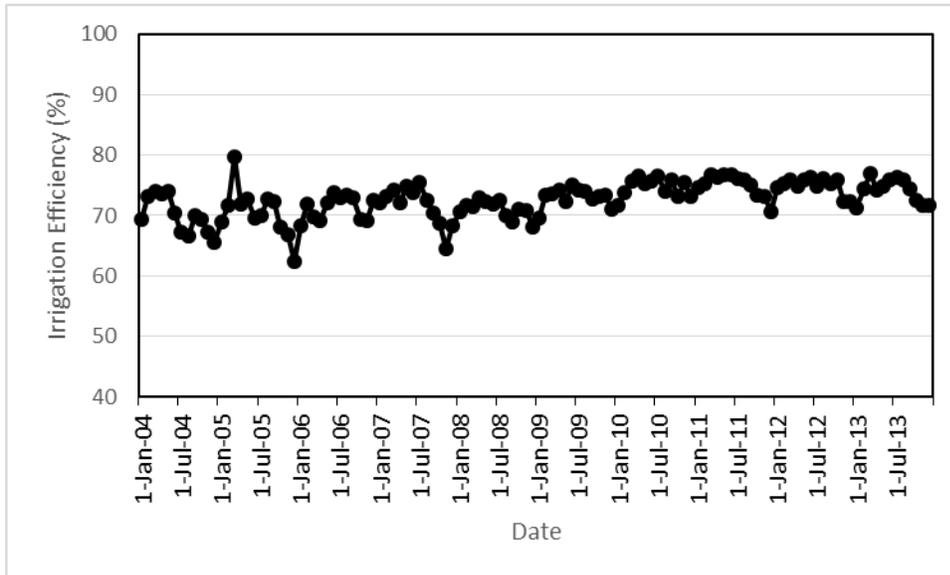


Figure 3.15 Irrigation Efficiency in WMIDD Estimated from Monthly Leaching Fractions

### **Water Use Efficiency (WUE)**

Crop yields in the Yuma area have increased significantly over the past 40 years due to improvements in crop genetics, agronomic practices, pest management procedures, tillage systems and irrigation management technologies. Crop evapotranspiration, as estimated by applying crop coefficients (Allen et al. 1998) to estimates of environmental evaporative demand known as reference evapotranspiration (ET<sub>o</sub>), has remained relatively constant over this same period, fluctuating only slightly from year to year based on growing season weather conditions and minor changes in cropping seasons. The only Yuma crops that have exhibited significant changes in ET<sub>c</sub> over the past 40 years are cotton and sudangrass, two summer crops that now are primarily grown using a shortened growing season to ensure that ground can be converted

to fall vegetable production in early September. Present production systems for cotton and sudangrass use significantly less water (ETc) than the long full summer production system used to produce these crops in the past.

Because yields continue to increase and ETc remains nearly unchanged, the WUE of crops grown in the Yuma area continues to improve. The production of head lettuce provides the most stellar example of improved WUE. Growers in 2010 produced 2734 pounds of lettuce per acre per inch of ETc, more than double the value of 1970 (See Figure 3.16).

Impressive improvements in WUE have occurred with other Yuma area crops over this same time frame, including durum wheat (increased 55 percent), alfalfa (increased 29 percent) and cotton (increased 16 percent).

## **Conclusion**

The productivity and efficiency of the Yuma County agricultural industry has improved dramatically over the past 40 years, and today, the region serves as one of the world's premier crop production regions. Water is a critical input for Yuma area production systems, and area growers have been quick to adopt new production and irrigation technologies that have dramatically improved crop yields while at the same time reducing overall water use. New technologies continue to be developed and deployed in agricultural production systems, and if recent history translates to the future, Yuma producers will be first in line to evaluate and implement these new technologies, technologies that will lead to an even more productive and water efficient agricultural system.

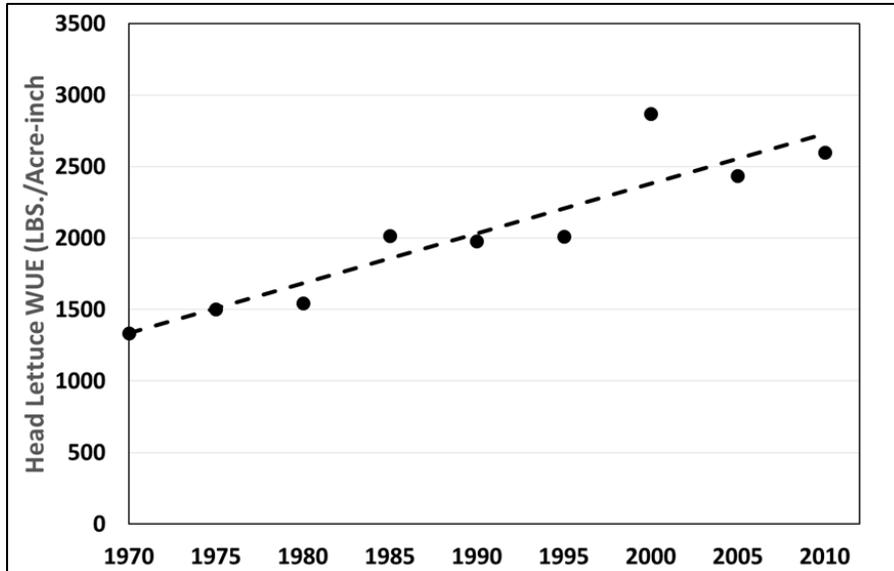


Figure 3.16 Water Use Efficiency of Head Lettuce in the Yuma Area – 1970 to 2010

## **References**

Allen, R.G., L.S. Pereira, D. Raes and M. Smith. 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. FAO Irrigation & Drainage Paper 56. Food and Agriculture Organization of the United Nations. Rome IT. 300 p.

ASCE. 2005. The ASCE Standardized Reference Evapotranspiration Equation. R.G. Allen et.al. (ed). American Society of Civil Engineers. Reston, VA. 59 p.

ASCE. 1990. Agricultural Salinity and Management. ASCE Manuals and Reports on Engineering Practice No. 71.

Brown, P.W., T. Machibya and B. Russell. 1995. Wind Flow Patterns at the University of Arizona Agricultural Centers. Tech. Bulletin 268. Univ. of Arizona Agricultural Experiment Station. 215 p.

Brown, P.W. 2005. Standardized Reference Evapotranspiration: A New Procedure for Estimating Reference Evapotranspiration in Arizona. Ext. Rpt.1324. College of Agricultural & Life Sci., Univ. of Arizona, Tucson, AZ.

Bureau of Reclamation. 2005. Quality of Water: Colorado River Basin. Progress Report No. 22. U.S. Dept. of Interior, Bureau of Reclamation, Upper Colorado Region. 69 p.

- Burt, C. M., A.J. Clemmens, T.S. Strelkoff, K.H. Solomon, R.D. Bliesner, L.A. Hardy, T.A. Howell, and D.E. Eisenhauer. 1997. Irrigation performance measures: efficiency and uniformity. *J. Irrig. Drain. Eng.*, 123(6) 423-442.
- Erie, L. J. and A.R. Dedrick. 1979. Level Basin Irrigation: A Method for Conserving Water and Labor. *USDA SEA Farmers' Bulletin* 2261. 23p.
- Hargreaves, G.H and Z.A. Samani. 1982. Estimating potential evapotranspiration. Tech. Note, *J. Irrig. & Drain. Eng.*, 108(3):225-230.
- Howell, T.A. 2003. Irrigation efficiency. In: B.A Stewart and T.A. Howell (ed). *Encyclopedia of Water Science*: 467-472. Marcel Dekker, Inc., New York.
- Pier, J. W., and T. A. Doerge. 1995. Concurrent evaluations of agronomic, economic, and environmental aspects of trickle irrigated water melon production. *J. Environ. Qual.* 24:79-86.
- Roth, R.L., C.A. Sanchez, and B.R. Gardner. 1995. Growth and yield of mature "Valencia" oranges converted to pressurized irrigation. *Applied Engineering in Agriculture.* 11:101-105.
- Sanchez, C. A., and D. Zerihun. 2004a. Irrigation Management Guidelines for Citrus and Alfalfa Grown on the Sandy Soils of the Yuma Mesa Irrigation Districts. Project Report Submitted to the United States Bureau of Reclamation. Yuma Area Office, Yuma AZ.
- Sanchez, C. A., and D. Zerihun. 2004b. Irrigation Management Guidelines for Furrow Irrigated Vegetable Production Systems in the Yuma Valley. Project Report Submitted to the United States Bureau of Reclamation. Yuma Area Office, Yuma AZ.
- Sanchez, C.A., D. Zerihun, T. S. Strelkoff, A. J. Clemmens, A. J., and K. L. Farrell-Poe. 2008a. Development of management guidelines for efficient irrigation of basins on sandy soils. *Appl. Eng. Agric. (ASABE)* 24(2):1-10.
- Sanchez, C. A., D. Zerihun, and K. L. Farrell-Poe. 2008b. Management guidelines for efficient irrigation of vegetables using closed-end level furrows. *Agric. Water Management.* 96:43-52.
- Thompson, T. L., and T. A. Doerge. 1995. Nitrogen and water rates for subsurface trickle irrigated romaine lettuce. *HortScience* 30:1233-1237.
- Thompson, T. L., and T. A. Doerge. 1996. Nitrogen and water interactions in subsurface trickle irrigated leaf lettuce. II. Agronomic, economic, and environmental outcomes. *Soil Sci. Soc. Am. J.* 60: 168-173.
- Viets, F. G. 1962. Fertilizers and the efficient use of water. *Adv. Agron.* 14:223-264.
- Zerihun, D., C. Sanchez, and K. Nolte. 2014. Field-scale sprinkler irrigation system hydraulic model. I: hydraulic characterization. *J. Irrig. Drain Eng.*, 140(7), 04014019.

Zerihun, D. and C. Sanchez. 2014. Field-scale sprinkler irrigation system hydraulic model. II: hydraulic simulation." J. Irrig. Drain Eng., 140(7), 04014020.



## **SECTION 4: THE ECONOMIC CONTRIBUTION OF AGRICULTURE IN YUMA COUNTY**

### **Section Summary**

#### *Defining the Issue*

- Yuma is a national center of agricultural production in the United States. The county ranks at the very top of U.S. counties in several measures of agricultural sales, acreage and production.
- Farm-level production only reflects a portion of agriculture’s contribution to the Yuma County economy, however. Agricultural production creates demands for goods and services in agricultural input and service sectors. It also creates demands for inputs from sectors not directly related to agriculture. Farm proprietors and employees also spend earnings and wages in local businesses in the county. Both spending on inputs and spending of earnings and wages generates additional demands for goods and services – and jobs – in the Yuma economy. These “multiplier effects” mean that the contribution of agriculture to the Yuma economy stretches beyond the farm gate.
- In order to determine the contribution of agriculture to the Yuma economy, one must take a comprehensive look at the industry, incorporating the economic activities of industries directly and indirectly related to agriculture.

#### *Findings of the Analysis of the Economic Contribution*

- Yuma ranks in the top 0.1 percent among U.S. counties in vegetable and melon sales, the top 0.5 percent in sales of all crops, in the top 1 percent in sales of all crop and livestock products combined. In terms of acreage, Yuma ranks in the top 0.1 percent among U.S. counties in vegetable acreage, the top 0.2 percent in lettuce acreage, the

top nine percent in durum wheat acreage, and the top nine percent in forage crop acreage.

- The total market value of on-farm capital assets (land, buildings, and farm machinery) in Yuma was nearly \$1.8 billion. Yuma's average value of land and buildings of \$3.9 million *per farm* is nearly four times the national average. More than 14 percent of Yuma operations had land and buildings valued at more than \$5 million. Only about 2.5 percent of operations in the rest of Arizona had land and buildings valued at more than \$5 million.
- Economists frequently use cash rents to measure the productivity and profitability of current agricultural production. This study compared Yuma cash rents to other areas using two different data sources: (a) survey estimates of average cash rents collected by the USDA NASS and (b) reports of ranges (low to high) of cash rents reported to the Arizona Chapter of the American Society of Farm Managers and Rural Appraisers. Both data sources indicate that Yuma cash rents are significantly higher than in other Arizona counties and in other areas of the Colorado River Basin.
- As one measure of water productivity, this study estimated the dollar value of crop sales per AF of water withdrawn. Gross crop receipts were \$681 per AF of water in Yuma County, while receipts ranged from \$162-\$520 per AF in the five other Arizona counties that utilize Colorado River water.
- Yuma is to U.S. agriculture what Silicon Valley is to U.S. computer and electronics production, what Detroit is to U.S. automobile production, and what Napa is to U.S. wine sales. A widely used measure of the relative importance of an industry to a local economy is its LQ (Siegel, et al., 1995). The LQ measures a local industry's share of

local employment relative to the national industry's share of national employment. One can also use LQs to identify national centers of production. The higher the LQ, the more specialized a region is in a particular industry. Based on recent data, the LQ for Wine and Spirit Merchant Wholesalers in Napa County, California was 13.3. The LQ for Computer and Electronic Equipment Manufacturing in Santa Clara County, California (Silicon Valley) was 13.6. The LQ for Motor Vehicle Manufacturing in Wayne County, Michigan (Detroit) was 16.3. For Yuma County, the LQ for agricultural production and support services was 24.5.

- Agriculture and supporting services is the single largest private sector contributor to Yuma's GDP. GDP measures the value of an economy's production of final goods and services. With a GDP of nearly \$5.4 billion, Yuma County's economy would rank 151<sup>st</sup> out of 192 countries, globally. Agriculture is not only Yuma County's single largest private sector industry (as measured by GDP); it is nearly as big as the next two industries (health care and all retail trade) combined.
- Valued at 2014 dollars, agriculture and related industries contributed \$2.8 billion in output to the Yuma economy. This included \$2.26 billion in direct sales effects from agricultural and related industries and an additional \$540 million in sales by other Yuma industries.
- Agriculture and related industries contributed to one in four jobs in Yuma County. Agriculture and related industries (such agricultural inputs and services, food and fiber processing) directly account for one in five jobs. Agriculture creates additional jobs in non-agricultural sectors when it purchases goods and services from those sectors.

When farming households and employees spend their incomes and paychecks at local businesses, this creates demand for even more jobs.

- Every 100 jobs in agriculture and agribusiness industries supported an additional 26 jobs in other industries throughout Yuma’s economy. Agricultural and agribusiness spending created demand for jobs in transportation, warehousing, real estate, banking, retailing, and wholesale trade, among many industries. Spending of agricultural paychecks and proprietors’ income on local goods and services created demand for jobs in health care, food and beverage service, retailing, banking, and auto repair among other industries.

#### *Methods*

- Data from various sources were analyzed to evaluate the role of agriculture and related industries in Yuma’s economy. Data sources included the USDA NASS *Census of Agriculture* and *Arizona Agricultural Statistical Bulletin* (and other data products of the Arizona NASS Field Office), the BLS *Quarterly Census of Employment and Wages*, the U.S. Department of Commerce, Bureau of Economic Analysis, *Regional Economic Accounts*, and the U.S. Census Bureau’s *Economic Census* and *County Business Patterns*, and the USGS *Water Use in the United States*.
- The importance of agricultural and related industries was determined by conducting an economic base analysis. This analysis allows for the identification of industries that serve as part of the economic base as well as highlights whether the industry employs more people in the region than the national average.
- The economic contribution of agriculture to Yuma County’s economy was estimated using input-output modeling and the premiere modeling software for this type of

analysis, IMPLAN. Agriculture's contribution to total output, value added (GDP), employment, and employee compensation was estimated.

### **Agricultural Cash Receipts**

Yuma cash receipts from crop and livestock sales have averaged about \$1.1 billion in recent years with crops accounting for more than 80 percent of receipts (See Figure 4.1). Data come from the USDA NASS Arizona Field Office *Annual Statistics Bulletin*. The most recent bulletin reporting detailed county level sales data was published in 2011. Inspection of bulletins through time revealed that NASS has revised initial estimates of Yuma cash receipts in subsequent years. For example, 2008 estimates were later revised upward by 1 percent in 2009, 2009 estimates were revised upward by 1 percent in 2010, and 2010 estimates were revised upward by 3 percent in 2011. If this pattern continues, the receipt numbers for 2011 may also be revised upward. Vegetable and melon sales account for most of the crop receipts in Yuma. At the same time, Yuma accounts for most of Arizona's total vegetable and melon sales (See Table 4.1). Data from the three most recent editions of USDA's *Census of Agriculture* show that Yuma has accounted for more than three-quarters of the state's sales of vegetables and melons (Table 4.1).

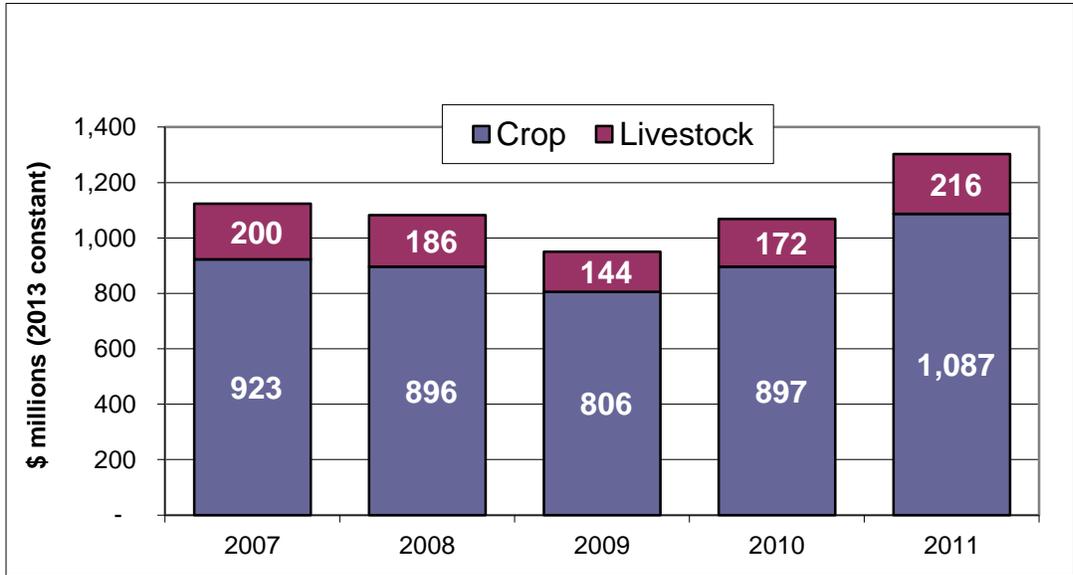


Figure 4.1 Yuma Case Receipts, Crop and Livestock Sales

Table 4.1 Cash Receipts from Sales Vegetable and Melons: Yuma and Arizona Totals

Year	Yuma	Rest of Arizona	Yuma's Share of Arizona's Sales
	— \$ millions current —		
2012	579	185	76%
2007	674	192	78%
2002	569	181	76%

Source: USDA, NASS, *Census of Agriculture*, various years

### **Yuma Area Sales and Acreage Rankings**

Yuma ranks highly among all U.S. counties in terms of crop sales, ranking in the top one percent in sales of all agricultural products and the top 0.5 percent in crop sales (See Table 4. 2). Yuma ranks in the top one-tenth of 1 percent in vegetable and melon sales. Crop specific figures only include counties that actually grow the crop. For example, there were 3,077 counties with agricultural sales in the United States, but only 2,802 counties that had vegetable

and melon sales. Yuma ranks in the top 0.1 percent of this smaller set of counties that grow vegetables and melons.

Table 4.2 Yuma’s Rank Among All Producing Counties in Crop Sales

Commodity	Rank Among US Counties in Sales
Vegetables & Melons <sup>1</sup>	Top 0.1%
All Crops	Top 0.5%
All Agricultural Products	Top 1.0%
Other Crops & Hay	Top 1.2%
Nursery, Greenhouse, & Floriculture	Top 23%
Grains, Oilseeds, Beans, & Peas	Top 28%

<sup>1</sup>Includes potatoes and sweet potatoes  
Source: USDA NASS 2012 *Census of Agriculture*

Yuma also ranks in the top 28 percent of U.S. counties in sales of grains and oilseeds. This category includes corn, soybeans and wheat that are grown extensively throughout the U.S. Midwest. Durum wheat (used for pasta) is the major grain crop in Yuma. Yuma’s relatively high ranking reflects price premiums for higher quality grain as well as relatively high yields. Yuma ranks among the top nine percent of U.S. counties of acreage in forage and durum wheat, the top 0.2 percent in lettuce acreage and in the top 0.1 percent in acreage of all vegetables (See Table 4.3).

Table 4.3 Yuma's Rank Among All Producing Counties in Crop Acreage

Commodity	Rank among US counties in acreage
Vegetables	Top 0.1%
Lettuce	Top 0.2%
Durum wheat	Top 9%
Forage	Top 9%

Source: USDA NASS 2012 *Census of Agriculture*

Yuma's annual crop cash receipts are by far the largest of any county in Arizona. Yuma's receipts of more than \$1 billion (in 2011) nearly equal total receipts of the next three largest counties combined (See Figure 4.2).

### **Yuma County Land Values**

Agricultural land and buildings are usually the primary assets that agricultural producers hold. The average value of agricultural land and buildings in Yuma according to the most recent, 2012 Census of Agriculture was \$1.55 billion. The average value per farm was nearly \$3.9 million. This compares to an Arizona average of \$844,065 and a U.S. average of \$1 million (See Table 4.4). Yuma agricultural land and building values per farm are roughly four times the national average. Yuma also has a higher proportion of operations with land and buildings valued at more than \$5 million. While more than 14 percent of Yuma operations have land and buildings valued at more than \$5 million, only about 2.5 percent of operations in the rest of Arizona have land and buildings valued at more than \$5 million. Land values are to some extent a reflection of people's expectations of the long-term profitability of agricultural production on that land. Yet, land values can be influenced by speculative demand for land (for conversion to

commercial or residential real estate). Such speculative demand would be lower in Yuma than in areas such as California, Florida or other areas with more dense or fast growing populations. One indicator of the current productivity and profitability of agricultural land is the annual rental rate paid for agricultural land. Cash rents reflect the profitability of agricultural land put to a current agricultural use. Cash rents are less subject to price fluctuations from asset bubbles and the influences of real estate speculation.

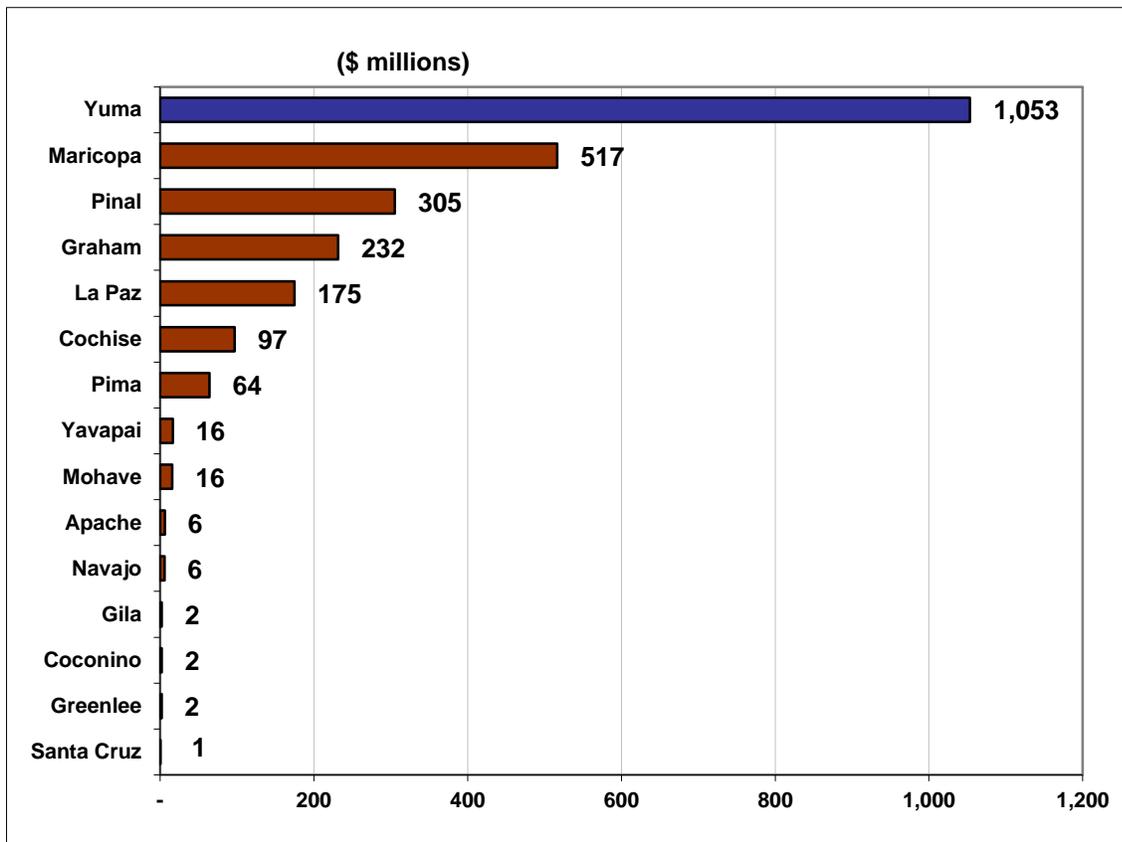


Figure 4.2 2011 Crop Cash Receipts by County

Source: USDA NASS

Table 4.4 Value of Agricultural Land and Buildings, Yuma, Arizona, and U.S. Averages

	Yuma	Arizona	U.S.
Value of agricultural land & buildings per farm	\$3,893,483	\$844,065	\$1,075,491

Source: 2012 *Census of Agriculture*

Yuma ranks first among Arizona counties in terms of cash rents (See Table 5). Yuma cash rents were 3.2 times higher than rents in the county with the next highest rents, La Paz County.

Yuma rents were also 5.3 times greater than the median value of remaining counties in Table 4.5.

Yuma cash rents are also significantly higher than in other areas of the Colorado River Basin.

Table 4.6 compares Yuma county cash rents of \$584 / acre (as in Table 4.5) with average cash rents for irrigated cropland for USDA Crop Reporting Districts that lie within the Colorado River Basin.

Table 4.5 Cash Rents in Arizona Counties, 2013

County	Cash Rent (\$/acre)
Yuma	\$584
La Paz	\$182
Maricopa	\$157
Pinal	\$120
Other Counties average	\$118
Cochise	\$111
Graham	\$108
Pima	\$99
Mohave	\$98
Navajo	\$68
Greenlee	\$60

Source: USDA, NASS

Crop Reporting Districts are groups of contiguous counties within a state with (relatively) similar climate and agronomic characteristics. Yuma is part of Arizona's Southern Crop Reporting District (CRD), which also includes La Paz, Maricopa, Pinal, Pima, Santa Cruz, Graham, Greenlee and Cochise Counties. One can see from Table 4.6 that Yuma County pulls up the Arizona Southern CRD average cash rent. Counties in the Southern California CRD include Imperial, Riverside, San Bernardino, San Diego, Orange, Los Angeles, Ventura, and Santa Barbara Counties.

In addition to comparing data from USDA and NASS, the study also examined data from presentations to the Arizona Chapter of the American Society of Farm Managers and Rural Appraisers (Havranek, 2014; Menvielle, 2014; Moody, 2014; Pendleton, 2014). These reports presented ranges (low to high) of cash rents for agricultural land in different areas and irrigation districts in the Yuma area and in Maricopa, and Pinal Counties in Arizona, and Imperial County in California for 2014. The Bard Water District is part of the USBR Yuma Project and is considered part of the Yuma area water districts. The range of estimates for different areas and districts are summarized in Figure 4.3. In Imperial County, lands are categorized by adaptability rather than specific district or area. Good Adaptability land has sandier soil for vegetable and good quality hay production. Average Adaptability land contains some clay for alfalfa production. Limited Adaptability land is more suited for Bermuda grass production. One can see that cash rent values in Yuma County tend to be higher (in many cases much higher) than in other areas of the Southwest. While a number of areas in Yuma County have cash rents reaching above \$800 per acre, no cash rents reached these levels elsewhere (See Figure

4.3). High values for cash rents in Maricopa County did not exceed \$300 per acre, while in Pinal County, they did not exceed \$200 per acre.

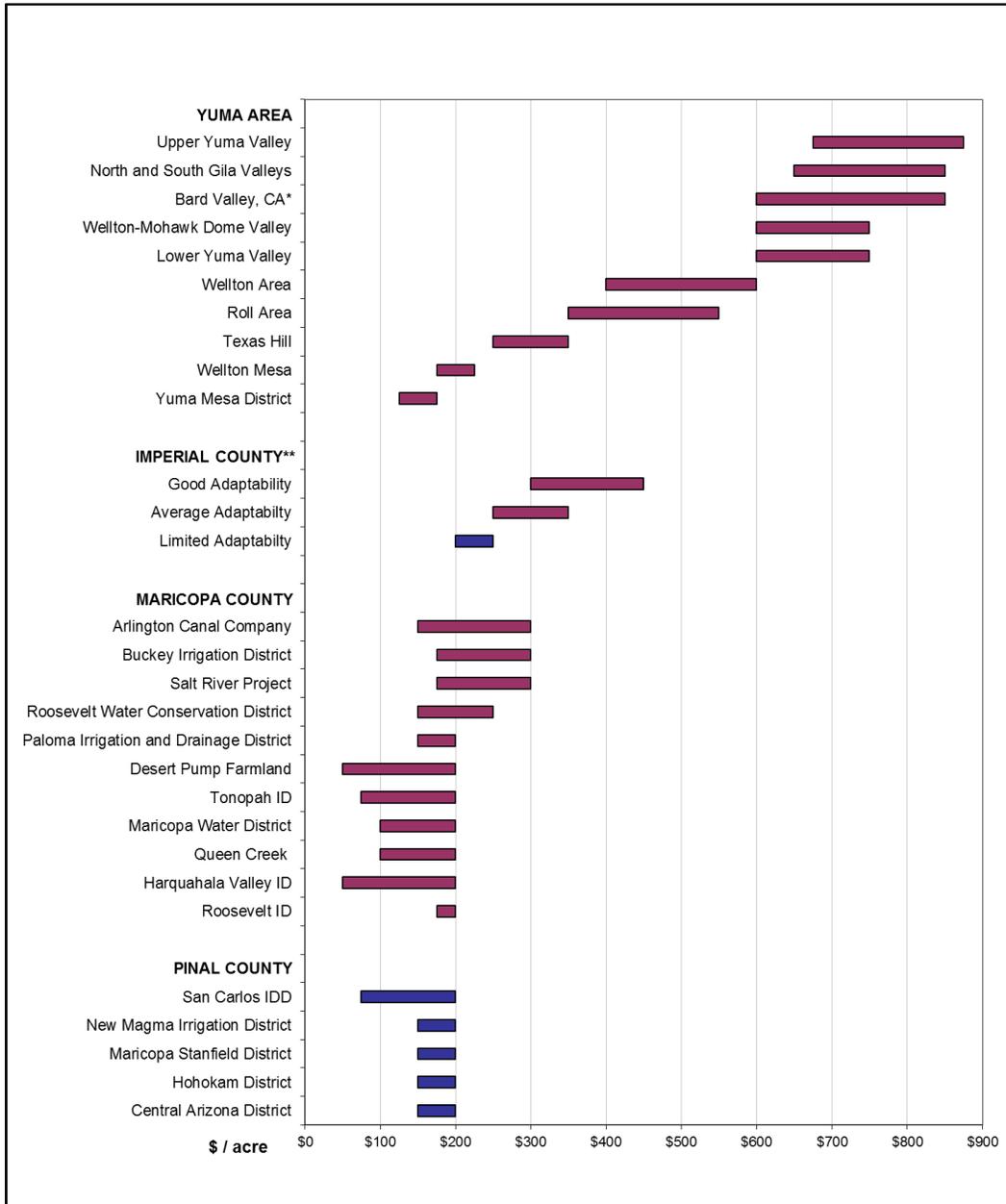
Table 4.6 Comparison of Cash Rents for Irrigated Land Between Yuma County and Crop Reporting Districts in the Colorado River Basin

State	County / Crop Reporting District	\$/Acre <sup>1</sup>
Arizona	Yuma County	\$ 584.00
California	Southern California	\$ 457.00
Arizona	Southern <sup>2</sup>	\$ 230.00
New Mexico	Southwest	\$ 185.00
Nevada	South	\$ 143.00
Wyoming	Southeast	\$ 102.00
Arizona	Northern	\$ 100.00
Wyoming	Northwest	\$ 95.50
Utah	Southern	\$ 93.00
New Mexico	Northwest	\$ 92.50
Wyoming	South Central	\$ 66.00
Colorado	Southwest	\$ 64.00
Wyoming	Northeast	\$ 63.50
Wyoming	West	\$ 60.00
Utah	Eastern	\$ 47.50
Colorado	Northwest and Mountain	\$ 37.00

<sup>1</sup> Cash rents are for 2013, except for New Mexico where survey data was not reported for 2013. Cash rents for New Mexico Districts are for 2014.

<sup>2</sup>Yuma is part of Arizona's Southern crop reporting district. Yuma values are included in calculation of the district average.

Source: USDA, NASS Quick Stats database.



\* Bard Valley, CA is part of the USBR Yuma Project and is considered here as part of the Yuma area

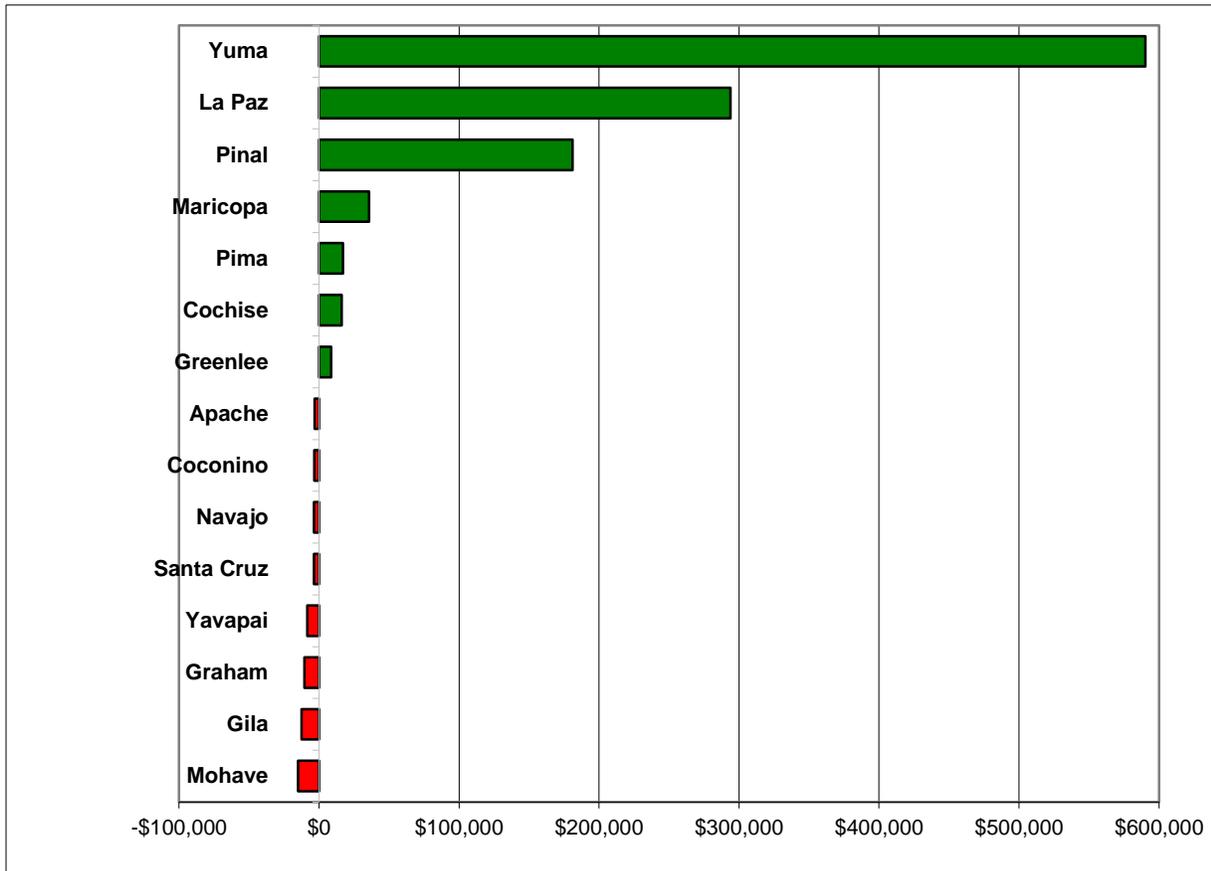
\*\* Imperial County land is classified by adaptability rather than region.

Source: Havranek, 2014; Menvielle, 2014; Moody, 2014; Pendleton, 2014

Figure 4.3 2014 Estimates of Range of Dollar per Acre Cash Rents

## **Net Cash Income**

Figure 4.4 shows data from the 2012 Census of Agriculture on average net cash incomes for Arizona counties. Net cash income averaged nearly \$600,000 per farm in Yuma. This was roughly double the next highest county – Pinal County with an average of nearly \$300,000 per farm. A number of counties reported negative average net cash incomes. While net cash incomes fluctuate from year to year, it is common for net farm incomes averaged over counties to be negative across several census years. Compared to other counties, Yuma has a preponderance of more highly profitable operations.



Source: USDA, NASS, *2012 Census of Agriculture*

Figure 4.4 Net Cash Income Per Farm by Arizona County, 2012

## **Crop Sales Per Water Withdrawals**

Measuring water productivity is made difficult by the fact that data on water use and agricultural output are collected by different government agencies for different years. For example, the USGS reports data for irrigation water withdrawals at five-year intervals: 2010, then each preceding five years (2005, 2000, 1995, etc.). The year 2010 is the most recent year of USGS data. USDA, NASS reports county level data for Arizona crop sales annually, but the most recent year of complete data is 2011. It is possible, then, to examine the value of crop output per AF of water withdrawn for the year 2010, which combines data from USGS and USDA. Table 4.7 compares the gross value of crop output per AF of water withdrawn between counties in Arizona that utilize Colorado River water.

Table 4.7 Gross Crop Cash Receipts per Acre-Foot of Water Withdrawn, Arizona Counties Using Colorado River Water, 2010

County	\$/AF
Yuma County	\$680.81
Pima County	\$519.91
Maricopa County	\$368.70
Pinal County	\$211.09
La Paz County	\$190.22
Mohave County	\$162.50

Source: USGS, *Water Use in the United States*; USDA NASS, *Arizona Annual Agricultural Statistical Bulletin*

## **Economic Base Analysis**

In regional economics, economic base theory divides sectors of a local economy (for these purposes, a county economy) into basic and non-basic sectors. In basic sectors, the primary markets for locally produced goods and services lay outside of that county. The county produces more of the goods or services than needed to meet local demands and much of what is produced locally is "exported" to other areas. Here, exports refer to sales to parties outside

the county and not necessarily to international exports. For example, in this context, sales to Phoenix would be considered exports. Basic sectors play an important role in the county economy because the sales they generate bring money into the county economy from outside. Non-basic sectors are those that depend on the local population as their main source of demand. Many non-basic sectors are those that provide goods and services to proprietors and workers in basic sectors as well as proprietors and workers in other non-basic sectors. These sectors might include grocery stores, pharmacies, barbershops, auto repair shops, etc. that serve primarily the local population.

A common way to evaluate a sector's contribution to a county's economic base is the application of location quotients (LQ). Mathematically, a LQ is usually measured as a local sector's share of the local employment divided by that same sector's national share of total national employment. The formula for the location quotient for a sector  $i$  can be written as

$$LQ_i = (e_i / E) / (n_i / N)$$

where

- $i$  = the particular economic sector
- $LQ_i$  = Location quotient for economic sector  $i$
- $e_i$  = County employment in economic sector  $i$
- $E$  = Total county employment
- $n_i$  = National employment in economic sector  $i$
- $N$  = Total national employment.

The LQ is often based on employment values because data is collected for local regions in great sector detail. Sectors that employ roughly the same share of employees as the national average will have location quotients near one. This implies they are employing people and producing output to fulfill their local needs. If a sector has a location quotient above 1.25 this

usually indicates that it is producing more than enough output to satisfy local demands and that the sector is exporting goods or services outside the county. In other words, a LQ of 1.25 or higher usually indicates that the sector is a basic sector – a sector that is bringing in money to the county from outside.

One can also use LQs to identify national centers of production. The more specialized a region is in a particular industry, the higher the LQ for that industry. Based on recent data, the LQ for Wine and Spirit Merchant Wholesalers in Napa County, California was 13.3. The LQ for Computer and Electronic Equipment Manufacturing in Santa Clara County, California (Silicon Valley) was 13.6. The LQ for Motor Vehicle Manufacturing in Wayne County, Michigan (Detroit) was 16.3. For Yuma County, the LQ for agricultural production and support activities was 24.5 (See Table 4.8). An LQ of 24.5 means that the share of these jobs in Yuma County as a share of all Yuma jobs is 24.5 times higher than the share of these types of jobs in the national economy.

The BLS reports location quotient data using the North American Industrial Classification System (NAICS) to categorize jobs. The NAICS provides different codes classifying jobs in finer and finer detail, increasing with the number of digits in the code. Agricultural activities account for the top three sub-sectors in Yuma's economy in terms of LQs. Sectors listed under NAICS 111 (crop production) are self-explanatory, but include nursery and greenhouse operations. NAICS 112 (animal production) in Yuma includes farms with cattle, feedlot operations, dairies, and some limited poultry and hog production. Jobs in support activities for crop production (NAICS 1151) include jobs in farm labor contracting, soil preparation, planting, cultivating, custom

harvesting, and other agricultural custom work, cotton ginning, and farm management services. Farm labor contracting work and custom work account for about 97 percent of the employment in this sector. The very large location coefficient illustrates the importance of farm labor contracting and custom agricultural work to Yuma's economy. A location quotient of 77.27 means that jobs in these activities as a share of Yuma's total jobs is 77 times the national average. A location quotient of 11.81 for crop production means that crop production's share of Yuma's employment is nearly 12 times the national share.

Table 4.8 shows that agricultural activities are a strong part of Yuma's economic base. Other industries that are part of the county's economic base, such as gas stations, general merchandise stores, accommodations, and food and beverage stores reflect the effects of tourism and demands created by people passing through Yuma in their travels. We note here that the BLS database only includes private sector jobs and so does not capture the role of military bases and other federal employment (such as Border Patrol) as part of the local economy's economic base.

Table 4.8 Ranking of Yuma 3-Digit NAICS Sectors by Location Quotient, 2011

Sector North American Industry Classification System (NAICS) Name	Location Quotient
Crop production, animal production, and support activities for crop production combined	24.5
Support activities for crop production	77.27
Crop production	11.81
Animal production	2.49
General merchandise stores	1.69
Motor vehicle and parts dealers	1.55
Gasoline stations	1.50
Heavy and civil engineering construction	1.45
Repair and maintenance	1.25
Accommodation	1.18
Food and beverage stores	1.05

Source: Bureau of Labor Statistics (BLS)

Table 4.9 shows LQs for selected sub-sectors of Yuma’s economy. There are several sectors with LQs well over 1.25, indicating that they are part of the county’s economic base. To avoid disclosing information about individual companies, the BLS did not report LQs for agricultural input industries (such as fertilizer, pesticide, or farm machinery manufacturers). The LQ for food manufacturing is relatively low (0.38).

**Agriculture is Yuma County’s Single Largest Private Industry**

GDP measures the value of an economy’s production of final goods and services, net of intermediate inputs. According to the U.S. Commerce Department, Yuma’s 2011 GDP was

nearly \$5.4 billion, with \$3.7 billion from private industries and \$1.8 from the public sector (federal, state, and local). If Yuma County were its own country, its GDP would rank 151st out of 192 countries globally. Agriculture and supporting services account for more than \$1 billion of the county's GDP.

**Table 4.9 Location Quotients for Selected Yuma Agricultural Sectors**

North American Industry Classification System Name	Location Quotient
Crop harvesting, primarily by machine	147.95
Farm labor contractors and crew leaders	97.34
Support activities for crop production	77.27
Other postharvest crop activities	61.84
Vegetable and melon farming	46.92
Hay farming	24.29
Cotton farming	18.27
Wheat farming	17.58
Soil preparation, planting, and cultivating	12.21
Water supply and irrigation systems	8.00
Farm supplies merchant wholesalers	5.93
Other grain farming	5.04
Oilseed and grain farming	3.96
Cattle ranching and farming	3.84
Fruit and tree nut farming	3.06
Animal production and aquaculture	2.49
Greenhouse and nursery production	2.48
Food manufacturing	0.38

Source: Bureau of Labor Statistics

Agriculture is not only the county's single largest private sector industry (as measured by GDP); it is larger than the next two sectors (health care and retail trade) combined (See Figure 4.5).

FIRE denotes finance, insurance and real estate. Figure 4.5 shows the direct effect of

agriculture and supporting services on county GDP. This direct effect does not capture the role of agriculture and agribusiness completely, however. For example, in Figure 4.5, agricultural input manufacturing and food and fiber processing are included in the manufacturing category rather than under agriculture. Likewise, sectors such as transportation and warehousing are moving and storing agricultural commodities. The presence of agricultural activity in the county stimulates demands for goods and services in this and other industries of the local economy. We turn now to contribution analysis, which accounts explicitly for the linkages between agribusiness industries and the broader economy.

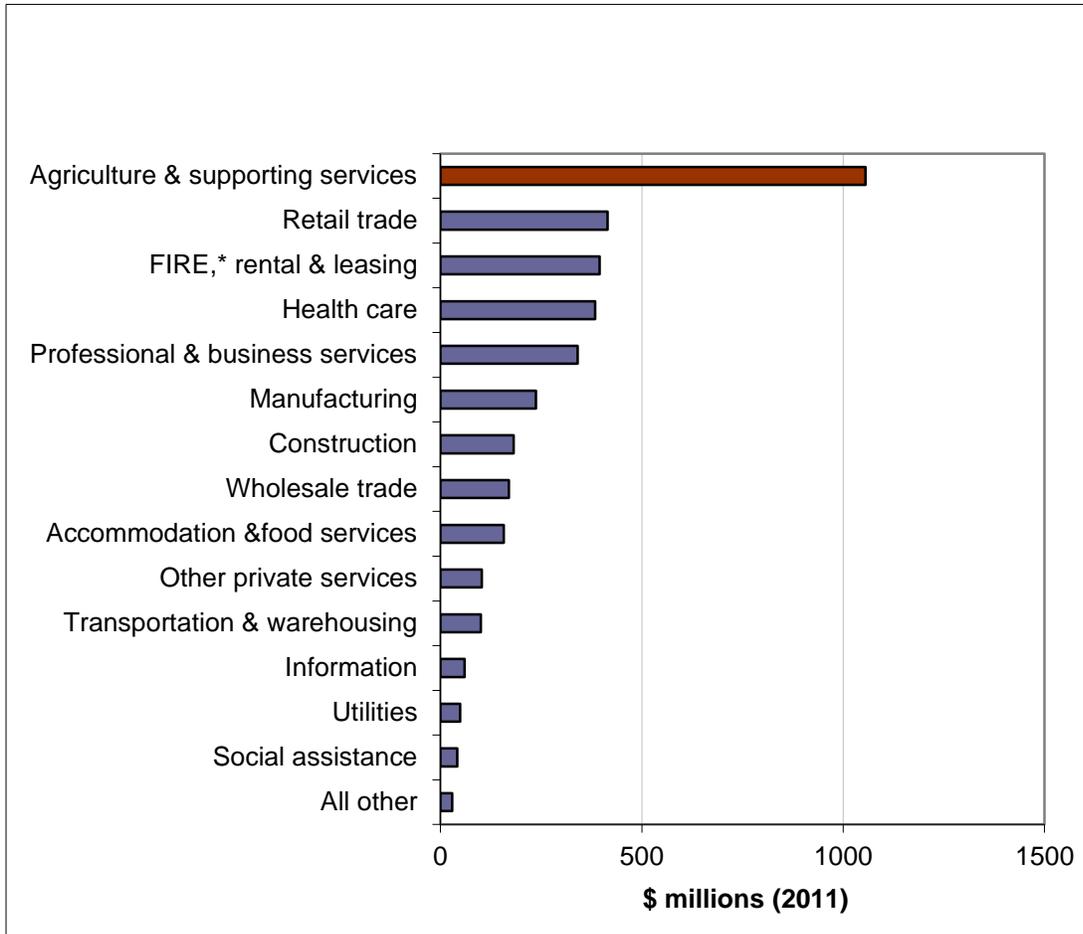
### **Contribution Analysis**

The contribution of agriculture to Yuma's economy extends beyond the commodities directly produced on farms and ranches. Several industries provide critical support for agricultural production, basing their own economic activity on Arizona agriculture. First, there are industries that almost exclusively provide goods and services as inputs to agricultural production. These agricultural service and supply industries, such as pest management consultants, fertilizer manufacturers, and pesticide manufacturers, provide jobs and wages for local residents and contribute to the overall economic activity of the county. Secondly, industries that process and pack agricultural products, or agricultural processing industries, also contribute to county economic activity. These input supply and output processing industries depend critically on Yuma agricultural production, thus increasing agriculture's role in the county economy.

This analysis examines the contribution of the entire agribusiness system to Yuma's economy. This includes primary commodity agriculture (crop and livestock production) as well as the

closely related supply and processing industries that depend on agricultural activity in Yuma.

The contribution of the agribusiness system may be measured in terms of output (sales), value added, employee compensation, and employment. An in-depth description of the industries included in the economic contribution analysis in Appendix D.



Source: U.S. Department of Commerce, Bureau of Economic Analysis  
Figure 4.5 Private Industry Components of Yuma GDP, 2011

Agricultural and agribusiness industries stimulate further demand for goods and services in other, non-agricultural industries. For example, industries that provide water, electricity, gas,

warehousing, transportation, and banking services supply critical inputs to agribusiness firms. Yet, these industries are not exclusively agricultural. They also provide their goods and services to other industries. A good example of this is the warehousing industry. While warehousing services are critically important to agricultural producers and processors, non-agricultural retail sectors and wholesale sectors also rely heavily on warehousing services. Warehousing is not exclusively agricultural. Nevertheless, because of agriculture, there is more demand for warehousing than there otherwise would be.

Economists call these increases in demand for inputs outside the direct industry *indirect effects*. Indirect effects also account for the fact that non-agricultural suppliers of inputs to agriculture must themselves purchase more inputs to supply goods and services. Thus, demands for agricultural inputs have additional backward linkages to other sectors of Yuma's economy. This "ripple" of economic activity is one part of the multiplier effect of agricultural activity. Induced effects are another important economic multiplier.

*Induced effects* measure the economic activity resulting from proprietors and workers in agriculture and processing industries (as well as employees at supplier firms) spending their earnings on consumer goods and services on local goods and services sold in the county. For example, these households take the paychecks they earn and spend them at the grocery store, at the doctor, and at restaurants and movie theaters, thus generating economic activity in sectors completely unrelated to agriculture. Both these multiplier effects (indirect and induced) are combined with the direct effects of agricultural and agribusiness spending and production to measure the total contribution of agriculture to Yuma's economy.

An economic contribution analysis was conducted using the input-output modeling software IMPLAN Version 3.1 to estimate the total economic contribution of Yuma agriculture and agribusiness. The IMPLAN model provides a detailed account of the Yuma economy, demonstrates how each sector in the economy is linked to one another, and essentially tracks the flow of all goods and services in the economy. In this analysis, it is used to assess the economic contribution of the agribusiness system by “removing” it from the model and examining how the removal affects economic activity in other sectors of the economy. The analysis estimates the total contribution (direct, indirect, and induced effects) of the agribusiness system on output, value added, labor income, and employment.

The model simulations were carried out for the base year 2011. Before running the model, several modifications were made to the IMPLAN baseline data to reflect conditions in Yuma. First, the data was modified to reflect county-level employee compensation of hired farm labor, farm proprietor income, and on-farm employment. IMPLAN base data for the number of hired workers closely matches reported data from the Bureau of Economic Analysis (BEA) and the BLS. The BLS acknowledges, however, that their data collection procedures may undercount hired agricultural workers. The USDA Census of Agriculture for 2007 and for 2012 report the total number of hired farm workers on payroll in Yuma County. USDA job counts were found to be significantly higher than either BLS or BEA counts. Differences between USDA counts and BLS and BEA counts were used to adjust agricultural job counts in the 2011 IMPLAN model to be more consistent with hired farm labor numbers reported by operators to USDA. Secondly, the production functions, or the mix of inputs used in primary agricultural sectors, were modified to reflect agricultural conditions and practices in Yuma, particularly regarding the use

of irrigation. Finally, the model was redefined to ensure that there was no double counting in the agribusiness system. A detailed discussion of the model specifications is presented in Appendix D.

*Total output*

Valued at 2014 dollars, agriculture and related industries contributed \$2.8 billion in output (gross sales) to the Yuma economy (See Figure 4.6). This included \$2.26 billion in direct sales effects from agricultural and related industries and an additional \$540 million in sales by other sectors of Yuma’s economy. The breakdown of output by direct, indirect, and induced effects is shown in Figure 4.6.

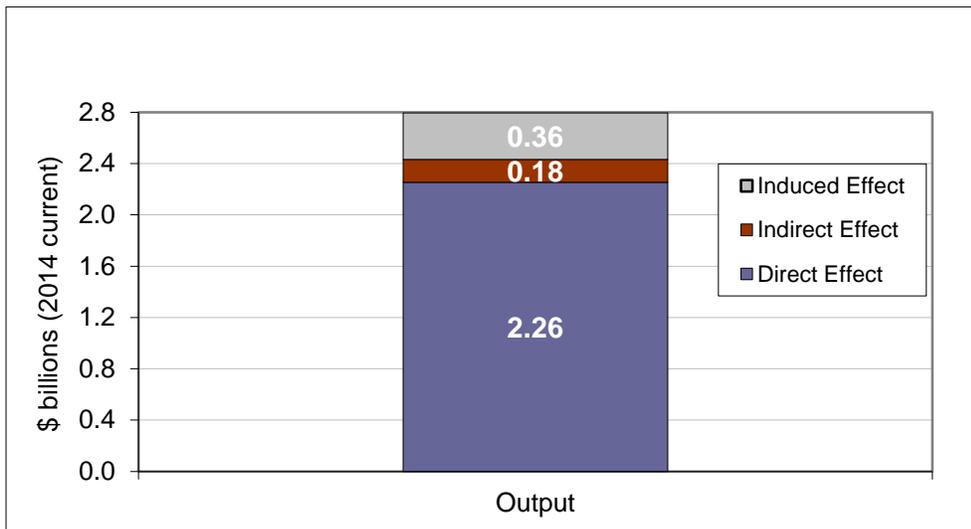


Figure 4.6 Yuma Agriculture and Agribusiness Contributions to Yuma County Output

## *Employment*

Agriculture and related industries contributed to one in four jobs in Yuma County.

Agriculture and related industries (such agricultural inputs and services, food and fiber processing) directly account for nearly one in five jobs. Agriculture creates additional jobs in non-agricultural sectors when it purchases goods and services from those sectors. When farming households and employees spend their incomes and paychecks at local businesses, this creates demand for even more jobs. When direct, indirect, and induced effects are accounted for nearly, agriculture and agribusiness supported more than one in four Yuma County jobs (26 percent) (See Figure 4.7).

Every 100 jobs in agriculture and agribusiness industries supported an additional 26 jobs in other industries throughout Yuma's economy. Agricultural and agribusiness spending created demand for jobs in transportation, warehousing, real estate, banking, retailing, and wholesale trade, among many industries. Spending of agricultural paychecks and proprietors' income on local goods and services created demand for jobs in health care, food and beverage service, retailing, banking, and auto repair among other industries.

The IMPLAN modeling system counts total jobs, but does not make a direct distinction between full- and part-time jobs. While agriculture and related industries supported about 26 percent of total jobs (directly and indirectly), agriculture contributed to 15 percent of the county's employee compensation. This difference reflects the part-time and seasonal nature of many agricultural jobs. In contrast, the high profitability of agriculture is reflected in its contribution to business income (proprietors' income and to other property income). The total contribution

of agriculture (direct and indirect) to county business income represents 35 percent of the county total.

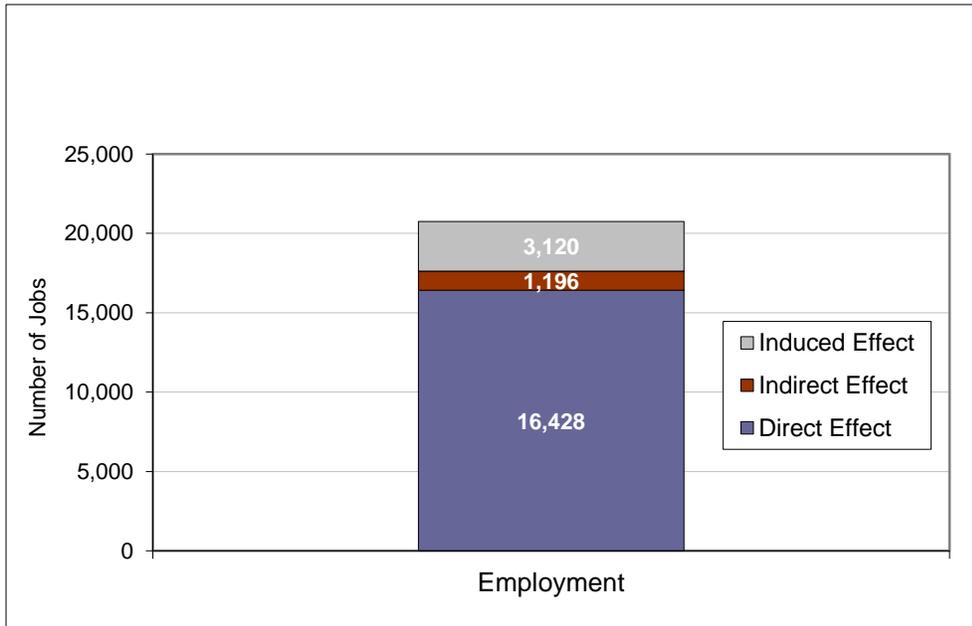


Figure 4.7 Jobs Supported by Yuma Agriculture and Agribusiness

## **References**

Day, Frances. 2014. Principles of Impact Analysis and IMPLAN Applications. IMPLAN Group, LLC. 16740 Birkdale Commons Parkway, Suite 206. Huntersville, NC 28078, [www. IMPLAN.com](http://www.IMPLAN.com)

English, Leah, Jennie Popp, and Wayne Miller. 2014. Economic Contribution of the Agricultural Sector to the Arkansas Economy in 2012. Arkansas Agricultural Experiment Station, University of Arkansas System, Division of Agriculture, Fayetteville. Research Report 994. Available at <http://arkansasagnews.uark.edu/994.pdf>.

Havranek, C. 2014. Maricopa County Market Trends. Presented at the 2014 Ag Forum Sponsored by the Arizona Chapter of the Association of Farm Managers and Rural Appraisers. Phoenix, AZ, February 21, 2014.

IMPLAN Group, LLC. 2011a. IMPLAN System (Version 3.1 data and software). 16740 Birkdale Commons Parkway, Suite 206. Huntersville, NC 28078, [www. IMPLAN.com](http://www.IMPLAN.com)

IMPLAN Group, LLC. 2011b. Estimating the Contribution of a Current Industry. Available at [http://implan.com/index.php?option=com\\_content&view=article&id=660:660&catid=253&Itemid=508](http://implan.com/index.php?option=com_content&view=article&id=660:660&catid=253&Itemid=508).

Leones, Julie P. and Neilson C. Conklin. 1993. Agriculture in the Arizona Economy. Arizona Department of Agriculture, Arizona State University and The University of Arizona.

Menvielle, T. 2014. Imperial County Market Trends. Presented at the 2014 Ag Forum Sponsored by the Arizona Chapter of the Association of Farm Managers and Rural Appraisers. Phoenix, AZ, February 21, 2014.

Moody, B. 2014. Yuma County Market Trends. Presented at the 2014 Ag Forum Sponsored by the Arizona Chapter of the Association of Farm Managers and Rural Appraisers. Phoenix, AZ, February 21, 2014.

Mortensen, Jorgen R. 2004. Economic Impacts from Agricultural Production in Arizona. Department of Agricultural and Resource Economics, The University of Arizona. Available at <http://ag.arizona.edu/arec/pubs/econimpacts/economicimpactsforweb.pdf>.

Mortensen, Jorgen R. 2009. Impacts from Agricultural Production and from Specialty Crops on the Arizona Economy 2007. Department of Agricultural and Resource Economics, The University of Arizona. Available at <http://ag.arizona.edu/arec/pubs/impactsfromagproduction2007.pdf>.

Mortensen, Jorgen R. 2010. Impacts of Agricultural Production and Specialty Crops on Arizona's Economy in 2007: Addendum Report. Department of Agricultural and Resource Economics, The University of Arizona. Available at <http://ag.arizona.edu/arec/pubs/impactsfromagproduction2007addendum2010.pdf>.

Pendleton, S. 2014. Pinal County Market Trends. Presented at the 2014 Ag Forum Sponsored by the Arizona Chapter of the Association of Farm Managers and Rural Appraisers. Phoenix, AZ, February 21, 2014.

Siegel, Paul B., Thomas G. Johnson, and Jeffrey Alwang. 1995. "Regional Economic Diversity and Diversification." *Growth and Change* 26, 261–284.

U.S. Department of Agriculture (USDA). 2014a. 2012 Census of Agriculture: United States Summary and State Data, Volume 1, Geographic Area Series, Part 51 AC 12-A-51. Issued May 2014. Available at <http://www.agcensus.usda.gov/Publications/2012/>.

U.S. Department of Agriculture (USDA). 2014b. 2012 Census of Agriculture: Arizona State and County Data, Volume 1, Geographic Area Series, Part 3 AC 12-A-3. Issued May 2014. Available at <http://www.agcensus.usda.gov/Publications/2012/>.

U.S. Department of Agriculture (USDA). Economic Research Service (ERS). 2011. U.S. and State-Level Farm Income and Wealth Statistics. Available at [http://www.ers.usda.gov/data-products/farm-income-and-wealth-statistics/value-added-years-by-state.aspx#.VE2\\_dRbp\\_fy](http://www.ers.usda.gov/data-products/farm-income-and-wealth-statistics/value-added-years-by-state.aspx#.VE2_dRbp_fy).

U.S. Department of Agriculture (USDA). Economic Research Services (ERS). 2014 Data Products: Major Land Uses. Available at <http://www.ers.usda.gov/data-products/major-land-uses.aspx#UvLE0z1dWi4>.

U.S. Department of Agriculture (USDA). National Agricultural Statistics Service (NASS). 2011. Arizona Agricultural Statistics Bulletin. Available at [http://www.nass.usda.gov/Statistics\\_by\\_State/Arizona/index.asp](http://www.nass.usda.gov/Statistics_by_State/Arizona/index.asp).

U.S. Department of Commerce. Bureau of Economic Analysis (BEA). 2011. Annual State Income and Employment. Farm income and expenses (SA45). Available at <http://www.bea.gov/iTable/iTable.cfm?reqid=70&step=1&isuri=1&acrdn=1#reqid=70&step=1&isuri=1>

U.S. Department of Labor. Bureau of Labor Statistics (BLS). 2011. Quarterly Census of Employment and Wages. Available at <http://www.bls.gov/cew/data.htm>.

U.S. Geological Survey. Water Use in the United States: 2010. County Data Tables. Reston, VA: USGS.

Ward, Ruby A., Paul M. Jakus, and Lassina Coulibaly. 2013. The Economic Contribution of Agriculture to the Economy of Utah in 2011. Department of Applied Economics, Utah State University, Center for Society, Economy, and the Environment Paper #2013-01. Available at <http://www.ag.utah.gov/documents/EconomicContributionOfAgriculture2011.pdf>.



## **SECTION 5: ENVIRONMENTAL WATER USE IN YUMA COUNTY AND THE LOWER COLORADO RIVER**

### **Section Summary**

- The Lower Colorado River Basin has been the subject of many actions to mitigate river operations by the USBR from Hoover Dam to the Mexican border. The National Wildlife refuges along the river were created for the purpose of conservation of fish and wildlife in association with mitigating effects of operation of the federal water projects.
- The LCR MSCP was implemented in 2005 to mitigate the effects of the discretionary operations of the dams by balancing the use of the Colorado River resources with the conservation of native species and habitats. Both agricultural water users and hydropower users in the Yuma area contribute substantially to Arizona's share of the program costs each year.
- Other environmental efforts in the Yuma area include the Yuma East Wetlands, activities within the Gila River channel and cross border environmental efforts.

### **General Considerations**

The Lower Colorado River Basin has been the subject of many actions to mitigate river operations by USBR from Hoover Dam to the Mexican border. The National Wildlife refuges along the river were created for the purpose of conservation of fish and wildlife in association with mitigating effects of operation of the federal water projects, including the Parker Dam Project, the Colorado River Front Work and Levee System and the Cibola Valley Channelization Project. The LCR MSCP is a continuation of that conservation, now more specifically focused on

species now listed under the Endangered Species Act (ESA) but that were originally covered within the defined purposes of the refuges.

### **National Wildlife Refuges**

The National Wildlife Refuges in the Yuma area are operated and maintained by the U.S. Fish and Wildlife Service and are unique within the National Wildlife Refuge System because they were established for the specific purpose of mitigating the effects of operations of the various water storage reservoirs from Hoover Dam to the international border with Mexico.

#### *Havasu and Bill Williams National Wildlife Refuges*

Havasu Lake National Wildlife Refuge, now known as Havasu National Wildlife Refuge, was created by presidential Executive Order (EO) 8647, dated January 21, 1941 that states, in part, that "...approximately 37,300 acres ...reserved and set apart...for use of the Department of the Interior as a refuge and breeding ground for migratory and other wildlife..." and "...for purposes of the Parker Dam Project, their reservation as the Havasu Lake National Wildlife Refuge is subject to their use for the purposes of the Parker Dam Project." The refuge is allocated 41,839 AF of Colorado River water but has never fully utilized the allocation. The core area of the Bill Williams National Wildlife Refuge was originally described and included in EO 8647.

#### *Imperial National Wildlife Refuge*

Imperial National Wildlife Refuge was created by EO 8685, dated February 14, 1941 that states, in part, that "...approximately 51,090 acres...reserved and set apart...for use of the Department of the Interior as a refuge and breeding ground for migratory and other wildlife..." and "...for

purposes in connection with the Imperial Reservoir...".The refuge is allocated 28,000 AF of Colorado River water but has never fully utilized the allocation.

#### *Cibola National Wildlife Refuge*

Cibola National Wildlife Refuge was established by Public Land Order 3442 dated August 21, 1964 for purposes of USBR projects mitigation. The Cibola National Wildlife Refuge was allocated 27,000 AF of Colorado River water but has never fully utilized the allocation.

#### **The Lower Colorado River Multi-Species Conservation Program**

Conservation for federally listed endangered species on the Lower Colorado River National Wildlife Refuges appears to be consistent with, and more specifically is contained within, the purpose for which the refuges were established. In the early 1990s, the USBR and the Lower Basin States decided that due to the ESA a comprehensive program was necessary to mitigate the effects of the discretionary operations of the Lower Colorado River dams. After several years of study and negotiation, the LCR MSCP was approved in 2005.

The LCR MSCP was created to balance the use of the Colorado River water resources with the conservation of native species and their habitats. The program works toward creating habitat to support the conservation of species currently listed under the ESA. It also reduces the likelihood of additional species listings. The program is to be implemented over a 50-year period and will accommodate current water diversions and power production and optimize opportunities for future water and power development by providing ESA compliance through the implementation of a Habitat Conservation Plan (HCP).

The program area extends over 400 miles of the lower Colorado River from Lake Mead to the southernmost United States border with Mexico, and includes Lakes Mead, Mohave, and Havasu, and Imperial Reservoir, as well as the historic 100-year floodplain along the main stem of the lower Colorado River. The HCP calls for the creation of over 8,100 acres of habitat for fish and wildlife species and the production of over 1.2 million native fish to augment existing populations. The plan will benefit at least 26 species, most of which are state or federally listed endangered, threatened, or sensitive species.

The USBR is the implementing agency for the LCR MSCP. Partnership involvement occurs primarily through the LCR MSCP Steering Committee, currently representing 57 entities, including state and federal agencies, water and power users, municipalities, Native American tribes, conservation organizations, and other interested parties, that provides input and oversight functions in support of LCR MSCP implementation. Program costs are evenly divided between the federal government and non-federal partners. Both agricultural water users and hydropower users in the Yuma area contribute substantially to Arizona's program costs each year. The program cost for the LCR MSCP over the 50 years of the program is \$626,180,000 in 2003 dollars, adjusted for inflation. The federal and non-federal parties cost share the program at 50 percent resulting in a non-federal party obligation of \$313,090,000. Arizona permittees are responsible for 25 percent of the non-federal obligation, or \$78,272,500. Arizona's annual payment for the LCR MSCP has historically averaged approximately \$2,500,000.

## **Environmental Restoration and Enhancement in the Yuma, Arizona area**

Apart from other important environmental activities along the lower Colorado River, a number of representatives from the Yuma area started pursued opportunities to create enhancements in the region. Water deliveries in the Yuma area provide a unique opportunity for the creation and maintenance of environmental enhancements. The delivery of water to agriculture in both the United States and Mexico provides benefits to the natural vegetation and to areas where riparian restoration has taken place. The integrity of the riverine environment is dependent upon the actions taken by Yuma area water users.

The construction of Hoover Dam changed the historic hydraulic regime of the river. This change in regime along with the establishment of non-native salt cedar trees, originally used to stabilize the banks of the river, fostered a diminution of native vegetation in the Yuma area.

### **Yuma East Wetlands**

Yuma area residents responded with efforts to restore native vegetation, marshes and wildlife that historically existed along the Colorado River. Despite the challenges posed by increased salinity in the water supply and in the soils, restoration was successful. One example of the efforts of the community is the 2002 Plan for the Yuma Crossing National Heritage Area that included two riverfront parks, waterside trails, commercial redevelopment on the downtown riverfront, and a major wetlands restoration project in the Yuma East Wetlands, beginning just east of the Ocean to Ocean Bridge. The success of that plan is evidenced, in part, by the creation of the Yuma East Wetlands. The reconstruction of the river channel was completed in

2000. Approximately 1,700 acres of mitigation lands were established in and along the river channel with more than 300 acres of cottonwood-willow habitat.

### **The Gila River Channel**

The WMIDD maintains water supplies to three of the riparian areas along the Gila River channel upstream of Yuma. Growler Pond, located in the eastern portion of the district, is maintained with water from district drainage wells. The Quigley Wildlife Area and the Effie May Pond are located near Tacna and also have access to water from WMIDD drainage wells. Additionally, several oxbow riparian areas located along the river channel have flow control structures that were installed after the flood event in 1993 to allow for controlled flow in the areas during times when the river has flow. Through agreements with the Arizona Game and Fish Department and the U.S. Army Corps of Engineers, the WMIDD maintains the constructed Gila River channel with annual dike inspections, clearing of vegetation along dikes and disking of the main channel.

### **Cross Border Environmental Restoration**

The Yuma community also wanted to undertake major environmental restoration along this stretch of the Colorado River and work cooperatively with Mexican environmental groups to develop a cross border restoration plan (Cross Border Plan). In April 2008, this plan was developed and presented at a bi-national conference titled "Common Ground" by two non-profit organizations, the Yuma Crossing National Heritage Area and Pro-Natura.

Because the Cross Border Plan also provided benefits for border security, it gained the strong support of law enforcement agencies while still meeting the needs of the USBR, the BLM, and the Arizona Game and Fish Department. In addition, funding support came from private foundations and the Arizona Water Protection Fund, with a commitment from the LCR MSCP for long-term maintenance. Pro-Natura, a Mexican non-governmental organization, made a commitment to begin restoration on the Mexican side of the border. On the United States' side, construction at Hunter's Hole began in September 2011 and irrigation and planting were completed in March 2012. Now included as a Conservation Area of the LCR MSCP, the area is being restored with native cottonwood-willow, marsh plants, salt grass and honey mesquite.



## **APPENDIX A: THE YUMA AND GILA PROJECTS**

### **The Yuma Project**

The Yuma Project, authorized by the Secretary in 1904, provides irrigation water for lands in the Colorado River floodplain in Arizona surrounding the towns of Somerton and Gadsden, portions of the City of Yuma and San Luis and portions of the Cocopah Indian Reservation; and in California the Bard and Winterhaven areas and a portion of the Quechan Indian Reservation. The project was divided into the Reservation Division in California, currently operated by the Bard Irrigation and Drainage District and the Valley Division in Arizona, currently operated by the YCWUA. The Reservation Division consists of 14,676 acres and is subdivided into the Bard Unit with 7,120 acres of private land and the Indian Unit with 7,556 acres that is part of the Quechan Reservation. The Valley Division consists of 53,415 acres of private land and several hundred acres of the Cocopah Indian Reservation.

The original features of the project included: (1) Laguna Dam constructed in 1909 on the Colorado River approximately 13 miles up river from the City of Yuma; (2) the main canal from Laguna Dam to the Siphon Drop Hydro-power plant (Siphon Drop); and (3) the Colorado River Siphon located about 3 miles south of the power plant. Laguna Dam and canal has not been used as a diversion structure since 1948 due to the construction of the Imperial Dam, 4 miles upstream of the Laguna Dam, and the All-American Canal.

The Yuma Main Canal diverts water from the All-American Canal at Siphon Drop and runs 3.5 miles south in California then through the Colorado River siphon under the Colorado River into

Arizona to deliver water to the Yuma valley. The Reservation Division diverts from the All-American Canal and the Yuma Main Canal in California. A portion of Mexico's deliveries are diverted through the Siphon Drop down the Yuma Main Canal and released into the Colorado River through the California Wasteway immediately above the Colorado River siphon. YCWUA rehabilitated the hydro-generating plant at Siphon Drop in 1987.

The delivery system for the Yuma Project is a gravity flow, concrete and earth lined main canal and lateral canal network delivering water to farm head gates and into farm irrigation ditches. The delivery system consists of approximately 61 miles of main canals and approximately 134 miles of lateral canals. Most of the delivery operation in the Valley Division is operated by a SCADA system from a central dispatch office.

The Yuma Project drainage system is a system of open ditch drains, supplemented by ground water wells in problem areas. Drains in the Reservation Division discharge into the Colorado River. Nearly 50 percent of the drainage system was installed to intercept seepage from the All-American Canal.

In the Valley Division, an open drain network is located throughout the valley. These drains also receive water pumped from wells along the east side of the valley. These wells reduce the elevation of the valley ground water table. The drain system terminates at the Boundary Pumping Plant at the International Boundary with Mexico at San Luis, AZ. This drain water (approximately 85,000 AF per year (AFY)) combined with any water that is pumped from USBR's Minute 242 well field (approximately 20,000 AFY) is pumped into a canal in Mexico and

is counted as part of the 1944 Treaty obligation to Mexico. Other drainage wells, primarily federal, pump water into the Yuma Mesa Conduit which can deliver drainage water to the MODE or to the Colorado River.

### **The Gila Project**

The Gila Project, located in southwestern Arizona, is divided into two divisions, the Yuma Mesa Division (YMD) and the Wellton-Mohawk Division (WMD). The YMD is further subdivided into three units, the Mesa Unit (located south and southeast of Yuma), and the North Gila Valley (NGVIDD) and South Gila Valley (YID) Units, which lie northeast and east of Yuma. The WMD is the WMIDD and begins about 12 miles east of the city of Yuma and continues upstream on both sides of the Gila River for about 45 miles.

The project provides irrigation service to 65,000 acres in the WMIDD (this acreage was reduced from 75,000 acres by the Colorado River Basin Salinity Control Act of 1974) and to 37,187 acres in the YMD, which includes 17,187 acres in the North and South Gila Valleys and 20,000 acres on Yuma Mesa. The project authorization would permit diversion of Colorado River water to satisfy beneficial consumptive use of 300,000 AF of water in each division. However, as a result of the Ak-Chin and Salt River Pima Maricopa Indian Water Right Settlement Acts, WMIDD was reduced to 278,000 AF and the YMD was reduced to 250,000 AF

The Gila Project features include: (1) the Gila De-silting works at Imperial Dam; (2) the Gila Gravity Main Canal; (3) the Yuma Mesa Pumping Plant; (4) the Yuma Mesa Canals and distribution system; (5) the lateral system in the North Gila Valley (originally constructed as part

of the Yuma Project); (6) the canal and pipeline distribution in the South Gila Valley; and (7) the Wellton-Mohawk Canal distribution and drainage systems and protective works.

Imperial Dam, which also serves the All-American Canal System, diverts Colorado River water at its east abutment through the de-silting basin into the Gila Gravity Main Canal. From turnouts in this canal, irrigation water is diverted to serve the North and South Gila Valleys and the Wellton-Mohawk area. The canal ends at the Yuma Mesa Pumping Plant, where water is lifted 52 feet to the head of the Yuma Mesa distribution system which conveys irrigation water to the Mesa Unit lands and to the Yuma Auxiliary Project (Unit B). The WMD of the Gila Project receives Colorado River water from a turnout on the Gila Gravity Main Canal. From this point, water is carried approximately 18.5 miles eastward and parallel to the Gila River through the Wellton-Mohawk Canal, from which it is diverted into the Dome, Wellton, and Mohawk canals. From these three canals, the water is released for delivery to farms and other water users. The irrigation system layout remains largely the same today as its original construction. All power for pumping is furnished by USBR's Parker Davis Project and through Western Area Power Administration's Parker-Davis transmission system.

### *Imperial Dam*

The Gila headworks of Imperial Dam were constructed with three sets of outlet units, each with three radial gates; water discharges through one gate unit into a settling basin. Original plans contemplated diversions to 585,000 acres, but the area of the Gila Project was reduced by the act of July 30, 1947 (61 Stat. 628) to 117,000 acres. The acreage was reduced again to 107,000 acres by the Colorado River Basin Salinity Control Act. One de-silting basin, 1,165 feet

long including transitions, is located between the Gila headworks of Imperial Dam and the Gila Gravity Main Canal diversion gates. This single basin has sufficient capacity under normal conditions for one year's accumulation of sediment.

A canal outage is scheduled every three years to permit draining of the de-silting basin for inspection, repair, and sluicing the accumulated sediment to the Colorado River below Imperial Dam. Water is discharged from the de-silting basin into the Gila Gravity Main Canal, which has a capacity of 2,200 cfs and extends from the de-silting works 20.5 miles in a southerly direction to the Yuma Mesa Pumping Plant. The canal consists of two tunnels, one 1,740 feet long and the other 4,125 feet long; the 0.39-mile Gila River Siphon; and about 19 miles of open unlined canal. It has 10 turnouts to divert water to the project area.

*North Gila Valley Unit (NGVIDD) -- Canals and Laterals*

This unit receives water from two turnouts in the Gila Gravity Main Canal, one seven and the other 11 miles from Imperial Dam. They have a capacity of 150 and 50 cfs, respectively. The unit contains 10.2 miles of canals and about 15 miles of laterals. Drainage is provided by open drains and the adjacent Colorado and Gila Rivers.

*South Gila Valley Unit (YID) -- Canals and Laterals*

Water is diverted to the South Gila Valley Unit from eight turnouts on the Gila Gravity Main Canal, four of which are equipped with re-lift pumps. The largest turnout, the South Gila Canal, located just upstream from the Yuma Mesa Pumping Plant, is approximately eight miles long and has a design capacity of 130 cfs. There is a total of 27 miles of underground pipeline

laterals in the unit. Total diversion capacity to the unit is 282 cfs, which is supplemented by three deep supply wells. There are 24 drainage wells operated by the USBR to maintain adequate ground-water levels. Three of these drainage wells can be used to supply additional irrigation water. Four concrete lined drainage channels carry the water from the wells to either the MODE or the Gila River depending on the salinity of the Colorado River being delivered to Mexico.

#### *Mesa Unit (YMIDD) Distribution System*

The Yuma Mesa Pumping Plant lifts water about 52 feet from the Gila Gravity Main Canal into the main canal of the Yuma Mesa distribution system, which carries water to about 20,000 acres in the Mesa Unit and to about 3,400 acres in Unit B. The main canal, with a capacity of 700 cfs, of the distribution system divides into the A and B Canals, which have a total length of 23 miles. There are 41 miles of laterals within the system. The present capacity of the pumping plant is 1,000 cfs.

#### *Wellton-Mohawk Unit (WMIDD) Canal and Distribution System*

The 18.5-mile Wellton-Mohawk Canal diverts from the Gila Gravity Main Canal about 15 miles below Imperial Dam and has a capacity of 1,300 cfs. It has two branches, the Wellton Canal and the Mohawk Canal, that are 19.9 and 46.8 miles long respectively. The Wellton Canal has a diversion capacity of 300 cfs and the Mohawk Canal has a diversion capacity of 900 cfs. Three large pumping plants along the Wellton-Mohawk Canal lift the water a total of 170 feet.

Thirteen relift pumping plants lift water from the main canals throughout the WMD. The Texas Hill Canal takes water from the Mohawk Canal north of the Mohawk Mountains and extends 9.8

miles to the east to irrigate lands in the Texas Hill area. It has an initial capacity of 125 cfs. The 13-mile Dome Canal branches off the Wellton-Mohawk Canal about 10 miles from its beginning and serves the western end of the division. Its diversion capacity is about 220 cfs. It has 7.5 miles of laterals.

*Operating Agencies*

The facilities within the Gila Project and the entities responsible for their operation are summarized below.

<b>Facility</b>	<b>Operating Entity</b>
Imperial Dam and Gila Diversion Works	Imperial Irrigation District
Gila Gravity Main Canal	Gila Gravity Main Canal Administrative Board
Yuma Mesa Pumping Plant	YMIDD
Wellton-Mohawk Pumping Plants 1-3	WMIDD



## APPENDIX B: THE LAW OF THE RIVER

The Law of the River is a term used to describe the many laws, court decisions and decrees, policies, contracts and treaties that govern the operation of the Colorado River system from its headwaters in Rocky Mountain National Park, Colorado south to the international border with Mexico. It is complex and interwoven. The following chronological timeline of the major events was developed to allow the reader to put the Law of the River into perspective.

<b>Year</b>	<b>Event or Occurrence</b>
<b>1800s</b>	Construction of an irrigation canal from the river to the Imperial Valley in California, using a gravity flow route through Mexico. Dissatisfaction with the operation of the system led to a major push for an "All-American Canal".
<b>1922</b>	Fall-Davis Report (S. Doc. No. 142, 67th Cong. 2nd Sess.) submitted to Congress recommending construction of the All-American Canal and a dam and reservoir at or near Boulder Canyon.
<b>1922</b>	Wyoming v. Colorado, 259 U.S. 419 (1922) United States Supreme Court apportions the waters between the two states based on principle of prior appropriation, heightening concerns that the downstream states (particularly California) would "appropriate" all of the water in the river, leaving little or none for the other states.
<b>1922</b>	Colorado River Compact adopts the compromise suggested by Secretary of Commerce Herbert Hoover to divide the basin into two halves, the Upper Basin and the Lower Basin, with the dividing point being a location in Arizona downstream of Glen Canyon Dam known as Lee Ferry. The Compact apportioned Colorado River water between the two basins but did not apportion the waters among the seven basin states, nor did it resolve the issue of whether any use of tributary water in a state will count against that state's eventual apportionment. Arizona refuses to ratify the Compact.
<b>1925</b>	The Colorado River Front Work and Levee System authorized (with several later amendments) for a drainage and construction program to control floods, improve navigation, and regulate flows of the lower Colorado River from Davis Dam to the Mexican border.
<b>1928</b>	Boulder Canyon Project Act authorized the construction of Hoover Dam (to eventually be located in Black Canyon) and ratification of the 1922 Compact. Six states (including California) approve ratification and California adopts the California Limitation Act limiting California's share of the Lower Basin water to 4.4 MAF per year. Section 5 of the act, authorized the Secretary of the interior to enter into contracts for delivery of Lower Basin mainstream water to California (4.4 MAF), Arizona (2.8 MAF) and Nevada (0.3 MAF) (43 U.S.C. para. 617-617t).
<b>1929</b>	California Limitation Act (1929), Cal. Stat. 1929, c. 16 at p. 38.

<b>Year</b>	<b>Event or Occurrence</b>
<b>1931</b>	Arizona filed suit in United States Supreme Court to block construction of Hoover Dam. Arizona v. California (283 U.S. 423, 1931) Leave to file petition is denied.
<b>1931</b>	California Seven Party Agreement approving apportionment of Section 5 contracts for seven California entities totaling 5.362 MAF.
<b>1934</b>	Arizona filed suit in United States Supreme Court to perpetuate testimony. Arizona v California (292 U.S. 341, 1934) Leave to file petition is denied.
<b>1936</b>	Arizona filed suit in United States Supreme Court to quiet title to the relative shares of the river. Arizona v California (298 U.S. 558, 1936) Leave to file petition is denied.
<b>1944</b>	United States enters into Treaty on the utilization of the water of the Colorado and Tijuana Rivers and of the Rivers and of the Rio Grande with the Republic of Mexico that guaranteed 1.5 MAF of Colorado River water to Mexico in "normal" years.
<b>1944</b>	Arizona contracts with Secretary of the Interior for delivery of 2.8 MAF of Colorado River water. With approval of this contract, Arizona ratifies the 1922 Compact.
<b>1948</b>	Upper Colorado River Basin Compact. Colorado, New Mexico, Utah and Wyoming agree to divide the waters of the Upper Basin according to percentages of the available supply. Arizona, which has land within the Upper Basin, is granted 50,000 acre feet per year for its permanent share, and ratifies the Compact. The Compact creates the Upper Colorado River Commission, which continues to oversee the allocation and use of water in the Upper Basin.
<b>1950-51</b>	Arizona's legislation to create the Central Arizona Project stalls in Congress, in part on the grounds that Arizona's entitlement to the water is not fully adjudicated.
<b>1952</b>	Arizona again files suit in the United States Supreme Court for apportionment of the river, and the petition is granted.
<b>1956</b>	Colorado River Storage Project Act authorizes the construction of Glen Canyon Dam and other water storage projects in the Upper Basin.
<b>1963</b>	Supreme Court issues its opinion determining that Congress, by passage of the Boulder Canyon Project Act of 1928, effectively allocated the waters of the lower basin at 4.4 MAF to California, 2.8 MAF to Arizona and 300, 000 AF to Nevada; also holding that each state shall be entitled to full use of its tributaries.
<b>1964</b>	Supreme Court issues its decree (1964 Decree) enjoining the use of mainstream Colorado River water between Lee Ferry and the International border except in conformance with the mandates of the Decree.
<b>1965</b>	Minute 218 to the 1944 Treaty with Mexico for the United States to construct an extension to the MOD as a temporary solution to the salinity problem.
<b>1968</b>	The Colorado River Basin Project Act authorizes construction of the Central Arizona Project but subordinated diversion of water into that project to California's full entitlement of 4.4 MAF entitlement. The act also authorized several projects in the Upper Basin.

<b>Year</b>	<b>Event or Occurrence</b>
<b>1970</b>	Criteria for coordinated long-range operation of Colorado River reservoirs adopted by the Secretary of the Interior in compliance with Colorado River Basin Project Act, establishing a minimum objective release of 8.23 MAF from Glen Canyon Dam into the Lower Basin.
<b>1972</b>	Minute 241 to the 1944 Treaty with Mexico includes recommendations to improve immediately the quality of Colorado River waters going to Mexico.
<b>1973</b>	Minute 242 to the 1944 Treaty with Mexico was the permanent and definitive solution to the international problem of the salinity of the Colorado River.
<b>1974</b>	Colorado River Basin Salinity Control Act authorizes construction of the Yuma Desalting Plant and other works to reduce salinity levels in the Colorado River, in both the Lower and Upper Basins.
<b>1999</b>	Rules for Off-stream storage of Colorado River water and release of intentionally created unused apportionment to facilitate interstate water banking.
<b>2001</b>	Interim surplus guidelines. Creates structure for determining "surplus" conditions in Lake Mead and apportionment of surplus flows.
<b>2003</b>	California Quantification Settlement Agreement. Agreement to quantify the unquantified rights of the early priorities under the California 7 party agreement to facilitate transfers among the California agencies. Also addresses restoration/mitigation of impacts to the Salton Sea.
<b>2008</b>	Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead, provided for critical shortage elevations in Lake Mead and quantified shortages at those levels; coordinated operations of Lake Mead and Lake Powell to prevent extreme imbalances; and allows "intentionally created surplus" for storage of water in Lake Mead for future use.
<b>2012</b>	Minute 319 to the 1944 Treaty with Mexico provided for storage and surplus sharing with Mexico for a five year trial period plus allowed for storage of water by Mexico in Lake Mead for future use.



## APPENDIX C: CROPS GROWN IN THE YUMA AREA

Alfalfa	Eggplant	Peas, Black Eyed
Alfalfa Seed	Endive	Peas, Dried
Artichokes	Escarole	Peas, Sugar
Artichoke Seed	Fennel	Pecans
Asparagus	Frisee	Peppers
Barley	Garbanzo Beans	Pomegranate
Basil	Gourd	Poppy
Beet Greens	Grapefruit, Pink	Pummelo
Beet Seed	Grapefruit, Red	Radish Seed
Beets, Table	Grapefruit, White	Safflower
Bell peppers	Greens, Asian	Sage
Bermuda Grass	Greens, Baby Leaf	Sesame seed
Bermuda Grass Seed	Guayule	Sorghum
Bok Choy	Hesperaloe	Soybeans
Broccoflower	Honeydew	Spinach, Bunched
Broccoli	Jojoba	Spinach, Leaf
Broccoli Seed	Kale	Strawberry
Broccolini	Leek	Sudan Grass
Cabbage	Lemon	Sudan Grass Seed
Cabbage, Napa	Lettuce, Butter	Sugar Beet
Cabbage Seed	Lettuce, Head	Sunflower
Cantaloupe	Lettuce, Leaf	Sweet Sorghum
Carrot	Lettuce, Oak Leaf	Swiss Chard Seed
Cauliflower	Lettuce, Romaine	Swiss Chard, Red
Cauliflower Seed	Lettuce Seed	Switchgrass
Celery	Lolla Rosa	Tangelo
Chinese Mustard Seed	Mexican Lime	Tango Baby Leaf
Chrysanthemum Seed	Mint	Three-awn Purple Seed
Cilantro	Mizuna	Three-awn Red
Citrus Trees (nursery)	Mustard, Red	Thyme
Clementines	Okra Seed	Tomato
Coriander Seed	Okra	Vegetable Transplants
Corn, Field	Olives	Watermelon
Corn, Sweet	Onion Seed	Watermelon Mini
Cotton	Onions Green	Wheat Durum
Cotton, Pima	Oranges, Arizona Sweet	Wheat Red
Date Palms	Oranges, Valencia	Wheat White
Dates	Ornamental Palms	Wild Rocket
Dill	Parsley	Yellow Squash



## **APPENDIX D: DEFINING THE CONTRIBUTION OF AGRICULTURE**

The agribusiness system is defined as “the primary agricultural sector plus the closely related industries that depend on agricultural activity in Arizona”. This definition was originally developed by Jorgen Mortensen’s 2004 University of Arizona Department of Agricultural and Resource Economics publication Economic Impacts from Agricultural Production in Arizona. The agricultural production, supply and processing industries, and their respective IMPLAN sector codes, included in the model are listed in Table A1 below.

Primary agriculture includes all industries in sector 11 of the North American Industry Classification System (NAICS) with the exception of forestry and logging (NAICS sub-sector 113) and fishing, hunting, and trapping (NAICS sub-sector 114). Thus, primary agriculture included all crop production, animal production, and agricultural support industries (IMPLAN sectors 1-14 and 19).

Agricultural supply and service industries include the fertilizer manufacturing sector (NAICS 32531 and IMPLAN sector 130), the pesticide and other agricultural chemical manufacturing sector (NAICS 35320 and IMPLAN sector 131), and the farm machinery and equipment-manufacturing sector (NAICS 333111 and IMPLAN sector 203). Agricultural processing industries include all sectors of the food-manufacturing sector (NAICS 311), with the exception of a few industries that were determined not to exist in the Arizona economy by the IMPLAN model. Only the winery sub-sector (NAICS 31213 and IMPLAN sector 72) is included from the

beverage and tobacco product-manufacturing sector (NAICS 312). A number of fiber processing industries were included.

Not every industry included in the list of agriculture and agribusiness cluster of industries necessarily had any production in Yuma County in 2011. Purchases by businesses in this cluster of goods and services from industries outside the cluster are counted in the model as indirect effects.

### **Data Sources and Methods**

Data from the 2011 IMPLAN Arizona model was used to estimate the economic contribution of agricultural production. Due to IMPLAN's ability to provide estimates for non-disclosed data and reconcile multiple data sources, we elect to use IMPLAN industry output data as the basis of this analysis. However, primary agricultural industry sales were compared to commodity cash receipt data obtained from NASS's Annual Statistical Bulletin and USDA Economic Research Service's (ERS) Farm Income and Wealth Statistics to identify any inconsistencies. IMPLAN estimates for total primary agricultural output are within 2 percent of USDA ERS figures. Modifications were made, however to IMPLAN baseline data to reflect state-level employee compensation of hired farm labor, farm proprietor income, agricultural taxes on production and imports , and on-farm employment . This 2011 state-level data was distributed among primary agricultural industries based upon the shares reported by the 2012 Census of Agriculture. Additional modification of the IMPLAN data was required to accurately represent agricultural practices in Arizona. The baseline production functions (also known as industry spending patterns) for each agricultural sector in IMPLAN are based on national averages. This means

that for some commodities, the spending pattern for Arizona can vary drastically from the same commodity in another region. The primary reason for this is irrigated agriculture (IMPLAN Group, LLC). The national average spending pattern may represent non-irrigated crop production, which is certainly not the case for semi-arid Arizona. Farm expense data was obtained from the 2012 Census of Agriculture and primary agriculture industry spending patterns were modified to reflect the shares of input expenditures.

As this analysis examines agriculture and its backward linked supply industries and its forward-linked processing industries, the model must be redefined to ensure that there is no double counting. The model was modified so that each industry is not able to purchase inputs from the previous stage of production- components that are already being captured in the model. IMPLAN's procedures for a multi-contribution analysis were followed to eliminate double counting in the estimates of indirect effects (IMPLAN Group, LLC, 2011b).

The Department of Agricultural and Resource Economics (AREC) at the University of Arizona has produced several reports in the past, the latest of which describes how agriculture's contribution to Arizona (Mortensen, 2010, 2009, 2004; Leones and Conklin, 1993). While efforts were made to keep this analysis consistent with previous AREC reports, a review of similar studies (English, Pop, and Miller, 2014; Ward, Jakus, and Coulibaly, 2013) influenced this report to include all food processing and manufacturing sectors (NAICS 311), some of which were not included in previous AREC reports. Due to these few discrepancies, direct comparisons from previous reports cannot be made with this report. Future analyses by the AREC Department will follow the methodology outlined in this report.

**Table D1. Industries Categorized as Agriculture and Agribusiness for Contribution Analysis**

<i>Industry Description</i>	
Oilseed farming	Cheese manufacturing
Grain farming	Dry, condensed, and evaporated dairy product manufacturing
Vegetable and melon farming	Ice cream and frozen dessert manufacturing
Fruit farming	Animal (except poultry) slaughtering, rendering, and processing
Tree nut farming	Poultry processing
Greenhouse, nursery, and floriculture production	Seafood product preparation and packaging
Tobacco farming	Bread and bakery product manufacturing
Cotton farming	Cookie, cracker, and pasta manufacturing
Sugarcane and sugar beet farming	Tortilla manufacturing
All other crop farming	Snack food manufacturing
Cattle ranching and farming	Coffee and tea manufacturing
Dairy cattle and milk production	Flavoring syrup and concentrate manufacturing
Poultry and egg production	Seasoning and dressing manufacturing
Animal production (except cattle, poultry and eggs)	All other food manufacturing
Support activities for agriculture and forestry	Wineries
Dog and cat food manufacturing	Fiber, yarn, and thread mills
Other animal food manufacturing	Broadwoven fabric mills
Flour milling and malt manufacturing	Narrow fabric mills
Wet corn milling	Nonwoven fabric mills
Soybean and other oilseed processing	Knit fabric mills
Fats and oils refining and blending	Textile and fabric finishing mills
Breakfast cereal manufacturing	Fabric coating mills
Sugar cane mills and refining	Carpet and rug mills
Beet sugar manufacturing	Curtain and linen mills
Chocolate and confectionery manufacturing from cacao beans	Textile bag and canvas mills
Confectionery manufacturing from purchased chocolate	All other textile product mills
Non-chocolate confectionery manufacturing	Fertilizer manufacturing
Frozen food manufacturing	Agricultural chemical manufacturing
Fruit and vegetable canning, pickling, and drying	Farm machinery manufacturing
Fluid milk and butter manufacturing	