Technical Memorandum 4 – Case Study Evaluations

Exploration of Quantification Methods for Agricultural Water Savings in the Lower Colorado River Basin

U.S. Department of the Interior September 2021

Mission Statements

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Exploration of Quantification Methods for Agricultural Water Savings in the Lower Colorado River Basin

prepared by

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Project Definition

The Exploration of Quantification Methods for Agricultural Water Savings in the Lower Colorado River Basin Pilot Study (Pilot Study) is a logical next step in the long-standing commitment of United States Bureau of Reclamation (Reclamation) and the Lower Colorado River Basin (LCRB, Lower Basin) stakeholders to ensure the resiliency, reliability, and sustainability of the Colorado River. The objective of this study was to work collaboratively with a diversity of stakeholders to explore the current methods used to quantify agricultural water conservation activities in the Lower Basin, including the relationship of those quantification methods to the Lower Basin consumptive use (CU) accounting, and to recommend approaches to improve agricultural water conservation quantification methods.

Project Activities

The Pilot Study commenced with a workshop (Workshop #1) held remotely November 9 and 10, 2020. The workshop included a summary of the *Colorado River Basin Supply and Demand Study* (Reclamation, 2012) and the *Colorado River Basin Stakeholders Moving Forward to Address Challenges Identified in the Colorado River Basin Water Supply and Demand Study* (Reclamation, 2015) reports. The workshop also provided an opportunity for stakeholders and participants to provide input regarding scope refinement for the Pilot Study. A summary of Workshop #1 and the refined project scope were provided in *Technical Memorandum 1 – Project Definition and Summary of Workshop #1*, herein referred to as TM1 (NRCE and Jacobs, 2021a).

The second step in the Pilot Study effort was to perform a review of scientific and technical literature, project reports, regional publications, reference books and other sources to document methods used to quantify CU reductions from agricultural irrigation conservation measures in the LCRB and elsewhere (e.g., full-year agricultural cropland fallowing, seasonal or partial-year cropland fallowing, deficit irrigation, switching crops or crop rotations to alternate crops requiring less irrigation water, irrigation methodology conversions, and similar topics). This documentation effort was divided into two portions: 1) a review of scientific literature and other sources to identify CU quantification methods, and 2) an overview of select conservation activities within the LCRB and associated CU quantification methods. This effort resulted in *Technical Memorandum 2 – Summary of Significant Findings from Literature Review and Recent/Current Activities in the Lower Basin* referred to as TM2 (NRCE and Jacobs, 2021b). TM2 includes general descriptions and discussions of quantification methods that are subsequently included in the present memorandum.

TM2 was made available for review and comment by participants prior to Workshop #2. That workshop was held remotely on March 2, 2021. During the workshop the reviews of literature and on-going agricultural water conservation activities in the LCRB documented in TM2 were presented. The workshop was also used as a platform to identify and discuss relevant case study opportunities in the LCRB for specific conservation activities and/or methods of quantifying CU reductions. A framework for categorizing case study opportunities was presented and input from workshop participants was sought regarding constraints and limitations for the case studies and the site selection. The results of Workshop #2 and the case study selection process were documented in *Technical Memorandum 3 – Summary of Case Study Definitions, Site Selection, and Evaluation Process* (TM3; NRCE and Jacobs, 2021c).

The purpose of the present technical memorandum (TM4) is to document the case study site visits, data obtained, and evaluations made, and to present recommendations for future agricultural water conservation programs. TM4 was made available for review and comment by participants prior to Workshop #3. Workshop #3 was held remotely on September 22, 2021. The primary objectives of the Workshop were to present the findings documented in TM4 and seek feedback from workshop participants regarding the information and any additional insights gleaned from other conservation efforts.

Case Studies Selected for Evaluation

Based on a review of the potential case studies and the interest in participating expressed by representatives from the potential participating organizations, the following six case studies were selected for evaluation as part of this effort:

- Gila River Indian Community (GRIC) Irrigation System Modernization
- Bard Water District (Bard) Seasonal Fallowing Program
- Palo Verde Irrigation District (PVID) Forbearance and Fallowing Program
- PVID Partial-Year Deficit Irrigation of Alfalfa Program
- Colorado River Indian Tribes (CRIT) Fallowing Program
- Mohave Valley Irrigation and Drainage District (MVIDD) Fallowing Program

These studies were selected from among the available choices to represent a variety of conservation activities, quantification methods, and project locations (shown in *Figure 1*) and are described in TM3. As discussed in TM3, the case studies were evaluated with the goal of gaining knowledge on CU quantification methods and approaches. The case study evaluation process included:

- In-person field visits
- Interviews with case study participants
- Review of documentation relating to the conservation project(s) and quantification methods
- Identification of the relationship of the conservation activity and quantification method to Reclamation's Colorado River Decree Accounting (Decree Accounting)[1], where applicable
- Identification of challenges and lessons learned
- Consideration of the accuracy of methods used in the project
- Consideration of costs and complexity of program implementation
- Assessment of opportunities for improvement of the quantification method(s)

The results of the case study evaluations are presented in the following sections named for the respective case studies. The information presented in this technical memorandum includes the input from the many individuals who participated in the case study discussions (see Acknowledgements at the beginning of the document). Some of these communications are cited; while a number of them are not, they are hereby acknowledged.

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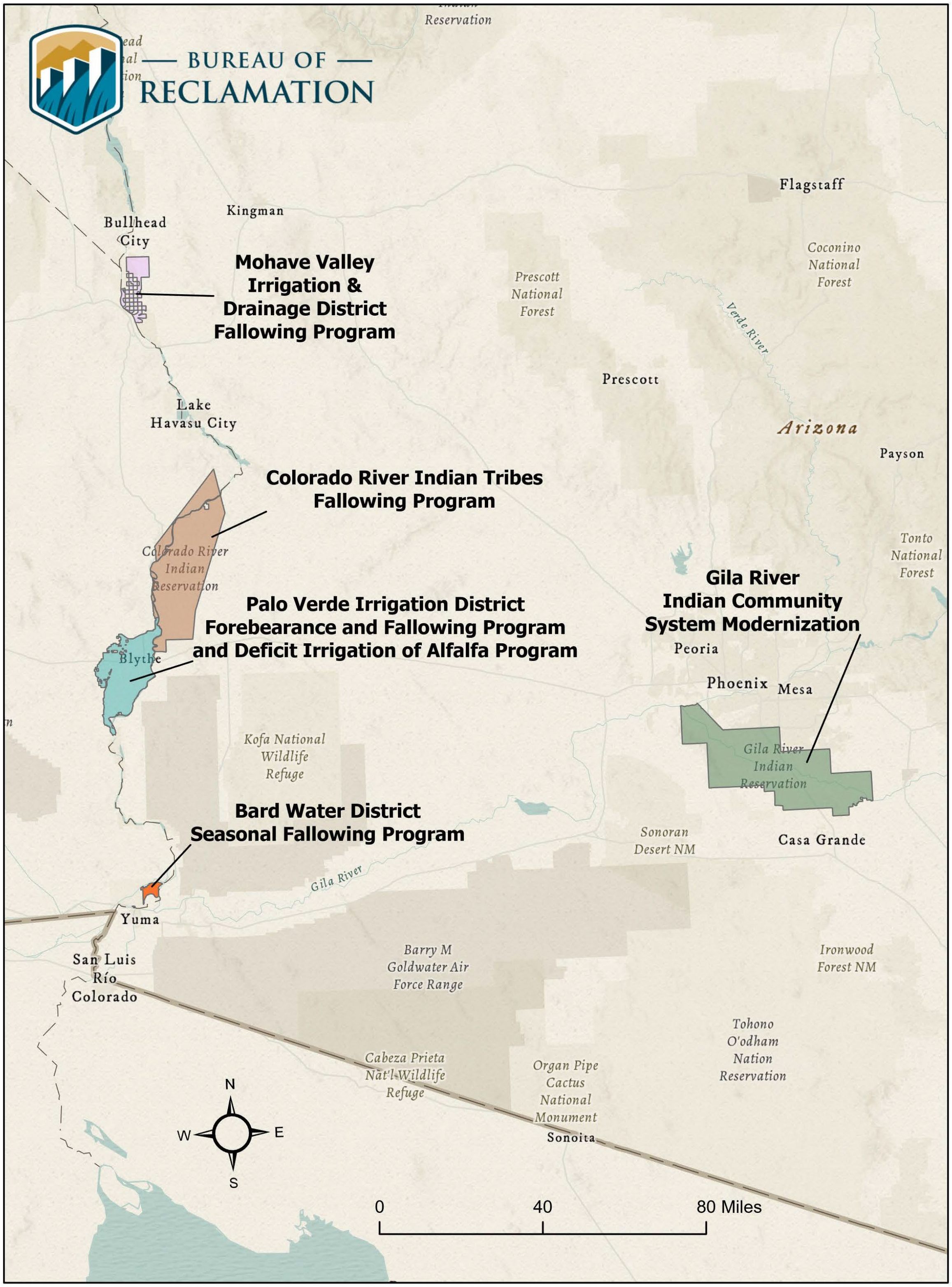
[1] *Colorado River Accounting and Water User Report: Arizona, California and Nevada* published annually in accordance with Article V of the Consolidated Decree of the United States Supreme Court in Arizona *v.* California, 547 U.S. 150 (2006).

Figure 1 Map of the Project Locations of the Six Case Studies



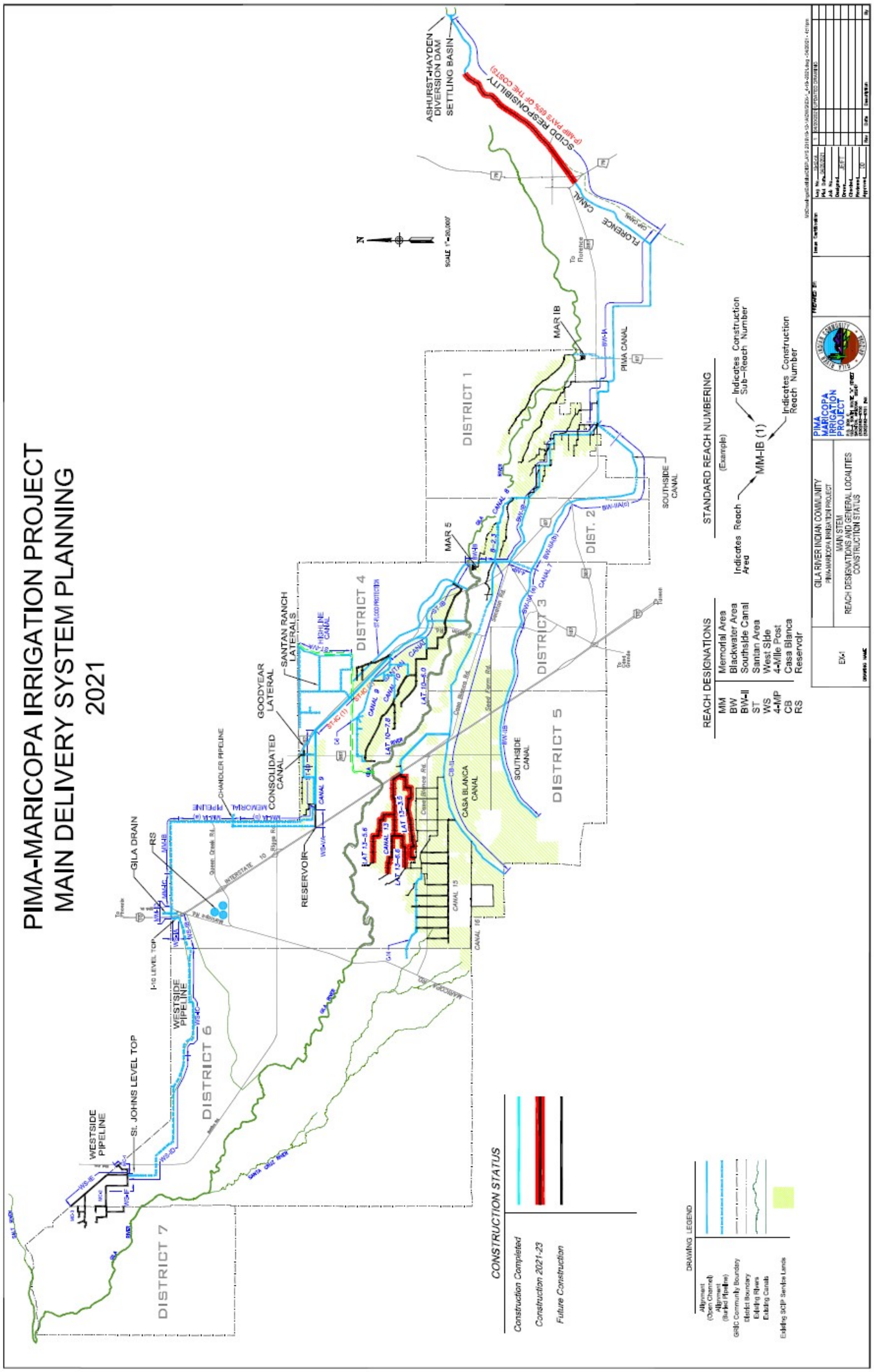
Gila River Indian Community Irrigation System Modernization

The Gila River Indian Community (GRIC, Community) is located just south of Phoenix in Central Arizona (*Figure 1*); and is home to the Akimel O'otham (Pima) and Pee-Posh (Maricopa) tribes. Growers in the Community raise alfalfa, cotton, small grains, and silage corn, among other crops (BIA, 2021).

The Community has been undertaking an extensive rehabilitation, rebuild, and expansion of existing irrigation infrastructure on and/or serving the Gila River Indian Reservation. This effort, which is referred to as the Pima-Maricopa Irrigation Project (P-MIP), was developed as part of GRIC's 1985 *Master Plan Report for Land and Water Use* (Franzoy Corey, 1985; GRIC and EcoPlan, 1997). P-MIP specifically refers to the capital improvement project for the irrigation system (*Figure 2*). The P-MIP irrigation water delivery and distribution system is planned to serve up to 146,300 total acres of land on the Reservation (GRIC and EcoPlan, 1997) and includes the rehabilitation and reconstruction of existing irrigation infrastructure within BIA's San Carlos Irrigation Project (SCIP) service area and areas in the northern and western portions of the Reservation located outside of the SCIP service area. The service area of the SCIP Indian Works (SCIP-IW) is 50,000 acres of land on the Reservation. The total project area that the P-MIP system may serve includes up to an additional 96,300 acres of new development. In connection with P-MIP, GRIC is also in the process of transferring operation and maintenance (O&M) responsibilities for the SCIP-IW division from BIA to a GRIC entity, the Gila River Indian Irrigation and Drainage District (GRIIDD), which will include O&M of all of the P-MIP system within the Reservation boundary.

The P-MIP system is being constructed to deliver all of the Community's 311,800 acre-feet per year (AFY) of Central Arizona Project (CAP) water. Additional water sources for P-MIP include: the Gila River (the source for the SCIP project), groundwater, the Salt River Project (SRP), the Roosevelt Water Conservation District (RWCD), and reclaimed municipal water from the cities of Chandler and Mesa. P-MIP improvements started in 1998 outside of the SCIP service area under the Community's Master Repayment Contract. Construction within the SCIP service area began in earnest in 2010 when consistent and reliable funding for the project became available as a result of the Arizona Water Settlements Act (AWSA), a water rights settlement between GRIC, the United States, and some 34 state parties (P-MIP, communication, August 19,2021). Construction is slated for completion in 2030. The project includes rehabilitation, modernization, and construction of canals, pipelines, turnouts, and measurement and control structures. The project will also include an extensive supervisory control and data acquisition (SCADA) system.

Figure 2   Map of the Pima-Maricopa Irrigation Project (Courtesy of the Pima-Maricopa Irrigation Project).



Technical Analysis

A technical analysis of the GRIC irrigation system modernization case study including a description of the conservation activities and quantification methods is presented in the following subsections.

Description of Conservation Activities

P-MIP includes a suite of system improvement activities. The goal of P-MIP is three-fold:

- Make efficient use of the portfolio of water supplies provided to GRIC through a complex array of sovereign rights, decrees, water rights settlements, and exchange agreements.
- Enhance and sustain a reliable irrigation system, and
- Modernize the GRIIDD system for the benefit of the Community. P-MIP infrastructure improvements led to the formation of GRIIDD and the corresponding transfer of O&M responsibilities from BIA SCIP-IW.

The above-mentioned improvement activities are described in the following subsections.

Additional Water Sources

P-MIP is served by multiple water sources, which increase the supply resiliency and allow the system to adequately serve water users and expand GRIC's irrigated area. The original primary source of the SCIP system is Coolidge Dam, which impounds water in San Carlos Reservoir. This reservoir is on the Gila River but has historically been an inconsistent and erratic water supply. For example, the Reservoir has reached full capacity in only five years[2]. The reservoir has a limited supply much of the time and it is not uncommon for it to be depleted early in the irrigation season according to a case study participant. For example, the reservoir was empty on April 7, 2021 and had impounded only 14,258 acre-feet (AF) as of August 17, 2021.

Because of the unreliable nature of the Gila River water source and the desire of the Community to increase irrigated agriculture, GRIC has pursued additional water sources. The combination of all these water sources adds operational complexity to the system. The P-MIP infrastructure and SCADA improvements, in concert with the consolidated O&M responsibilities of GRIIDD are necessary to improve the efficient use and management of the system's relatively large number of water sources.

Infrastructure Improvements

P-MIP includes extensive system rehabilitation and additional infrastructure construction. These improvements include measures to improve water delivery management and to reduce system losses and spills through:

- Reconstruction of all main canals and most laterals
- Concrete lining of all main canals and most laterals
- Construction of pipelines and siphons

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[2] As cited in *San Carlos Apache Tribe v. United States, 272 F. Supp. 2d 860* (2003). United States District Court for the District of Arizona. No. CV 99-255 TUC DCB. July 9, 2003. Available at: https://cite.case.law/f-supp-2d/272/860/#p867. Both the BIA and P-MIP indicated three fills, which differed in included years, none of which were after the 2003 order, just cited.

- Construction or reconstruction of check and drop structures

All reconstructed canals have been designed to provide sufficient head to serve adjacent fields. The canals have also all been designed to have the same uniform bed-slope.

Some highlighted major improvements include:

- Construction of the concrete-lined Florence Canal, to replace the present, unlined, Florence-Casa Grande Canal, which carries Gila River water to both tribal and non-Indian users. This is a shared project between P-MIP and the non-Indian users and is currently under construction.
- Concrete lining of the Pima Canal, which is the primary canal entering the Reservation and includes the Pima Feeder Canal which delivers CAP water to the Community (*Figure 3*).
- Reconstruction of the Casa Blanca Canal. This is a major canal serving much of the GRIC irrigated area. The Casa Blanca Canal was originally constructed by modifying an existing waterway, the Little Gila River. Reconstruction has included raising and realigning the canal, concrete lining, and construction of control structures (*Figure 4*). The capacity of the reconstructed canal is 350 cubic feet per second (cfs) at its head and 75 cfs near its tail.
- Extensive reconstruction and lining of canal laterals, including the Southside Canal (425 cfs down to 75 cfs), the Santan Canal (700 cfs) and new construction that includes over 24 miles of reinforced concrete pipe (108-inch diameter down to 54-inch diameter) in the Memorial and Westside areas.

P-MIP improvements are for the canal conveyance system only, they do not include any on-farm improvements including farm ditch reconstruction. However, P-MIP improvements do include turnouts with measurement capabilities to serve farms and the reconstruction of any farm ditches that must be moved to facilitate P-MIP infrastructure. This includes moving farm ditches that are within the P-MIP rights-of-way so that they are outside of the rights-of-way.

Figure 3 Photos of the Lined Pima Canal (Left) and of the Pima Canal Including a Portion of the Casa Blanca Canal Headworks and Well Discharge (Right) (Credit: L. Perkins, May 24, 2021).

Water Measurement and Automation

Historically, the SCIP system had a limited number of water measurement sites and records were often in hardcopy (SCIP, communication, June 30, 2021). These measurements were made using staff gauge readings and sedimentation could have affected these measurements according to communications from the BIA. The P-MIP improvements include an extensive monitoring network, with automated measurement structures placed at the heads of canals and throughout the system (*Figure 4*), though not necessarily at all spill sites. The improvements also include measurements of all source waters including installation of flow meters on all supply wells (*Figure 5*). The new measurement devices are all presently equipped with telemetry or will be in time. This facilitates real-time observation of system conditions and electronic data storage and retrieval.

Figure 4 Photo of an Automated Drop Control Structure on the Reconstructed Casa Blanca Canal (Left; Credit: B. Barker, May 24, 2021); and Photo of the Casa Blanca Canal Headworks and Unlined Pima Canal Before Improvements (Right; Courtesy of David DeJong, 2006).

Figure 5 Photo of an Irrigation Supply Well for the Pima Canal with a Flow Meter Installed in the Discharge Pipe (Credit: B. Barker, May 24, 2021).

The system improvements also include automated gates, which are incorporated, along with the measurement structures, into a full SCADA system. While the SCADA system is not fully completed at present, real-time observation and control operations are conducted from an interim location. A dedicated central monitoring and control building has been constructed for the project and will be used in the future.

The improved management made possible by the SCADA system will enable the system operators to better match supply with demand. However, even without an operational SCADA system, some of this benefit has already been realized. For example, the Casa Blanca Canal, which is a primary canal on the Reservation, and which does not yet have operating SCADA, historically spilled into a "sump" at its tail (some of which water could be pumped and reused). As a result of the canal reconstruction, lining, measurement, and operation, spills from that canal are notably less than in the past[3].

P-MIP does not include extensive measurements of drain (surface or subsurface) discharge; though, one drain does have discharge measurement (BIA, 2021). However, in the context of the Decree Accounting, drain discharge in this case is not considered a return flow to the Colorado River system because it does not flow as surface water to the Colorado River and any possible subsurface connection to the river or the Colorado River Alluvial Aquifer is considered negligible. Accordingly, P-MIP drain water is not considered in the CU quantification, because P-MIP is an off-mainstream (of the Colorado River) system.

Consolidated Management

GRIC is also implementing organizational changes in connection with the infrastructure improvements of P-MIP in the formation of GRIIDD. While this is an administrative activity, it has relevance for future system efficiency and conservation. This change will result in a single organization, GRIIDD, being responsible for all of the O&M responsibilities of the P-MIP system within the Reservation. Presently, both GRIC and BIA share responsibilities for the system. Consolidation of O&M responsibilities will facilitate a streamlining of communication and system response. The simplification of the system management will better allow the operators to match supply with demand, thus reducing the risk of operational spills or inadequate supplies, which may result from communication lags. These benefits will particularly be possible once the full SCADA system is operational. After this management transfer, BIA will continue to operate the portions of the system that are upstream of the Reservation and that serve both GRIC and non-Indian users. This includes operation of Coolidge Dam. The process of transferring O&M responsibilities to GRIIDD will be completed in late 2022.

Additional Conservation Measures

In addition to the P-MIP and GRIIDD conservation measures, on-farm improvements have been undertaken by some P-MIP water users. A specific example is that a notable number of users have taken advantage of the U.S. Department of Agriculture Natural Resources Conservation Service's (NRCS's) Environmental Quality Incentives Program (EQIP) to improve farm fields. These efforts have included laser grading and field ditch and pipeline improvements for surface irrigated fields.[4] In total from 2006 to 2020, 78 fields were improved under this program covering a total of about 1,813 acres (*Table 1*). According to the BIA, in general, this has resulted in shorter application times

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[3] According to BIA (2021), there is one other location within the P-MIP service area that no longer has spills; and there are also three locations that currently do spill within P-MIP, though spills are infrequent for one of them.

[4] Most of the irrigation in the P-MIP service area is surface irrigation, with about 1,051 acres within the SCIP-IW service area and 2,199 acres outside of the SCIP-IW service area in center pivots (P-MIP, communication, August 19, 2021).

per irrigation event, which may be evidence of less applied water and consequently greater application efficiencies (e.g., less deep percolation).

Table 1 Summary of Total Areas of Fields Served by the Pima-Maricopa Irrigation Project that Received U.S. Department of Agriculture Natural Resources Conservation Service's Environmental Quality Incentives Program (EQIP) Funded Improvements (GRIIDD, 2021).

Year	Improved Area (acres)	Year	Improved Area (acres)	Year	Improved Area (acres)
2006	46.0	2011	61.7	2016	62.2
2007	320.9	2012	27.6	2017	94.6
2008	692.4	2013	0.0	2018	0.0
2009	142.6	2014	68.1	2019	87.5
2010	10.1	2015	44.2	2020	154.9
Grand Total (acres)					**1,812.8**

CU Quantification Methods

The change in CU (ΔCU) from the system improvements was quantified using variations of a project-level water balance (TM2). The P-MIP system can be considered an off-mainstream water user in relation to the Colorado River since return flows do not make it to the mainstream of the Colorado River. Therefore, under the Decree Accounting definition of CU as diversions less return flows, CU for P-MIP is equivalent to diversion because there are no return flows to the Colorado River mainstream[5]. Therefore, ΔCU resulting from efficiency improvements can be quantified by comparing diversion records before and after the improvements, assuming all else is equal.

There are a few challenges with applying the principle of CU equaling diversion to quantify ΔCU for P-MIP. The first challenge is that, based on the site visit discussion with P-MIP, GRIIDD, and SCIP personnel and the fact that the P-MIP build-out is not completed, it was decided that ΔCU would be evaluated for sub-areas of the P-MIP. A second challenge is that the particular ΔCU of interest for the present study is that relating to the infrastructure and management efforts of P-MIP and GRIIDD as compared to those relating to grower practices. A third challenge is that the system service area has changed and is intended to change along with the P-MIP improvements. A final difficulty is that historical records of irrigated area, diversions, and flows are not as extensive nor as easily processed or analyzed as the flow records after the infrastructure improvements. Such conditions, which are certainly not unique to P-MIP, pose a direct challenge to quantifying ΔCU.

To address the first challenge, it was necessary to consider ΔCU in partial terms. This could be done based on the supply water inflow to the area in question (Q_{In}), which would be some value less than the equivalent diversion at the water source(s) serving that area. For subareas that have other service areas downstream, it is necessary to subtract the supply water that flows past the area of interest (Q_{Out}), which value does not include spills or drainage. Thus:

$$CU = Q_{In} - Q_{Out}$$

[5] Of the various water sources for P-MIP, only CAP water is included in the Decree Accounting and that water is accounted as having no return flows (e.g., Reclamation, 2021a).

In order to assess the impact of irrigation conveyance system improvements on CU, it is helpful to consider conveyance system losses (L_{Conv}), which can be defined as:

$$L_{Conv} = Q_{In} - Q_{Out} - F$$

where F is water delivered to farm turnouts in the area of interest (*Figure 6*). It is also helpful to compute the application efficiency (E_{Conv}), which can be defined as:

$$E_{Conv} = \frac{F}{Q_{In} - Q_{Out}} = 1 - \frac{L_{Conv}}{Q_{In} - Q_{Out}}$$

Because the service area of the irrigation system has changed from year to year, it is helpful to consider CU and L_{Conv} on a per-acre basis:

$$\frac{CU}{A_{Irr}} = \frac{Q_{In} - Q_{Out}}{A_{Irr}}$$

and

$$\frac{L_{Conv}}{A_{Irr}} = \frac{Q_{In} - Q_{Out} - F}{A_{Irr}}$$

where A_{Irr} is the area irrigated, which would be the area listed in the "then being irrigated" (TBI) acreage tracked by the Gila Water Commissioner (OGWC; 2021), which is intended to be only cropland that is irrigated[6].

The final ΔCU comparison is then:

$$\frac{\Delta CU}{A_{Irr}} = \frac{Q_{In}^{Before} - Q_{Out}^{Before}}{A_{Irr}^{Before}} - \frac{Q_{In}^{After} - Q_{Out}^{After}}{A_{Irr}^{After}}$$

where the superscripts *After* and *Before* are relative to the improvements. The final change in conveyance losses (ΔL_{Conv}) comparison is:

$$\frac{\Delta L_{Conv}}{A_{Irr}} = \frac{Q_{In}^{Before} - Q_{Out}^{Before} - F^{Before}}{A_{Irr}^{Before}} - \frac{Q_{In}^{After} - Q_{Out}^{After} - F^{After}}{A_{Irr}^{After}}$$

Changes in E_{Conv} can be made without dividing by A_{Irr}.

As mentioned, the ΔCU analysis was for subareas of the entire P-MIP system. The first and largest subarea was for the 50,000-acre SCIP-IW service area on Community lands starting at the Reservation boundary (this subarea is referred to as the Full System for simplicity). There are other GRIC lands served by P-MIP that are under GRIIDD that were not included. The system

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[6] In the past, TBI acreage was computed as a percentage (85%-90%) of the leased area. However, in the "last two years," according to BIA (communication, August 31, 2021), the TBI acreage was delineated using a geographical information system (GIS) and was found to be about 85%-90% "in most cases."

improvements have not yet been completed for the Full System, therefore, the analysis was also performed for the Division 1 subarea, known as the Blackwater Area, for which improvements are complete. These improvements include the lining of the Pima Canal and a reconfiguration of secondary canals in the area to serve as laterals off the Pima, thus reducing the conveyance distance in unlined canals (*Figure 7*; *Figure 8*; BIA, communication, August 27, 2021). The comparisons were performed for the years 2010 and 2011, which were before many of the system improvements and 2019 and 2020, which were after many improvements.

For both studied areas, Q_{In} does not represent the system diversion, but rather the supply at the head of the respective service area, which is the Pima Canal at the Reservation boundary for the Full System and the heads of respective laterals for the Blackwater Area. Q_{In} also included any additional sources downstream of these locations (i.e., groundwater). In 2010 and 2011, there was some groundwater pumped into the laterals in the Blackwater Area, but in 2019 and 2020, groundwater in that area was only pumped into the Pima. For 2010 and 2011, half of the groundwater pumping in the Blackwater Area was assumed to contribute to the laterals in the area and half was assumed to discharge into the Pima. In 2019 and 2020, there were also some farm turnouts served directly from the Pima in the Blackwater Area, which was not the case in 2010 and 2011. Using the Reservation boundary as the starting point was selected because of the presence of flow measurement at that location and because the said location captures the effects of notable improvements, including some of the Pima Canal lining and, in the case of the Full System, the reconstruction of the Casa Blanca Canal. Notable improvements not included are the portion of the Pima Canal upstream of the Reservation boundary (fully improved and concrete lined with new checks and control structures) and the new Florence Canal, which is not yet completed, and which is located upstream of the Reservation boundary[7].

Figure 6 Simplified Representation of the Project-Level Water Balance Approach for Quantifying CU Reductions for the Pima-Maricopa Irrigation Project Infrastructure.

$$\frac{\Delta CU}{A_{Irr}} = \frac{Q_{In}^{Before} - Q_{Out}^{Before}}{A_{Irr}^{Before}} - \frac{Q_{In}^{After} - Q_{Out}^{After}}{A_{Irr}^{After}} \qquad \frac{\Delta L_{Conv}}{A_{Irr}} = \frac{Q_{In}^{Before} - Q_{Out}^{Before} - F^{Before}}{A_{Irr}^{Before}} - \frac{Q_{In}^{After} - Q_{Out}^{After} - F^{After}}{A_{Irr}^{After}}$$

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[7] It is known that there are significant seepage losses of water between Coolidge Dam and the Reservation, some of which will be reduced by the Florence Canal project. All CAP water is conveyed in the Pima Canal. Gila River diversions will still be subject to losses in the Gila River between Coolidge Dam and the Ashurst-Hayden Diversion Dam.

The Q_{Out} would differ for the two studied areas. For the Blackwater Area, Q_{Out} would be the outflow from lateral canals back into the Pima Canal in 2010 and 2011. There was no Q_{Out} from the Blackwater area in 2019 and 2020 because there was no longer any return to the Pima. For the Full System, Q_{Out} would be zero in all cases because, according to a communication from the BIA, no SCIP-IW water was delivered to the GRIIDD managed portion of P-MIP in the study years, and operational spill is considered CU for this project. Therefore, the $\Delta CU/A_{Irr}$ for the Full System was computed as:

$$\frac{\Delta CU}{A_{Irr}} = \frac{Q_{In}^{Before}}{A_{Irr}^{Before}} - \frac{Q_{In}^{After}}{A_{Irr}^{After}}$$

and $\Delta L_{Conv}/A_{Irr}$ was computed as:

$$\frac{\Delta L_{Conv}}{A_{Irr}} = \frac{Q_{In}^{Before} - F^{Before}}{A_{Irr}^{Before}} - \frac{Q_{In}^{After} - F^{After}}{A_{Irr}^{After}}$$

Figure 7 Simplified Representation of the Pima-Maricopa Irrigation Project Infrastructure (Blue Lines), Gila River Indian Community, San Carlos Irrigation Project Indian Works Service Area (Full System Area), and the Blackwater Area (Derived from Figure 2 and BIA Communication).

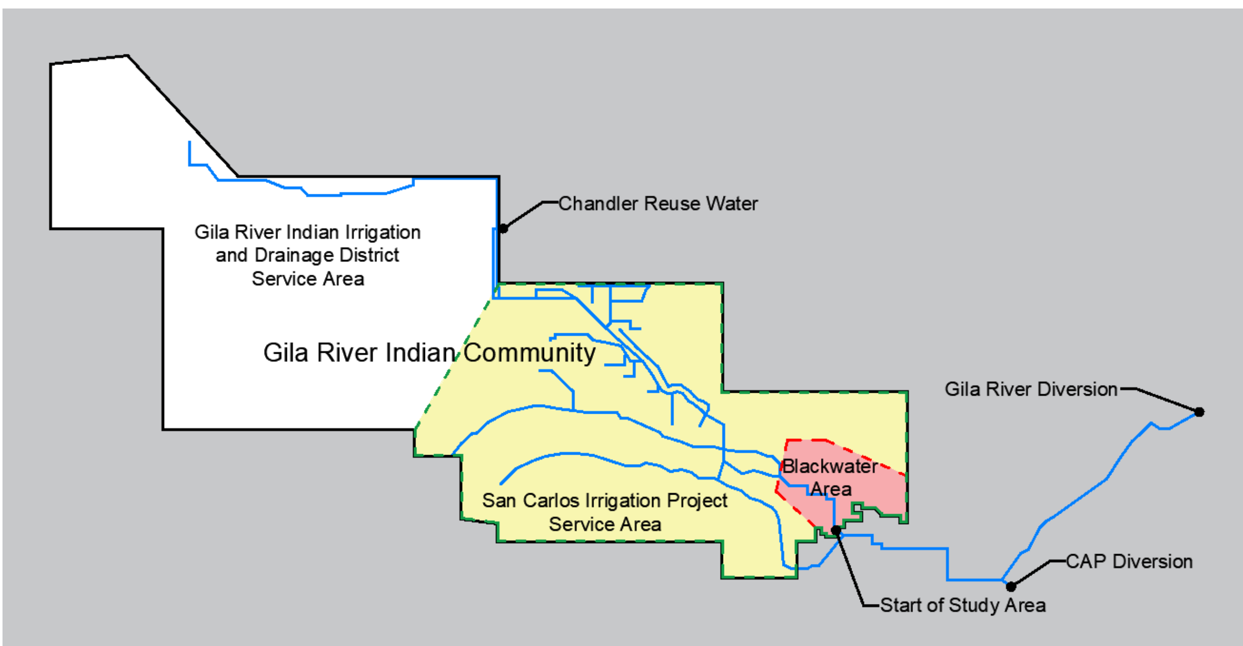

Figure 8 Photo of a Field in the Blackwater Area (Credit: B. Barker, May 24, 2021).

CU Results

Supply and service area data were provided by BIA SCIP staff for the Full System starting at the Reservation boundary. Improvements are ongoing for the full project, therefore supply and service area data were also provided for the Blackwater Area (*Figure 2*; *Figure 7*), for which improvements are complete. The Full System was about 24,800 irrigated acres in 2010-2011, effectively before any P-MIP improvements within the SCIP-IW system (*Table 2*). The service area was about 17,200 irrigated acres in 2019-2020, which was after many improvements. The total CU/A_{Irr} varied notably between the two years before the P-MIP improvements; being 8.7 AF per acre (AF/ac) in 2010 and 6.9 AF/ac in 2011. However, the total F/A_{Irr} was similar for both years (about 4.7 AF/ac). The estimated L_{Conv} was about 4.0 AF/ac in 2010 and 2.2 AF/ac in 2011. The estimated E_{Conv} for the portions of the system on the Reservation varied accordingly from about 54% in 2010 to 69% in 2011. Since this was prior to most of the system improvements, the difference may be a result of management practices.

After the improvements were made, the CU/A_{Irr} for the Full System was about 8.3 AF/ac in 2019 and 10.3 AF/ac in 2020. The total F/A_{Irr} was about 5.7 AF/ac in 2019 and 6.0 AF/ac in 2020. The estimated L_{Conv} was about 2.6 AF/ac in 2019 and 4.3 AF/ac in 2020. Both the $\Delta CU/A_{Irr}$ and $\Delta L_{Conv}/A_{Irr}$ were negative (indicating an increase in both CU/A_{Irr} and L_{Conv}/A_{Irr} for the Full System from 2010 and 2011 to 2019 and 2020). On average, $\Delta CU/A_{Irr}$ was -1.5 AF/ac for an increase in CU/A_{Irr} of about 19% from 2010-2011 to 2019-2020. The $\Delta L_{Conv}/A_{Irr}$ was about -0.33 AF/ac representing an increase of about 11% in L_{Conv}/A_{Irr} from 2010- 2011 to 2019-2020. These increases could be a result of the decreased farmed area, changes in cropping practices, changes in on-farm irrigation management, increased irrigation adequacy of farm deliveries (if deliveries were insufficient prior to improvements), and/or improved measurement accuracy. The E_{Conv} for the Full System was about 69% in 2019 and 58% in 2021, or about 2.6 percentage points greater, on average, than in 2010-2011, prior to the improvements. These differences are subject to the data quality and completeness[8], analysis assumptions, and partial build-out nature of the project.

The ΔCU values for the Full System were compared to the ΔCU for the Blackwater Area, for which P-MIP improvements have been completed. The Blackwater Area is about 1,400 acres in size

[8] There was "major concern" from SCIP regarding the 2010 and 2011 "data quality" including the irrigated acreage.

(*Table 3*). The total CU/A_{Irr} for the Blackwater Area was about 9.4 AF/ac in 2010 and 11.0 AF/ac in 2011. This is compared to about 4.4 AF/ac for both 2019 and 2020. On average, the $\Delta CU/A_{Irr}$ was 5.8 AF/ac, or about a 57% decrease from 2010-2011 to 2019- 2020. In contrast to the full system, the F/A_{Irr} was similar before and after the improvements were made. In 2010, F/A_{Irr} in the Blackwater Area was about 3.8 AF/ac, and in 2011, it was 3.9 AF/ac. In 2019, the total water turned out to farms was about 3.8 AF/ac and in 2010 it was 3.5 AF/ac. The combined effect of these changes in F/A_{Irr} and the $\Delta CU/A_{Irr}$ was that L_{Conv}/A_{Irr} was reduced from about 5.6 AF/ac and 7.2 AF/ac in 2010 and 2011, respectively to 0.6 AF/ac and 0.9 AF/ac in 2019 and 2020, respectively. The resulting $\Delta L_{Conv}/A_{Irr}$ was about 5.6 AF/ac, on average, or a decrease of about 88%.

The E_{Conv} for the Blackwater Area was estimated to be about 41% in 2010 and 35% in 2011. This increased notably after the improvements to 86% in 2019 and 79% in 2020, for an improvement of about 45 percentage points, on average (*Table 3*). This apparently clear improvement is subject to the methods and assumptions used in the analysis (*Table 2*). However, with this caveat in mind, the efficiency improvement for the Blackwater Area is much greater than observed for the full system.

Table 2 Summary of Water Use for the Pima-Maricopa Irrigation Project (P-MIP) Service Area within the Gila River Indian Community Before and After P-MIP Improvements (Full System; Data Provided by BIA).

Year	Irrigated Area[1]	Total Water Supplied (Q_{In}-Q_{Out}=CU)[2]		Total Water to Farms (F)[3]		Conveyance Losses (L_{Conv})		Efficiency[4] (E_{Conv})
	(acre)	(AF	(AF/ac)	(AF)	(AF/ac)	(AF)	(AF/ac)	
Before P-MIP Improvements[5]								
2010	24,782	216,526	8.74	116,825	4.71	99,701	4.02	54.0%
2011	24,857	171,473	6.90	117,572	4.73	53,901	2.17	68.6%
Average	24,819	193,999	7.82	117,198	4.72	76,801	3.10	60.4%
After P-MIP Improvements for Casa Blanca and Pima Canals[5]								
2019	17,188	141,837	8.25	97,746	5.69	44,091	2.57	68.9%
2020	17,250	177,435	10.29	103,454	6.00	73,981	4.29	58.3%
Average	17,219	159,636	9.27	100,600	5.84	59,036	3.43	63.0%
Before - After (AF/ac)[6]		**$\Delta F/A_{Irr}$**	**-1.45**	**$\Delta CU/A_{Irr}$**	**-1.12**	**$\Delta L_{Conv}/A_{Irr}$**	**-0.33**	**-2.61%**
Before - After (%)[6]		**$\Delta F/A_{Irr}$**	**-18.6%**	**$\Delta CU/A_{Irr}$**	**-23.7%**	**$\Delta L_{Conv}/A_{Irr}$**	**-10.7%**	**-4.32%**

[1]Then being irrigated" area (see OGWC, 2021), which is intended to only be irrigated crop area.

[2]Total supply is gross supply in the Pima Canal at the Community boundary plus the gross supply from all other water sources that enter the system downstream of that location. This, therefore, is not a total gross diversion value, because it does not account for losses upstream of the Community boundary. Quantities are based upon flow measurement records. This includes Gila River water, SRP, reclaimed municipal water, and groundwater. CAP water was only included in the 2019 and 2020 values, because data were not available for 2010 and 2011 (SCIP, communication August 27, 2021).

[3]Total farm-turnout water is the net delivered water used in the analysis. Based upon water orders, nominal delivery flow estimates and duration.

[4]Conveyance efficiency for the respective subarea computed as Total Water Turned Out to Farms/Total Water Supplied to Area.

[5]Before P-MIP improvements means before any P-MIP infrastructure improvements. After P-MIP improvements means after the lining of the Pima Canal and the reconstruction of the Casa Blanca Canal and some of the laterals in the Casa Blanca system. There were also some on-farm improvements during this time (e.g., *Table 1*).

[6]Before P-MIP improvements minus after P-MIP improvements. The percentage change = (before – after)/before.

The difference in E_{Conv} before and after the system improvements is apparent, as is the difference in E_{Conv} when considered at different spatial scales. It should be remembered that the E_{Conv} values that are presented here are not relative to the diversion works, but to the Reservation boundary and that additional system losses occur upstream of the areas included in this analysis. However, according to P-MIP, CAP losses are expected to be small since the ditch is concrete lined.

The differences between the Full System and Blackwater Area results are evidence both of the impact of the relative completeness of the improvements and of the study area scale. The relative completion of the improvements is represented because the Full System, while benefitting from major improvements like the Casa Blanca and Pima Canals, is incomplete; while improvements for the Blackwater Area, which is upstream of the Casa Blanca Canal, are complete. The Blackwater Area is also smaller than the Full System and is located at the head end of the Full System. Therefore, the distance that water must travel in canals to serve the average farm turnout in the Blackwater Area is shorter than for the Full System. This shorter travel time will tend to reduce conveyance losses. Therefore, the Blackwater area is expected to have greater E_{Conv}, on average, than the Full System.

Table 3 Summary of Water Use for the Blackwater Area Before and After Pima-Maricopa Irrigation Project Improvements (Data Provided by BIA).

Year	Irrigated Area[1]	Total Water Supplied (Q_{In}-Q_{Out}=CU)[2]		Total Water to Farms (F)[3]		Conveyance Losses (L_{Conv})		Efficiency[4] (E_{Conv})
	(acres)	(AF)	(AF/ac)	(AF)	(AF/ac)	(AF)	(AF/ac)	
Before P-MIP Improvements[5]								
2010	1,405	13,180	9.38	5,344	3.80	7,836	5.58	40.5%
2011	1,398	15,430	11.03	5,406	3.87	10,024	7.17	35.0%
Average	1,402	14,305	10.21	5,375	3.83	8,930	6.37	37.6%
After P-MIP Improvements[5]								
2019	1,255	5,539	4.42	4,776	3.81	763	0.61	86.2%
2020	1,074	4,702	4.38	3,723	3.47	979	0.91	79.2%
Average	1,165	5,120	4.40	4,250	3.64	871	0.76	83.0%
Before - After (AF/ac)[6]		**$\Delta F/A_{Irr}$**	**5.81**	**$\Delta CU/A_{Irr}$**	**0.20**	**$\Delta L_{Conv}/A_{Irr}$**	**5.61**	**-45.42%**
Before - After (%)[6]		**$\Delta F/A_{Irr}$**	**56.9%**	**$\Delta CU/A_{Irr}$**	**5.2%**	**$\Delta L_{Conv}/A_{Irr}$**	**88.1%**	**-120.88%**

[1]Then being irrigated" area (see OGWC, 2021), which is intended to only be irrigated crop area.

[2]Total supply is for the heads of canals and laterals serving the Blackwater Area (plus groundwater pumping and minus returns to the Pima from Canals 3 and 4 in 2010 and 2011). This, therefore, is not a total gross diversion value. Quantities are based upon flow measurement records. In 2010 and 2011, Well discharge records did not specify whether wells discharged into canals serving just the Blackwater Area or the Pima Canal, which primarily conveyed water past the Area. The full discharge for two of the wells in the Area plus half of the discharge from all other wells were assumed not to be available for the Blackwater Area (SCIP, communication, August 17, 2021).

[3]Based upon water orders, nominal delivery flow estimates and duration.

[4]Conveyance efficiency for the respective subarea computed as Total Water Turned Out to Farms/Total Water Supplied to Area.

[5]Before P-MIP improvements means before any P-MIP infrastructure improvements in the Blackwater area. After P-MIP improvements means after the improvements. There may also have some on-farm improvements during this time (e.g., *Table 4*).

[6]Before P-MIP improvements minus after P-MIP improvements. The percentage is a percentage of the before P-MIP improvements conditions.

Anecdotal Evidence of CU Reduction

Prior to the present case study, the ΔCU had not previously been computed for the P-MIP improvements. However, evidence of the combined benefits of the P-MIP and on-farm improvements have been observed in the form of decreased water order durations as mentioned by a BIA SCIP representative during the site visit.

Discussion of Method Assumptions

The method used to quantify ΔCU does not represent the ΔCU for the entirety of P-MIP in terms of estimated differences in total diversion. In addition to this caveat, some assumptions relating to the methods and other implications of the conservation efforts were discussed above. Further discussions of method assumptions are provided in this section.

Assumption 1: ΔCU for periods with differing service areas can be represented using the ratio of ΔCU to "then being irrigated" land.

This assumption is reasonable, as a means of comparing conditions before and after major changes in irrigated area as in the case of P-MIP. From the perspective of GRIC, an increase in irrigated area is beneficial to the Community and therefore, the amount of water applied per acre irrigated is a valuable metric of system efficiency. Even more complete measures of efficiency would be in terms of crop yield or crop value.

However, system losses may not be proportional to the TBI acreage. This concept is discussed in further detail in the Bard Water District case study discussion. Further, this method of comparison includes the inherent assumption that the cropping patterns and irrigation water requirements were similar, for the average TBI acre, before and after the improvements were made and that the fraction of land that was double-cropped was also similar. These considerations are described in the discussion of Assumption 2 below.

Additionally, P-MIP includes multiple types of system improvements and the administrative changes with the O&M responsibilities of GRIIDD make it difficult or impossible to attribute ΔCU to specific actions. Only the aggregate effects can be evaluated.

Assumption 2: ΔCU resulting from efficiency improvements can be quantified by comparing diversion records before and after the improvements, assuming all else is equal.

The assumption that all else is equal after an efficiency improvement may- or may not- be accurate in practice. This is because ΔCU is still dependent upon the crops grown[9], crop timing, the area irrigated, and the irrigation water users' demand[10]. All of these things may change from season-to-season. This challenge is analogous to the situation faced in quantifying ΔCU for fallowed fields in some of the other case studies. This difficulty is further compounded by the addition of water sources and the expansion of the service area. It is also possible that lands served by the improved system are now more adequately supplied than they were previously, a condition which could result in increased CU.

Assumption 3: The diversion and delivery records in 2010 and 2011 were comparable to those in 2019 and 2020.

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[9] Crop reports were not available for 2010 and 2011, therefore, further discussion of cropping pattern differences was not possible.

[10] Changes in irrigation water demand may result from weather conditions, irrigation timing, or changes in on-farm efficiency, among other things. However, grower irrigation practices may also be tied to tradition or other factors and may not be well represented by crop evapotranspiration or other quantifiable conditions.

This assumption was known to not be fully satisfied because of the general increase in data availability, detail, and accuracy in 2019-2020 versus 2010-2011. For example, in 2010 and 2011, CAP delivery data were missing for the full system. For the Blackwater Area in 2010 and 2011, the disposition of well discharge was not documented; therefore, it was assumed that half of the well discharge was into laterals serving the Blackwater Area and half into the Pima Canal. The uncertainty associated with such an assumption is apparent. These deficiencies have been addressed and were not challenges for 2019 and 2020. However, the completeness of historical records, even those that are only a decade old, is a challenge for quantifying the benefits of conveyance system improvements.

Assumption 4: ΔCU can be represented by subareas of the total system.

This assumption is apparent with the inclusion of the Blackwater Area analysis. However, the Full System analysis is also a subdivision of the total system because the analysis only includes the system downstream of the GRIC Reservation boundary. This location is downstream of the diversion and, thus does not include losses in the system upstream of the boundary. Therefore, some portions of total ΔCU are not included. This includes not only the ΔCU associated with upstream improvements, but also the dependence of upstream losses on the downstream improvements. This is because system losses upstream of a given improvement may be dependent upon that improvement. The improvement may have affected the total diversion and losses would, in-turn, be dependent upon the diversion. Therefore, considering only downstream portions of the system does not provide a complete representation of ΔCU. The impact is difficult to assess, because it is related to the total diversion of Gila River water and also CAP water and the relative fraction of additional water sources within the Reservation.

Despite the stated limitations regarding the use of system subdivision to quantify ΔCU, the methods used are useful for assessing any ΔCU directly resulting from the system improvements in the areas studied. Caution should be used in this type of method for comparison when evaluating either volumetric ΔCU or changes in system conveyance efficiencies.

Assumption 5: For the anecdotal evidence of ΔCU: the change in duration of the irrigation turns is indicative of ΔCU.

Irrigation applications consist of both an applied flow of water and a duration of application. A reduced duration of a water turnout can be evidence of one or more of the following: 1) an increased flow at the farm turnout resulting from reduced canal losses, 2) increased flow at the farm turnout not resulting from reduced canal losses, 3) increased on-farm efficiency resulting in a lower irrigation water requirement, and 4) decreases in crop water requirements resulting from a change in crop type or variety, or changes in meteorological conditions (atmospheric demand).

It is evident that not all of these causes may be evidence of irrigation system conveyance or application efficiency improvements. However, it is expected that a widespread presence of reduced water turnout durations would more likely be evidence of widespread changes, of which the P-MIP improvements are the most evident.

Assumption 6: The mean of two years before improvements and two years after improvements is sufficient for computing ΔCU.

The CU, L_{Conv}, and E_{Conv} were all characterized for two years before P-MIP improvements and for the most recent two years as of the analysis to capture the effects of P-MIP improvements up to the time of the analysis. However, it is evident that considerable interannual variability exists in CU and L_{Conv}, making it difficult to separate conservation effects from the typical interannual noise. The selection was a practicality decided upon during the site visit. However, it generally could be considered that the more years prior to- and following improvements the better the quantification could be characterized.

The P-MIP system improvements have been comprehensive, multifaceted, and concurrent with other changes in the system including those to management and source water. This makes it difficult to attribute changes in efficiency to any one particular activity. For example, is canal lining a primary activity contributing to changes in efficiency? Is canal reconfiguration? Is increased automation and remote control? Is increased source reliability? This is a universal challenge for any project that includes multiple activities. To completely associate the activity with the corresponding change in efficiency would require performing only one activity at a time so that before and after comparisons could be made, which is obviously impractical for a major system rehabilitation and improvement project.

Considerations for Multiple-Source Systems

The P-MIP system includes multiple water sources, only one of which, CAP, is directly associated with the Colorado River mainstream[11]. In a mixed system, water conservation may be considered on the whole, as it is herein, or individually for each water source. For example, there may be specific incentive or need to prioritize conservation efforts for one source above another. When considering only one particular source, shifting water use to other supplies may be accounted as conservation, with CU for that source decreasing even if CU increases commensurately for other sources. It may also be necessary to ensure CU reductions for a given source without increasing CU from other sources. It should also be acknowledged that the conveyance efficiency between any one given source and the portion of the service area that it contributes to may differ from the efficiency between source and service area for other sources. For example, Gila River diversions must be conveyed to the Community through an extensive canal system to reach the average field. Conversely, a well located near the tail of the system will discharge into a canal relatively near the average field that it serves. This is even evident based on the different estimated efficiencies presented by GRIC and EcoPlan (1997) for Gila River water and CAP water under a scenario with no P-MIP improvements.

Reflections

The P-MIP system is complex, with multiple water sources, combined system improvements and expansions, and multiple types of system or administrative modifications. There are many lessons that can be learned from the P-MIP experience. One such lesson is regarding the feasibility of the project. P-MIP is a comparatively large project that has been made possible by the reliable and consistent funding associated with the Arizona Water Settlements Act (Public Law 108-451--December 10, 2004) and the GRIC Water Rights Settlement contained in Title II therein. Such funding has allowed for the extensive design, planning, and construction of the project.

[11] Some of the municipal reclaim water may ultimately originate from CAP also.

GRIC has a commitment to pursue development and implementation of system improvements as a means of providing a resilient, reliable, and efficient irrigation system to serve GRIC's interests now and into the future.

In addition to the funding and infrastructure, the changes in system management, including the reduction in the number of organizations involved with the system O&M, provide not only increased water conveyance and use efficiency, but also potential efficiencies in administrative effort and expense.

For all of the possible and realized management and infrastructure benefits of the system, quantifying certain benefits, e.g., changes in CU, can be challenging. This is because the improvements include the addition of measurements and/or databases that were not available pre-improvement. Thus, CU for the improved system may be determined with accuracy and relatively little effort, but the pre-improvement conditions may be difficult or impossible to assess. This is somewhat of a universal challenge likely experienced by many water service providers.

Another observation relative to the system improvements concerns the interdependence of water sources and other systems. BIA (2021) provided anecdotal evidence of apparent decreased groundwater recharge from the canals now that they have been lined. This may indicate, as would be expected, that some of the groundwater that has historically been pumped into the system has been a recovery of seepage losses from the canals and that increasing efficiency may reduce another down-gradient water source. In this case, the responsible and affected parties may be the same. The Community has, however, begun on-Reservation recharge in an effort to balance groundwater extraction with groundwater recharge.

Finally, a consideration for improved assessment would be to conduct a *post facto* analysis of historical satellite images to model seasonal evapotranspiration (ET) representative of pre- and post-conservation measures. With this information, total modeled ET divided by total water supplies could be used as a composite metric for system-wide irrigation efficiency.

Bard Water District Seasonal Fallowing Program

Bard Water District (Bard) is located in southeastern California. The Bard Water District is part of the Yuma Project Reservation Division. The Reservation Division includes two subunits, which are the Bard Unit and the Indian Unit. The Indian Unit is comprised of Quechan Tribal lands, while the Bard Unit is comprised of non-Indian lands (*Figure 9*). Bard Water District serves both units, but in the present context will refer to specifically the Bard Unit. The Bard Unit serves about 7,120 acres of land (Bard, 2021).

Figure 9 Map of the Bard Water District (http://mwdh2o.granicus.com/MetaViewer.php?view_id=7&clip_id=1595&meta_id=43649).

Only the Bard Unit is participating in the seasonal fallowing program. The Bard seasonal fallowing program has been going, in different forms, since 2016. Bard first participated in a seasonal fallowing pilot program with the Metropolitan Water District of Southern California (MWD) in 2016 and 2017. Bard then participated in a pilot seasonal fallowing program with Reclamation for the 2018 and 2019 growing seasons and is now in a longer duration program with MWD for 2020 – 2026. The discussion herein will focus on the present program with MWD. Participating growers do not grow or harvest crops or irrigate fields from fallowed land during summer months (e.g., April 1 through July 31). Thus, this program is a seasonal (partial-year) fallowing program, enabling growers to grow crops during the rest of the year. MWD uses the conserved water for diversion or Lake Mead storage (Businesswire, 2019).

The maximum fallowable land each year is 3,000 acres (MWD, 2019a). The fallowing agreements are between MWD the respective grower, and the district. MWD pays each grower a flat rate based upon the area fallowed (each fallowed area must be 10 contiguous acres or greater), not water conserved. MWD also pays Bard a flat rate to cover administrative costs (25% of the MWD payment for the fallowed land) and a per-acre rate that is to be used for district infrastructure improvements. The latter, among other things, was beneficial in obtaining the consent of growers not participating in the program.

Technical Analysis

A technical analysis of the Bard seasonal fallowing case study is presented in the following sections.

CU Quantification Methods

Reductions in CU, resulting from fallowing, are estimated using the principles of a project-level water balance (TM2). These estimates are based on Reclamation's Decree Accounting (e.g., Reclamation, 2021a; MWD, 2021a).

The CU estimates for the Bard seasonal fallowing program are based upon Reclamation's Decree Accounting (e.g., Reclamation, 2021a) for the YPRD (MWD, 2021a), which includes both the Bard Unit and the Indian Unit of the YPRD. In the Decree Accounting, diversions, unmeasured return flows, and a portion of the measured return flows are reported by Unit. However, large fractions of the total return flows are measured in a shared drain and are, thus, not divided between the two units. These measured flows are referred to as "unassigned" returns (Reclamation, 2021a).

In the CU estimates for the Bard fallowing program, the unassigned returns are divided between the two irrigation units based on the total fraction of measured and unmeasured returns for each unit as:

$$R_{Tot}^{Bard} = R_{Meas}^{Bard} + R_{Unmeas}^{Bard} + R_{Meas}^{Unassigned}\left(\frac{R_{Meas}^{Bard} + R_{Unmeas}^{Bard}}{R_{Meas}^{Bard} + R_{Unmeas}^{Bard} + R_{Meas}^{Indian} + R_{Unmeas}^{Indian}}\right)$$

where *R* is return flows, the superscripts refer to the unit to which the flows were assigned and the subscripts *Tot*, *Meas*, and *Unmeas* represent total, measured, and unmeasured, respectively. Following the Decree Accounting, CU is then computed as:

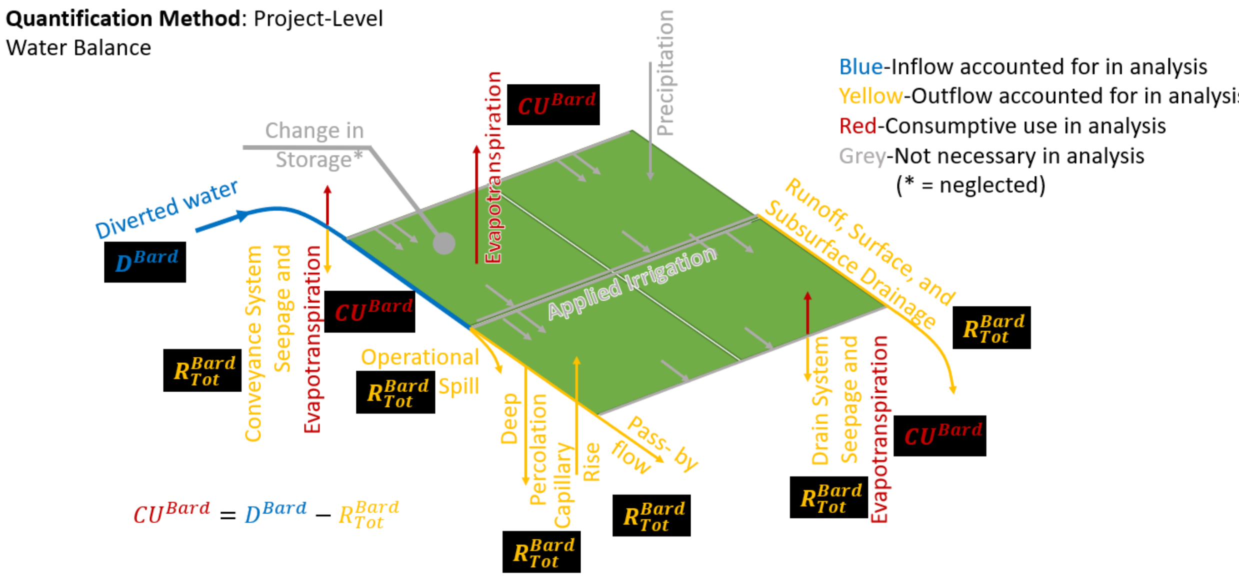
$$CU^{Bard} = D^{Bard} - R_{Tot}^{Bard}$$

where *D* is diversion, and subscripts and superscripts were as previously defined (see also *Figure 10*). The ΔCU for fallowing can then be computed as:

$$\Delta CU = A_{Fallow}^{Bard}\left(\frac{CU^{Bard}}{A_{Irr}^{Bard}}\right)$$

where A_{Fallow}^{Bard} is the fallowed area in the Bard Unit, A_{Irr}^{Bard} is the irrigable area of the Bard Unit (i.e., area that *could* be irrigated, excluding fallowed area) during the fallow period, and the ratio (CU^{Bard}/A_{Irr}^{Bard}) may be referred to as the consumptive use factor. A mean water savings factor is calculated for the fallowing period based on historical data, and the final ΔCU is calculated as the mean consumptive use factor multiplied by the April – August fallowed area. For example, for 2020, the five-year mean CU^{Bard}/A_{Irr}^{Bard} for 2016 – 2020 was multiplied by the 2020 A_{Fallow}^{Bard} to compute ΔCU.

Figure 10 Simplified Representation of the Project-Level Water Balance Approach for Quantifying Consumptive Use Reductions for the Bard Water District Seasonal Fallowing Program.



Fallowed Land Delineation Methods

Another important aspect of the CU quantification for the Bard seasonal fallowing program is the delineation of irrigated lands. This delineation is done by MWD personnel. The areas used to represent the irrigable land both participating in and not participating in the fallowing program (A^{Bard}_{Fallow} and A^{Bard}_{Irr}, respectively) are mapped to exclude roadways, ditches, and other non-farmed areas (according to MWD, ca. May 25, 2021). This likely represents the most time-consuming task in this CU quantification method.

Example CU Results

Two of the benefits of this methodology are: 1) it is tied to the Decree Accounting methods, and 2) it is relatively simple to execute (e.g., MWD, 2021a). The series of calculations necessary to compute the consumptive use factor for a given year can easily be done in a spreadsheet and displayed in a table (*Table 4*). For 2020, an area weighted, five-year average consumptive use factor was used to compute ΔCU (*Table 5*). The mean consumptive use factor was 2.21 AF/ac and the total ΔCU was 6,075 AF.

Table 4 Consumptive Use Factor Estimates for the Bard Water District Seasonal Fallowing Program, 2020.

Description	Apr	May	Jun	Jul	Aug	Total
Diversions, Bard Unit (AF)[1]	3,393	3,599	3,277	2,774	3,325	16,368
Returns, Measured, Assigned to Bard Unit (AF)[1]	29	14	49	41	60	193
Returns, Unmeasured, Assigned to Bard Unit (AF)[1]	567	601	547	463	555	2,733
Returns, Measured, Assigned to Indian Unit (AF)[1]	108	46	108	70	128	460
Returns, Unmeasured, Assigned to Indian Unit (AF)[1]	1,077	990	670	456	680	3,873
Bard Unit Fraction of Unassigned Returns[2]	0.33	0.37	0.43	0.49	0.43	0.40
Returns, Measured, Unassigned, Both Units (AF)[1]	2,146	2,545	2,522	1,997	1,906	11,116
Returns, Measured, Unassigned, Bard Unit (AF)[2]	718	948	1,094	977	824	4,561
Returns, Total, Bard Unit (AF)[2]	1,314	1,563	1,690	1,481	1,439	7,487
Consumptive Use, Bard Unit (AF)[2]	2,079	2,036	1,587	1,293	1,886	8,881
Irrigable Area, Bard Unit (ac)[2]	3,823	3,823	3,823	3,823	3,823	3,823
Consumptive Use Factor, Bard Unit (AF/ac)[2]	0.54	0.53	0.42	0.34	0.49	2.32
Fallowed Area, Bard Unit (ac)[2]	2,749	2,749	2,749	2,749	2,749	2,749
Consumptive Use Reduction, Fallow, Bard Unit (AF)[2]	1,495	1,464	1,141	930	1,356	6,385

[1]Source: Reclamation (2021a)

[2]Taken from, or based upon, MWD (2021a).

Table 5 Consumptive Use Reduction (ΔCU) Estimates for the Bard Water District Seasonal Fallowing Program, 2020 (MWD, 2021a).

Year	Area Fallowed (acres)	Reported CU Factor (AF/ac)
2016	509	1.87
2017	1,641	2.32
2018	973	1.99
2019	1,984	2.14
2020	2,749	2.32
Area-Weighted Mean	1,571	2.21
------------- 2020 ΔCU -------------		
2020 Fallowed Area (ac)		2,749
2020 ΔCU (AF)		6,075

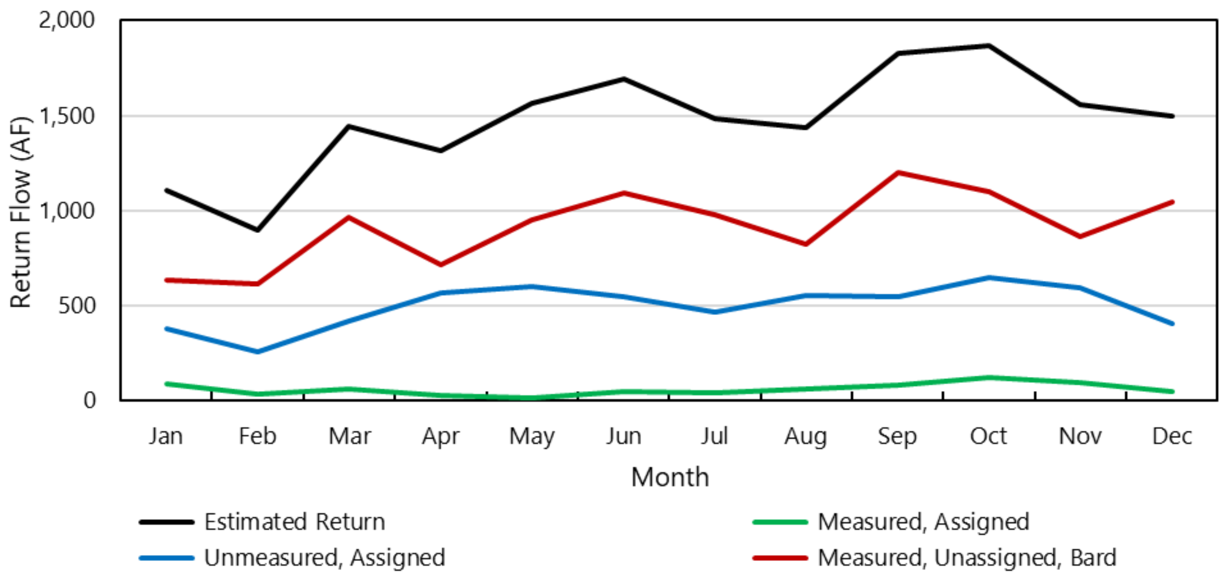
Discussion of Method Assumptions

The ΔCU method includes several assumptions, which are either explicit or implicit in the method. The primary assumptions are discussed below.

Assumption 1: The unassigned return flows are proportional to the total assigned return flows for the two respective units.

The need for this assumption is apparent. It is necessary, for the purposes of the seasonal fallowing program CU quantification, to attribute a fraction of those unassigned flows to the Bard Unit. Some possible options for estimating the Bard Unit portion of the unassigned flow include basing the proration on respective diversions, measured return flows, measured and unmeasured return flows (the method selected by MWD), and service areas. The impact of this assumption is not trivial because the unassigned return flows make up the majority of the estimated returns for the Bard Unit (*Figure 11*).

Figure 11 Estimated Return Flows for the Bard Unit, 2020 (Reclamation, 2021a; MWD, 2021a).

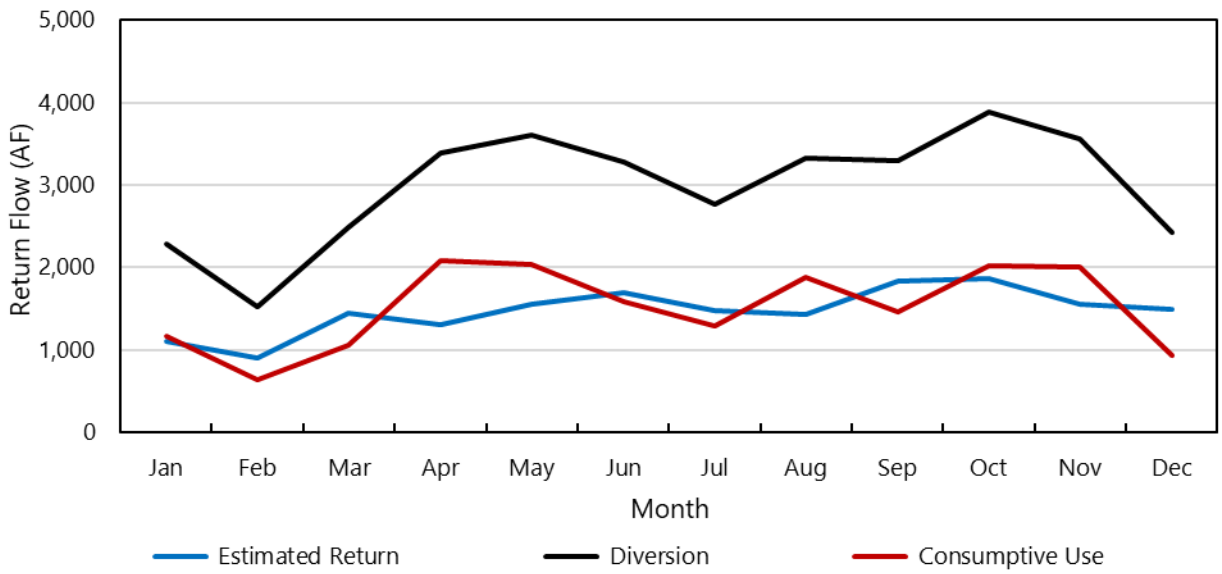


Assumption 2: There is no effective lag in the return flows.

This assumption is implicit in using return flows estimated for the same reporting period as the diversion flows. In reality, it takes water some time to travel through the irrigation system and then return to the river. The amount of time involved could be quite short, in the case of spills back to the river from the canal system, or it could be longer for some drainage water. This is because drainage water must percolate below the root zone and then flow laterally though soil to a drain or the river. Thus, some fraction of the return flows will have originated from pre-fallowing diversions and conversely, some water from diversions during the fallow period will be expected to return to the river post-fallowing.

For the measured returns, the duration of the lags and the associated impact would be difficult, if not impossible, to fully assess. Furthermore, neglecting these lags is inherent in the Decree Accounting methodology. For the unmeasured return, the effect of lag is essentially accounted for because return flows are computed as a fraction of the diversion (17% of the diversion for the Bard Unit throughout the year; Reclamation, 2021a). This is, of course, assuming that the estimated fraction of unmeasured return flow is accurate for each month, and, in this case, that it is consistent throughout the year. Based on a plot of estimated diversions, returns, and CU, for the Bard Unit in 2020 there is possible, but not clear, visual evidence of some return flow lag (*Figure 12*). This possible evidence is the difference between the timing of relative peaks in the diversion and return flow curves. However, if such a lag exists, as might be expected, the evidence is not strong. As with other assumptions, this is a practical solution to a theoretically complicated problem.

Figure 12 2020 Estimated Diversion, Return Flows, and Consumptive Use for the Bard Unit, 2020 (Reclamation, 2021a; MWD, 2021a).



Assumption 3: The *ΔCU* for the fallow fields is proportional to the Bard Unit-wide CU divided by the area irrigated during the fallow period.

This assumption includes the concept that the crops, or at least CU, would be similar in the fallow fields, if irrigated, as it was in the non-fallowed areas of the Bard Unit. In this assumption, any evaporation from the fallowed fields is neglected.

A common difficulty in quantifying *ΔCU* for any conservation activity is estimating what the CU would have been if the activity had not been practiced. The difficulty associated with this is partly addressed by aggregating the conservation for all of the fallowed fields together, rather than speculating what *ΔCU* would be for each, individually. However, it is impossible to know what growers would have done had they not fallowed. For example, growers may specifically elect to fallow instead of planting certain low-return crops. Or they may elect to fallow instead of growing crops that increase the difficulty of land preparation (seedbed preparation) for the winter cash crop season, as was related by one grower during the site visit.

Furthermore, the Bard Unit has a notable fraction of land that is used to produce permanent crops. These areas are not likely to be fallowed. Thus, these areas would not be representative of the *ΔCU* for the fallowed land. To illustrate this point, a total of 1,528 acres in the Bard Unit were reported to be planted to permanent crops (dates and citrus), with the majority of that area (1,499 acres) being dates (*Table 6;* Bard, 2021). The total irrigable area of the unit was reported to be 6,899 acres (Bard, 2021). Thus, about 22% of the Unit's irrigated land was estimated to be in permanent crops in 2020. The total irrigable area used by MWD when computing *ΔCU* was 6,572 acres with about 2,749 acres fallowed in 2020. This left about 3,823 acres of land (58%) not being fallowed. If 22% of the irrigable land in the unit was permanent crops and 58% of the land was not fallowed, then about 38% (22% × 100% ÷ 58% = 38%) of the non-fallowed land was in permanent crops.

The actual impact of the permanent crops on the ΔCU is dampened when CU, not acreage is considered. To illustrate this point, estimates of crop ET (ET_c) were made using the reference ET and crop coefficient method using methods similar to the *Lower Colorado River Annual Summary of Evapotranspiration and Evaporation* (e.g., Reclamation, 2019b; *Table 7*). Short crop reference ET (ET_o), computed using the American Society of Civil Engineers Standardized Reference Evapotranspiration Equation (ASCE, 2005), was obtained for the Arizona Meteorological Network (AZMET; UA, 2021) used in Reclamation (2019b)[12]. The ET_o was then averaged across the three sites as in Reclamation (2019b). Crop coefficients were obtained from Jensen (2003). For crops assumed to be summer crops, the areal-weighted average ET_c was 33.9 inches for April – August if permanent crops were included and 29.2 inches if permanent crops were excluded (*Table 7*). Thus, the effect of permanent crops on ET_c was a (33.9 inches – 29.2 inches) / 29.2 inches × 100% = 16% increase. The exact effect for the Bard Unit may differ from this illustration. Addressing the effect of the permanent crops would require some means of estimating ΔCU only for irrigated fields that did not have permanent crops.

Table 6 Cropped Areas from Bard Unit Crop Report, 2020.

Crop	Area (acres)	Season
Bok Choi	5	Winter
Broccoli	1,751	Winter
Cabbage	9	Winter
Cauliflower	984	Winter
Celery	496	Winter
Cilantro	51	Winter
Citrus	29	Summer
Cotton	819	Summer
Dates	1,499	Summer
Fennel	38	Winter
Greens (Kale)	185	Winter
Lettuce	4,035	Winter
Onion (Dry)	197	Winter
Other Forage (Napa)	55	Winter
Other Hay (Sudan)	970	Summer
Pasture	67	Summer
Spinach	135	Winter
Sugar Beet	22	Summer
Watermelon	117	Summer
Wheat	1,421	Summer
Total Bard Unit Area	7,120	---
Total Irrigable Area	6,899	---

Source (including crop titles): Bard (2020).

[12] These stations were Yuma North Gila, Yuma South, and Yuma Valley.

Table 7 Illustrative Crop Evapotranspiration Estimates for Crops Grown in the Bard Unit, April 1 – August 31, 2020 to Demonstrate the Potential Impact of Permanent Crop Evapotranspiration on Consumptive Use Estimates.

Reported Crop[1]	**Cotton**	**Other Hay (Sudan)**	**Pasture**	**Sugar Beet**	**Water-melon**	**Wheat**	**Citrus[3]**	**Dates[3]**	**Total or Average**	**Total or Average Excluding Permanent Crops**
Modeled Crop[2]	**Cotton**	**Sudan Hay**	**Bermuda …**	**Sugar Beet**	**Melon, Spring**	**Small Grains[4]**	**Citrus, Mature**	**Dates**		
Area (acres)	*819*	*970*	*67*	*22*	*117*	*1,421*	*29*	*1,499*	4,944	3,416
Month	**Estimated Crop ET (inches)**									
April	4.0	6.5	2.9	1.7	6.6	7.4	2.9	6.7		
May	3.5	8.7	7.2	6.3	7.9	6.0	5.1	8.6		
June	6.6	10.8	8.1	0.0	0.0	0.0	5.5	9.4		
July	10.2	11.8	8.8	0.0	0.0	0.0	5.9	10.1		
August	11.5	10.9	8.5	0.0	0.0	0.0	5.8	9.9		
Total	35.8	48.7	35.5	8.0	14.6	13.4	25.2	44.7	**33.9**	**29.2**

[1]Source: Bard (2020)
[2]Source: Jensen (2003)
[4]Permanent crop.
[3]The crop coefficient curve was temporally scaled and shifted based upon reported experimental planting and harvest dates in Ottman (2014).

Technically, there is some quantity of evaporation from the bare soil during the fallow period that would either increase the irrigation requirement or decrease the return flows at the end of the period. This ΔCU method neglects evaporation from the fields during the fallow period, or it is otherwise assumed that bare soil evaporation is accounted for. Any soil evaporation from the irrigated lands is accounted for in the Decree Accounting of CU. In computing ΔCU, the evaporation from rainfall is not important, because the ΔCU of interest is that derived from irrigation water and the Decree Accounting definition of CU is diversions less return flows. Therefore, the methodology implicitly accounts for precipitation on the irrigated lands. Furthermore, precipitation is small enough that it is generally negligible. For example, in 2020, there was a measured average of 0.4 inches of rainfall[13].

Of greater note than precipitation is the practice of irrigating the fallowed fields prior to fallowing in an effort to produce a soil crust to reduce wind erosion (*Figure 13*). Depending on the timing of this practice, the evaporation of water from this application may or may not be negligible during the fallow period. Growers also sometimes cultivate the fields in an effort to kill weeds that may contribute ET during the fallow period (*Figure 14*), though this practice is expected to have a negligible effect on total evaporation.

[13] This is averaged across the available records for the three previously cited AZMET stations and four National Oceanic and Atmospheric Administration (NOAA) climate stations used by Reclamation (2019) (NOAA, 2021a,b; UA, 2021). The NOAA stations were: Yuma MCAS, Yuma 13.8 ESE, Yuma Quartermaster Depot, and Yuma Proving Ground. This rainfall all effectively occurred between April 8 – April 11, 2020, inclusive. An average of <0.01 inches also was estimated for August 18, 2020 (precipitation was recorded at only one station for this event).

Figure 13 Photo of a Bard Fallowed Field with a Soil Crust (credit: B. Barker, May 25, 2021).

Figure 14 Photo of a Bard Fallowed Field Cultivated for Weed Control (credit: B. Barker, May 25, 2021).

Assumption 4: The reduction in ET from field ditches, canals, and drainage ditches resulting from fallowing is proportional to the fallowed land in comparison with the irrigated land.

It is also important to consider the assumption that the reduction in ET (incidental CU including in-ditch water evaporation, seepage, canal loss, and phreatophytes) from field ditches, canals, and drainage ditches resulting from fallowing) would be proportional to the area fallowed in relation to the irrigated area. This assumption would neglect any ET during the drying up of farm ditches and any service laterals that are not used during the fallow program. Under this assumption, the ET from the canal and drainage systems would be proportional to the area served, or to the water conveyed. This may not be entirely accurate as vegetative growth along many of the ditch banks may be similar with or without the fallowing program. Evaporation from the conveyed water itself and from the ditch banks may also not be proportional to the delivered volume of water, but evaporation is often considered a negligible conveyance loss.

Assumption 5: Any carry-over effects of fallowing on CU are negligible.

This assumption is directly related to the assumption that the CU from fallowed land and the associated ditches is negligible. This assumption is valid so long as evaporation from the fields and the dried-up ditches can be considered negligible during the fallow period.

Assumption 6: The CU of irrigated crops for a fallow period that includes partial calendar months (e.g., April 15 – August 15) can be represented by the CU estimated for the respective full calendar months (e.g., April 1 – August 31).

This assumption is only relevant for some years of the program. For example, in 2018, the fallow period was April 15 – August 15, but the CU computation period was April 1 – August 31 (*Table 8*). A similar condition is observed for 2020; however, the fallow period was full months (April 1 – July 31), but the CU computation period was April 1 – August 31. This assumption for some fallowing years, is likely a practicality of working with the Decree Accounting CU values, which are provided as monthly values (Reclamation, 2021a). For years like 2020, the assumption may be a carryover for consistency with other fallowing program years or in acknowledgment of prolonged lack of irrigation outside of the following period resulting from farming logistics. However, the difference could effectively add an additional month to the CU computation period (e.g., April 1 – August 31 vs. April 15 – August 15). This, of course, is assuming that there would be irrigation and ET in the non-fallowed fields during the entire additional included time; such may be the case only a portion of that time.

The effect of this assumption can be demonstrated by using the same analysis presented in *Table 7*, but with monthly summations based on the April 15 – August 15. This example analysis was performed for 2020 data for illustration. Based on this analysis, the ET_c for April 15 – August 15 may be roughly 80% of that for April 1 – August 31 (*Table 9*). Coincidentally, the length of time from April 15 – August 15, inclusive, is about 80% of the length of time from April 1 – August 31, inclusive. The actual impact of this assumption would depend upon the planting, growth, harvest, precipitation, and irrigation in the irrigated fields during the added CU-period, i.e., April 1 – April 14 and August 16 – August 31 in this example.

One possible method of adjusting ΔCU to approximate the fallowing period is to prorate the monthly ΔCU values based on the number of days of each respective month included in the actual fallowing period, where necessary. If this were done, the ΔCU would be less than that used by MWD (2021a) for all years except 2016 (*Table 9*).

For 2020, an area-weighted mean ΔCU for the different fallow years was used. However, the period included in the mean varied among years. If the mean were computed over the April 1 – July 1 period for all years (matching the 2020 fallowing period), then the ΔCU would be 0.33 to 0.40 AF/ac less than the value used by MWD (2021a), depending on whether an area-weighted mean or an arithmetic mean were used[14].

[14] See Footnote 6 in *Table 8*.

Table 8 Consumptive Use Reduction Compared with Fallowing Periods for the Bard Unit, 2016-2020.

Year	Fallow Period[1]	ΔCU Period[1]	Area Fallowed[1] (acres)	Reported ΔCU[1,2] (AF/ac)	Adjusted ΔCU[1,3] (AF/ac)	April 1 - July 31 ΔCU[1,4] (AF/ac)	April 1 - August 31 ΔCU[1,4] (AF/ac)
2016	April 1 – July 31	April 1 – July 31	509	1.87	1.87	1.87	2.03
2017-1[5]	March 15 – July 15	March 1 – July 31	752	2.06	1.71	---	---
2017-2[5]	April 15 – August 15	April 1 – August 31	889	1.89	1.46	---	---
2017 (for 5-year mean)[6]	---	March 1 – August 31	1,641	2.32	---	1.64	1.89
2018	April 15 – August 15	April 1 – August 31	973	1.99	1.52	1.71	1.99
2019	April 15 – August 15	April 1 – August 31	1,984	2.14	1.76	1.93	2.14
2020	April 1 – July 31	April 1 – August 31	2,749	2.32	1.83	1.83	2.32
Mean				2.13	---	1.80	2.08
Area-Weighted Mean				2.21[7]	---	1.80	2.13

[1]Taken from, or based upon, MWD (2021a).
[2]Value used by MWD (2021a).
[3]Adjusted to better match the CU period. For partial months, the value was prorated based on the number of days in the month included in the fallow period.
[4]*ΔCU* for the stated period, inclusive, for each year.
[5]2017-1 is the first fallow period in 2017, 2017-2 is the second fallow period in 2017, neither of these are included in the means.
[6]In computing the area-weighted mean, the total area of the two 2017 fallow periods was used even though that total area was only effectively fallowed during the overlapping periods fallowing period of April 15 - July 15.
[7]Value used by MWD (2021a), see also Reclamation (2021a).

Table 9 Illustrative Comparison of Crop Evapotranspiration Estimates for Crops Grown in the Bard Unit to Demonstrate the Impact of Computation Period on Consumptive Use Estimates April 1 – August 31 and April 15 – August 15, 2020.

Reported Crop[1]	Cotton	Other Hay (Sudan)	Pasture	Sugar Beet	Watermelon	Wheat	Citrus	Dates	Total	Total Excluding Permanent Crops
Modeled Crop[2]	**Cotton**	**Sudan Hay**	**Bermuda Grass (Seed)**	**Sugar Beet**	**Melon, Spring**	**Small Grains[3]**	**Citrus, Mature**	**Dates**		
Area (ac)	819	970	67	22	117	1,421	29	1,499	4,944	3,416
Computation Period: April 1 - August 31										
Month	**Estimated Crop ET (inches)**									
April	4.0	6.5	2.9	1.7	6.6	7.4	2.9	6.7		
May	3.5	8.7	7.2	6.3	7.9	6.0	5.1	8.6		
June	6.6	10.8	8.1	0.0	0.0	0.0	5.5	9.4		
July	10.2	11.8	8.8	0.0	0.0	0.0	5.9	10.1		
August	11.5	10.9	8.5	0.0	0.0	0.0	5.8	9.9		
Total	**35.8**	**48.7**	**35.5**	**8.0**	**14.6**	**13.4**	**25.2**	**44.7**	**33.9**	**29.2**
Computation Period: April 15 - August 15										
Month	**Estimated Crop ET (inches)**									
April	1.0	1.9	1.9	3.9	4.0	4.4	2.4	3.9		
May	3.5	8.7	7.2	6.3	7.9	6.0	5.1	8.6		
June	6.6	10.8	8.1	0.0	0.0	0.0	5.5	9.4		
July	10.2	11.8	8.8	0.0	0.0	0.0	5.9	10.1		
August	5.7	5.7	4.3	0.0	0.0	0.0	2.9	4.9		
Total	**27.0**	**38.9**	**30.2**	**10.2**	**11.9**	**10.4**	**21.8**	**36.9**	**27.1**	**22.9**
April 15 - August 15 Percent of April 1 - August 31									**80%**	**78%**

[1]Source: Bard (2020)

[2]Source: Jensen (2003)

[3]The crop coefficient curve was temporally scaled and shifted based upon reported experimental planting and harvest dates in Ottman (2014).

Assumption 7: The *ΔCU* is best represented by a mean of multiple years.

For the 2020 fallowing period, the *ΔCU* was computed as an area-weighted mean across the five years, then included in the various Bard fallowing periods (MWD, 2021a). One benefit of using an average, as opposed to the estimated *ΔCU* for the conservation year only, is that an average may better represent typical conditions and reduce the uncertainty involved with assumptions and measurements in any one year. Furthermore, it can be expected that the annual variability in ET for a given crop will not be too great (e.g., SCS, 1993). It is conversely possible that the methods used to estimate *ΔCU* for a given year are sufficiently accurate to be more representative than a mean across years.

The type of mean used is also important to consider. The mean used for the 2020 *ΔCU* estimates was a weighted mean based on fallowed area for each year.[15] This would put more numerical value on the *ΔCU* for years with more fallowed area. Thus, providing a mean *ΔCU* value that could be representative, if grower practices for the non-fallowed land are affected by the amount of land

[15] See Footnote 6 in *Table 8*.

fallowed. An alternative weighting could be to use the irrigated land as the weighting factor since it is the irrigated area that the CU used in computing ΔCU is based upon. It may also be reasonable to expect that the mean ΔCU (in terms of AF/ac) would better represent the typical CU of irrigated crops in the Bard Unit.

Finally, the varying length of the periods used in computing ΔCU have an impact on the results. For example, if a simple mean of ΔCU for the period April 1 – July 31 across the five years were used, the final ΔCU would be 1.80 AF/ac compared to the 2.13 AF per acre if varying periods are used for the calculations (*Table 8*).

Reflections

From the grower's perspective, fallowing can be considered like one of several potential crops in a crop rotation. The fallowing program can be logistically favorable for the timing of tillage operations for the winter vegetable crops, where a summer crop may constrain the amount of time available for such operations. Furthermore, growers may see benefits to fallowing land that is less productive, which in some cases may require additional irrigation diversion (not necessarily CU), and that seed, labor and other inputs associated with producing a summer crop may be marginally or not economically profitable (e.g., because of low mid-year grain prices).

The district itself has also experienced benefits from the Program. While the fallowing program adds more complexity and effort for district staff (which does receive some administrative funding from MWD as part of the program), it has been able to take advantage of the reduced water deliveries during the fallowing period. For example, Bard has been able to coordinate with growers to concentrate the fallowed land to certain areas to help facilitate improvement projects, like canal lining. The reduced demand during the fallowing program also can help logistically with implementation of improvement projects. One such project, the Five Gates Reconstruction Project, was in progress during the site visit on May 25, 2021 (*Figure 15*; *Figure 16*). This project involves the reconstruction of a major bifurcation near the head of the system.

Figure 15 Photo of Five Gates Reconstruction Project in the Bard Water District (credit: B. Barker, May 25, 2021).

Figure 16 Photo of a Fallowed Field Being Used as a Staging Area for the Five Gates Reconstruction Project (credit: B. Barker, May 25, 2021).

Finally, the program includes infrastructure improvement funds paid to Bard from MWD as an incentive for participation and to offset the reduction in excess water fees that Bard may have collected from growers who may have exceeded their standard delivery allotments had they not fallowed land.

One challenge for Bard relates to the software they use to track water orders. The software was not designed to accept a field being fallowed (or have no allowable deliveries). This has required software program modifications to facilitate the fallowing program.

In addition to the individual considerations of growers and the district, the program fills an important role from the standpoint of water leases. This is because the Bard Unit has an unquantified water right, meaning that the water users have the right to irrigate a certain amount of land, rather than a right to a specified volume of water. Therefore, the only means of leasing water to other users, e.g., MWD, is through a program where a conservation practice, like fallowing, is implemented and the ΔCU is used to quantify the amount of water that can be leased. Thus, as with other programs the accuracy of the ΔCU is of importance to all parties involved. To this end, MWD is presently developing a revised method for quantifying ΔCU for the program, which will include precipitation and estimates of ET (MWD, communication, May 25, 2021).

The amount of water conserved is also related to the size of the program. The current program is considered by some to be a good size to appropriately balance potential impacts on agronomics and the local economy. In addition, the payment for fallowing is important. The Bard Board of Directors, for example, pushed to have the payment from MWD to growers not be too great out of concern that too many growers would elect to fallow.

Palo Verde Irrigation District Forbearance and Fallowing Program

The Palo Verde Irrigation District (PVID) is located in southeastern California (*Figure 17*). PVID serves over 131,000 acres of land including most of which is in the Colorado River flood plain but roughly 27,000 acres are on the Palo Verde Mesa (PVID, 2021b). In 2004, MWD entered into a 35-year agreement with PVID and landowners within PVID's service area wherein MWD pays for valley land to be fallowed (MWD, 2019b). Annual payments to farmers vary in response to actual acreage fallowed. The forborne water is then made available for use by MWD on a direct acre-foot for acre-foot basis. The amount of land under the forbearance program is allowed to fluctuate between 9 and 35 percent, as determined by MWD (MWD, 2019b).

Participation in the program is voluntary and participants entered into a landowner agreement prior to the start of the program in 2004. Easements were acquired by MWD for the parcels included in the program. The land is fallowed for a minimum of one year and a maximum of five years at a time (MWD, 2019b). A minimum of five acres must be fallowed and portions of fields are allowed to be fallowed (*Figure 18*). Maximum limits have been placed on the amount of land fallowed in the program.

Figure 17 Map of the Palo Verde Irrigation District (Source: Environmental Impact Report for the Proposed Palo Verde Irrigation District Land Management, Crop Rotation, and Water Supply Program, PVID, 2002).

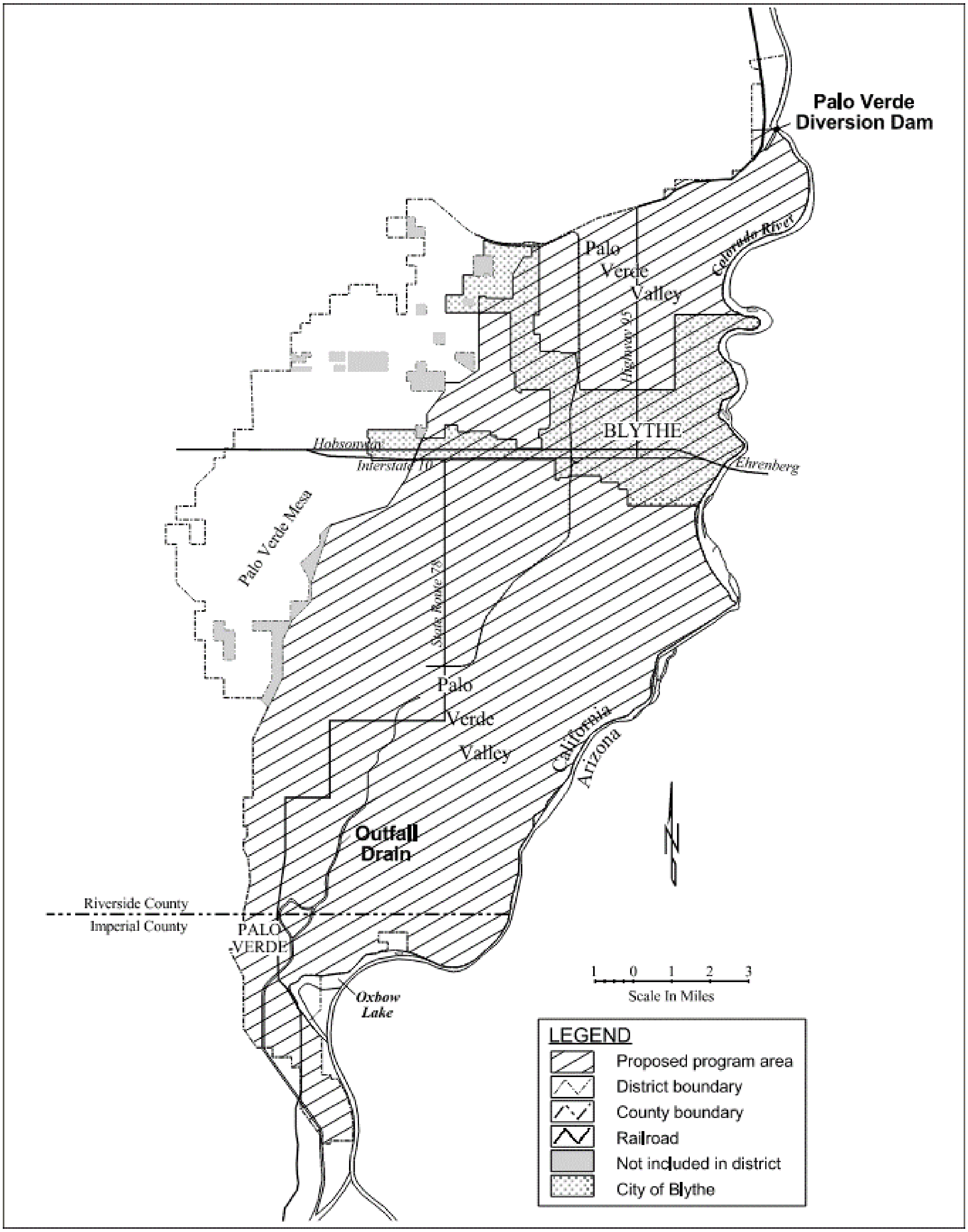


Figure 18 Photo of Partial-Field Fallowing at Palo Verde Irrigation District (credit: L. Perkins).

Technical Analysis

A technical analysis of the PVID forbearance and fallowing case study is presented in the following sections.

CU Quantification Methods

The methods used to quantify CU reductions from the PVID forbearance and fallowing program are based on a project-level water balance (TM2). These methods include three basic components: 1) verification of the fallowing practice, 2) estimation of the average CU for fields under cultivation in PVID, and 3) determination of the CU reduction for fallowed lands. CU is quantified over various historical periods using measured diversions, measured return flows, and estimates of unmeasured return flows from Reclamation's decree accounting data. The method used to translate estimated average CU for fields under cultivation into CU reductions for fallowed fields includes an assumption that fallowed lands would have had similar CU as the rest of PVID during the various analysis periods.

The CU estimates for the PVID fallowing program are based upon Reclamation's Decree Accounting (e.g., Reclamation, 2021a; *Figure 19*) for PVID (MWD, 2021b). The Decree Accounting CU for PVID includes CU from several areas that are aggregated together for accounting purposes. These areas include agricultural lands irrigated with water diverted at the Palo Verde Diversion Dam, agricultural areas receiving water "…pumped from the river…" (Pumped), the Palo Verde Ecological Reserve (PVER), the Palo Verde Ecological Reserve South (PVER-So), and the Dennis Underwood Conservation Area (DUCA) (Reclamation, 2021a; MWD, 2021b). The latter three are Lower Colorado River Multi-Species Conservation Program (LCR MSCP, or MSCP) units. The agricultural lands receiving water diverted from Palo Verde Diversion Dam can further be defined as "Valley lands," located in the Colorado River Valley, and "Mesa lands," which are above the valley (*Figure 17*; MWD, 2021b).

The fallowing program is only on lands that would be considered Valley lands. Therefore, the CU estimated for the fallowing program is estimated by subtracting out the CU for those areas outside of the Valley lands as (MWD, 2021b):

$$CU_{Valley} = CU_{Total} - CU_{Mesa} - CU_{Pumped} - CU_{PVER} - CU_{PVER-So} - CU_{DUCA}$$

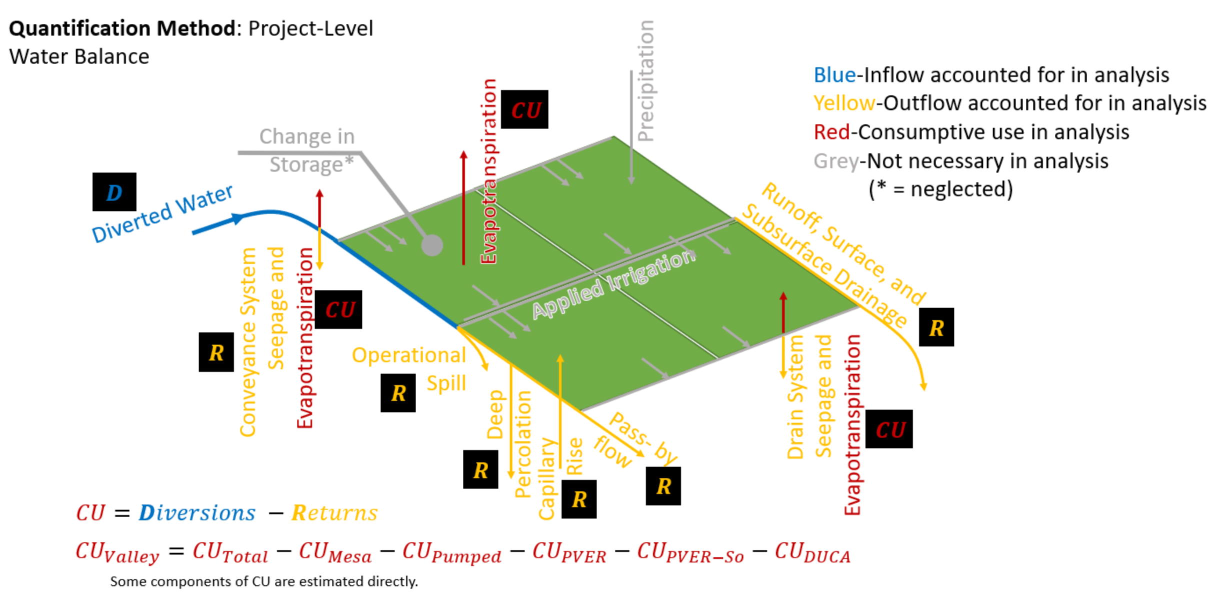
where the subscripts represent the respective CU component. The CU_{Total}, CU_{Pumped}, CU_{PVER}, $CU_{PVER\text{-}So}$, and CU_{DUCA} values are all provided by Reclamation (MWD, 2021b; Reclamation, 2021b). The CU estimates from Reclamation (2021b) are obtained from an academic journal article, Federal agency reports, a plan report (LCR MSCP, 2004), and sources to support assumptions made. Reclamation (2021b) opined that the assumptions made in these CU estimates were "conservative," in that the resulting CU was more likely to be overestimated than underestimated. In the case of CU_{Pumped}, the Blaney-Criddle Method is used to estimated ET (USGS, 2021a). CU_{Mesa} is assumed to be equal to the "…deliveries to the Mesa," from "…PVID records" (MWD, 2021b).

The CU reduction (ΔCU) for fallowing is effectively computed as:

$$\Delta CU = A_{Fallow}^{Toll}\left(\frac{CU_{Valley}}{A_{Irr}^{Toll}}\right)$$

where A is area, the superscript *Toll* indicates that the area is in terms of water toll acres (the area used in water assessments, which may differ from the net area irrigated), and the subscripts *Fallow* and *Irr* represent fallowed land and land irrigated, respectively. These calculations are performed on a monthly basis.

Figure 19 Simplified Representation of the Project-Level Water Balance Approach for Quantifying Consumptive Use Reductions for the Palo Verde Irrigation District Fallowing Program.



Fallowed Land Verification

As with other fallowing programs, the PVID fallowing program includes multiple verifications of fallowing practice. This verification includes the following tasks:

- Inspection of all fields in PVID's service area three times per year by PVID staff.
- Field verification by a representative of MWD that all participating fields are indeed fallowed.
- Field verification of a randomly selected five percent of the participating fields by Reclamation twice per year.
- Verification of field eligibility with each crop rotation.
- Maintenance of a spreadsheet by PVID to verify that the fallowed acreage balances on a daily basis.

In addition, the district's water order system flags fallowed fields so that no water orders are accepted, and no deliveries are allowed on fallowed fields.

Example CU Results

Two of the benefits of the quantification strategy used in this fallowing program are: 1) it is tied to the Reclamation Decree Accounting methods, and 2) it is relatively simple to execute (e.g., MWD, 2021b). The series of calculations necessary to compute ΔCU can easily be done in a spreadsheet (*Table 10*).

Table 10Consumptive Use Reduction Estimates for the Palo Verde Irrigation District Fallowing Program, 2020.

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
D_{PVID} (AF)[1]	35,240	44,410	37,460	69,840	91,680	92,910	102,300	96,870	81,800	61,260	39,160	39,130	792,060
D_{Pumped} (AF)[1]	81	102	139	150	183	222	243	233	183	154	109	107	1,906
R_{Meas} (AF)[1]	26,815	27,098	28,533	28,760	33,629	33,423	35,360	36,741	36,162	36,116	32,101	31,371	386,109
R_{Unmeas} (AF)[1]	2,846	3,624	4,448	6,065	5,866	6,632	7,307	7,357	6,684	5,427	2,735	2,781	61,772
CU_{Total} (AF)[1]	5,660	13,790	4,618	35,165	52,368	53,077	59,876	53,005	39,137	19,871	4,433	5,085	346,085
CU_{PVER} (AF)[2]	189	224	367	477	941	993	976	593	527	397	245	182	6,111
CU_{DUCA} (AF)[2]	3	3	7	14	23	25	26	24	18	12	5	1	161
$CU_{PVER\text{-}So}$ (AF)[2]	0	0	1	4	6	6	6	6	5	3	1	0	38
CU_{Pumped} (AF)[2]	47	59	81	88	107	129	142	136	107	90	64	62	1,112
CU_{Mesa} (AF)[3]	1,027	1,035	706	1,176	1,211	1,268	1,299	1,632	1,789	1,632	1,250	1,351	15,376
CU_{Valley} (AF)[4]	4,394	12,469	3,456	33,406	50,080	50,656	57,427	50,614	36,691	17,737	2,868	3,489	323,287
A_{Irr} (ac)[4]	76,484	76,484	76484	76,484	76,484	76,484	76,484	76,484	76,484	76,484	76,484	76,484	76,484
Valley CU Factor (AF/ac)[4]	0.06	0.16	0.05	0.44	0.65	0.66	0.75	0.66	0.48	0.23	0.04	0.05	4.23
A_{Fallow} (ac)[4]	10,376	10,376	10,376	10,376	10,376	10,376	10,376	10,376	10,376	10,376	10,376	10,376	10,376
ΔCU (AF)[4]	596	1,692	469	4,532	6,794	6,872	7,791	6,866	4,978	2,406	389	473	43,858

[1]From Reclamation (2021a). *D* is diversion, *R* is return, *CU* is consumptive use, *PVID* is Palo Verde Diversion Dam, *Pumped* is "…pumped from River…," *Meas* is measured, *Unmeas* is unmeasured, and *Total* is total.
[2]From MWD (2021b), see also Reclamation (2021b). CU is consumptive use, *PVER* is Palo Verde Ecological Reserve, DUCA is Dennis Underwood Conservation Area, PVER-So is Palo Verde Ecological Reserve South.
[3]From MWD (2021b) based on Palo Verde Irrigation District delivery records. *Mesa* refers to Palo Verde Irrigation District Mesa lands.
[4]From or based upon MWD (2021b).

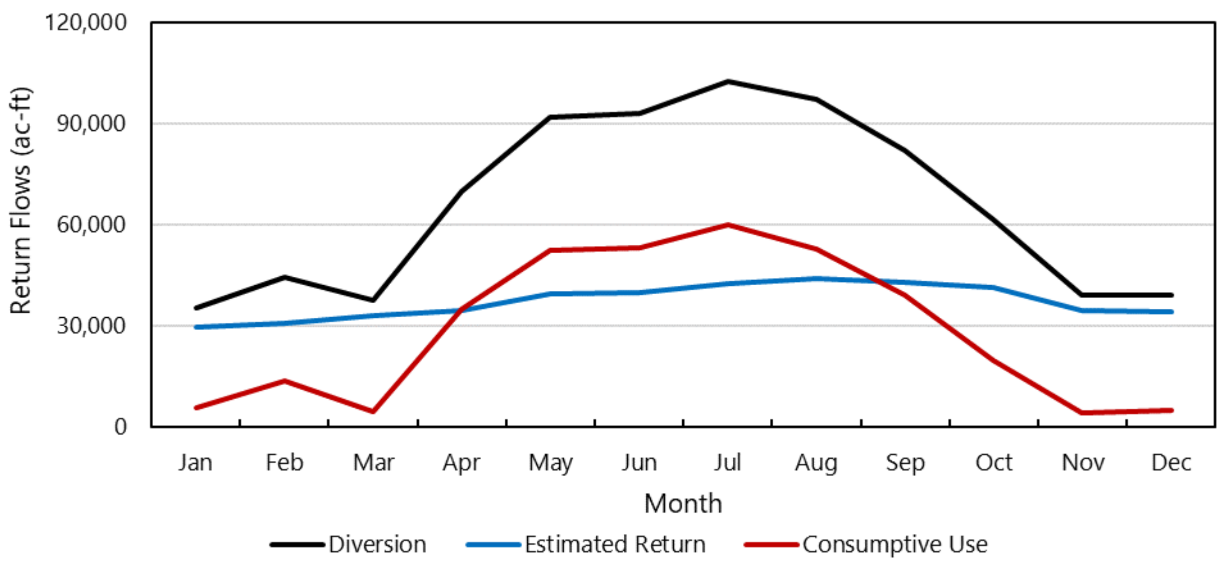
Discussion of Method Assumptions

The *ΔCU* method includes several assumptions, which are either explicit or implicit in the method. The primary assumptions are discussed below.

Assumption 1: There is no effective lag in the return flows.

This assumption was discussed previously in the *Discussion of Method Assumptions* section of the Bard Water District Seasonal Fallow Program case study analysis. Additional considerations for the PVID fallowing program are discussed here. For instance, the return flows from the PVER, PVER-South, DUCA, etc. are computed as diversion less estimated CU, the latter of which is estimated using methods described by Reclamation (2021b). This, of course, is assuming that the estimated fraction of unmeasured return flow is accurate for each month. Based on a plot of estimated diversions, returns, and CU for PVID in 2020, there is not clear, visual evidence of return flow lag, or lack of such lag (*Figure 20*). Because of the duration of the fallowing program (minimum one year per field), the effect of any lag may be dampened. As with other assumptions, this is a practical solution to a complicated problem.

Figure 20 Estimated Diversion, Return Flows, and Consumptive Use for PVID, 2020 (Reclamation, 2021a).



Assumption 2: The per-acre *ΔCU* for the fallow fields is similar to the CU for the Valley lands divided by the area irrigated during the fallow period.

This includes the assumption that crops, or at least CU, would be similar in the fallow fields, if irrigated, as it was in the non-fallowed areas of the Valley lands. Further discussion of this assumption has been provided in the *Discussion of Method Assumptions* section of the Bard Water District Seasonal Fallow Program case study analysis. Additional considerations for the PVID fallowing program are discussed here. For example, growers may also elect to fallow historically less productive land with challenging soils as communicated during the site visit.

For the PVID fallowing program, there is also the consideration of fallowable crops. Based on a crop report for 2020 from PVID (2021a), PVID served 94,057 total water toll acres in 2020

(*Table 11*). This included 2,054 acres of MSCP lands (e.g., PVER, PVER-So, and DUCA; CDFW, 2021; LCR MSCP, 2018, 2021a,b), 73 acres in fish ponds (likely related to the LCR MSCP), 3,436 acres of idle land, 10,796 acres of fallowed land, and 1,167 acres of permanent crops. The permanent crops included citrus, golf course, orchard, palm, and roses (PVID, 2021a). The 94,057 acres also includes the Mesa lands. According to PVID (2005) and Google (2021), it is apparent that the permanent crops are predominantly grown on the Mesa lands. Since the MSCP lands are accounted for by subtracting out CU_{PVER}, $CU_{PVER\text{-}So}$, and CU_{DUCA}, the associated MSCP land covers and fishponds can be neglected. This leaves a total of 90,763 water toll acres, if the 3,436 acres of "idle or diverted" land is also removed, the resulting area is 87,327 acres, which is not much greater than the total 86,860 water toll acres in the Valley lands from (MWD, 2021b). The difference could be related to possible non-permanent crops grown on Mesa lands (e.g., Google, 2021). Since it is apparent that the vast majority of the crops grown on the Valley lands are annual, and thus easily fallowed, the assumption that the crop mix would be similar on the fallowed lands, were they not fallowed, may be reasonable.

Table 11 Cropped Areas from Palo Verde Irrigation District Crop Report, 2020.

Description	Water Toll Acres		
	Gross Area	Adjustment for Double Cropping	Net Area
Field Crops, Annual	89,106	-15,997	73,109
Field Crops, Permanent	1,167	0	1,167
Vegetables	4,051	-2,781	1,270
Melons	2,167	-15	2,152
MSCP Habitat	2,054	0	2,054
Fish Ponds	73	0	73
Fallow	14,880	-4,084	10,796
Idle or Diverted	3,436	0	3,436
Total	116,934	-22,877	94,057

Source: PVID (2021a). Description names are directly from PVID (2021a) with exception of Annual and Permanent identifiers. MSCP is the Lower Colorado River Multi-Species Conservation Program.

Assumption 3: The reduction in ET from field ditches, canals, and drainage ditches resulting from fallowing is proportional to the fallowed land in comparison with the irrigated land in terms of water toll acres.

This assumption is discussed in the *Discussion of Method Assumptions* section of the Bard Water District Seasonal Fallow Program case study analysis.

Assumption 4: Water toll area is representative for use in per-acre CU quantification.

When computing per-acre CU, it is important to understand what acreage is being used. For the PVID program it is water toll acreage, or the acreage at which fields are assessed for water service. According to PVID, water toll acreage includes some non-cropped areas like access roads in the fields. This is somewhat different than the program's enrolled area, which was based on field delineations made relative to the California Environmental Quality Act and excludes some non-cropped areas (e.g., stack yards for hay). Furthermore, it is assumed that the water toll acreage is correct for all fields in the Valley lands (the water toll area for some PVID fields was known to be inaccurate in the past, based on communications from PVID and MWD representatives, May 26, 2021). The water toll area of the program fields was not reassessed prior to enrollment (i.e., for suspected errors). So, if any discrepancy exists between the field and water toll area, it is not accounted for in this quantification method.

Assumption 5: The CU from the fallowed fields (and possibly the irrigation and drainage ditches serving the fallowed land) is negligible.

This assumption is discussed in the *Discussion of Method Assumptions* section of the Bard Water District Seasonal Fallow Program case study analysis. However, a PVID-specific example is provided here. First, it should be recalled that in computing ΔCU, the evaporation from rainfall is not important, because the ΔCU of interest is that derived from irrigation water using the definition of Decree Accounting (*CU* is diversions less return flows). Furthermore, precipitation is small enough that it is generally negligible.

To illustrate this point, precipitation data were obtained for weathers stations used in Reclamation (2019b)[16]. The average annual precipitation for 2020 from the available records for the remaining stations was 2.6 inches, with a maximum daily value of about 0.6 inches. It is probable that all of this precipitation would be evaporated in the fallow fields. A portion of this precipitation would theoretically reduce irrigation water CU for the irrigated fields by about 2.6 inches either in the form of increased return flows or decreased irrigation application (plus any consumptive conveyance losses). Much of the portion of the 2.6 inches that did not offset irrigation water CU would likely be evaporated.

In addition, there would be some prolonged evaporation during the fallow period that would deplete soil water that had carried over from the previous irrigation season (Jensen and Allen, 2016), though this may be small in magnitude. The magnitude of evaporation would depend on the length of the fallow period, presence of crop residue, the soil water content at the initiation of fallowing, and field tillage operations including those used to kill weeds. The relative impact of any evaporation would be dampened the longer that a field were fallowed.

Assumption 6: The CU for the Mesa lands is equal to the water deliveries to the Mesa lands.

This assumption is basically that return flows are negligible from the Mesa lands. This would include an assumption that all irrigation inefficiencies related to those deliveries were consumptive. Because irrigation water is pumped to the Mesa lands (PVID, 2005), it is probable that conveyance losses (and the associated returns) between the PVID canals and those lands is negligible. Because the Mesa lands are predominantly permanent crops with pumped supply (PVID, 2005), it is possible that many of these crops are irrigated using sprinkler or drip irrigation. These Mesa lands likely have less return flows than the Valley lands based on these irrigation methods. However, a certain amount of deep percolation will be necessary for salt leaching. The water quality at the United States Geological Survey (USGS) station Colorado River Below Palo Verde Dam (No. 09429100) averaged about 0.95 deci-Siemens per meter between September 2020 and May 2021 (USGS, 2021b). Based on the commonly used leaching requirement equation of Rhodes (Suarez, 2012) and the salt sensitivities of lemons and oranges (Grieve et al., 2012), the leaching requirement could be as much as 15% - 17%

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[16] These included four NOAA climate stations (Ehrenberg, AZ, Blythe ASOS, CA, Blythe, CA, and Parker, AZ; NOAA, 2021a,b), two AZMET weather stations (Parker, and Parker #2; UA, 2021), and three California Irrigation Management Information System (CIMIS) stations (Blythe NE, Ripley, and Palo Verde II; CDWR, 2021). One of these stations (CIMIS Palo Verde II) had notably lower precipitation than the other stations and was, thus, excluded.

of applied irrigation water. Though notable, this is expected to be less than the deep percolation on the Valley lands based on a communication with A. Montazar (May 26, 2021). Because of distance, there is also expected to be a lag in the return of this leached water to the river that could be difficult to estimate.

General Accuracy of the CU Adjustments

The reductions made to the Decree Accounting CU so that it better represents Valley lands have varying levels of impact relative to the estimated CU_{Total} and CU_{Valley} (*Table 12*). For 2020, CU_{Valley} was about 93% of CU_{Total}. Therefore, the total adjustment for year 2020 was less than 7% of the CU_{Total}. Any uncertainty or error in the various adjustments would reasonably be less than the full magnitude of the respective adjustment. Therefore, any resulting error would be expected to be notably less than 7% of CU_{Total} and would probably be negligible. For example, if the leaching requirement adjustment of about 16%, as described in the previous paragraph, is multiplied by 4.4% (CU_{Mesa} relative to CU_{Total}), this would be about an 0.7% error relative to CU_{Total} (about an 0.8% error relative to CU_{Valley}). There are other uncertainties in measurements and estimates that are larger than this.

Table 12 Consumptive Use Adjustments for the Palo Verde Irrigation District, 2020.

Description		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
CU_{Total}[1]	(AF)	5,660	13,790	4,618	35,165	52,368	53,077	59,876	53,005	39,137	19,871	4,433	5,085	346,085
	% CU_{Total}	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
CU_{PVER}[2]	(AF)	189	224	367	477	941	993	976	593	527	397	245	182	6,111
	% CU_{Total}	3.3%	1.6%	7.9%	1.4%	1.8%	1.9%	1.6%	1.1%	1.3%	2.0%	5.5%	3.6%	1.8%
CU_{DUCA}[2]	(AF)	3	3	7	14	23	25	26	24	18	12	5	1	161
	% CU_{Total}	0.1%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%
$CU_{PVER\text{-}So}$[2]	(AF)	0	0	1	4	6	6	6	6	5	3	1	0	38
	% CU_{Total}	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CU_{Pumped}[2]	(AF)	47	59	81	88	107	129	142	136	107	90	64	62	1,112
	% CU_{Total}	0.8%	0.4%	1.8%	0.3%	0.2%	0.2%	0.2%	0.3%	0.3%	0.5%	1.4%	1.2%	0.3%
CU_{Mesa}[3]	(AF)	1,027	1,035	706	1,176	1,211	1,268	1,299	1,632	1,789	1,632	1,250	1,351	15,376
	% CU_{Total}	18.1%	7.5%	15.3%	3.3%	2.3%	2.4%	2.2%	3.1%	4.6%	8.2%	28.2%	26.6%	4.4%
CU_{Valley}[4]	(AF)	4,394	12,469	3,456	33,406	50,080	50,656	57,427	50,614	36,691	17,737	2,868	3,489	323,287
	% CU_{Total}	77.6%	90.4%	74.8%	95.0%	95.6%	95.4%	95.9%	95.5%	93.8%	89.3%	64.7%	68.6%	93.4%

[1]From Reclamation (2021a). *D* is diversion, *R* is return, *CU* is consumptive use, *PVID* is Palo Verde Dam, *Pumped* is "...pumped from river...," *Meas* is measured, *Unmeas* is unmeasured, and *Total* is total.

[2]From MWD (2021b), see also Reclamation (2019b). CU is consumptive use, *PVER* is Palo Verde Ecological Reserve, DUCA is Dennis Underwood Conservation Area, PVER-So is Palo Verde Ecological Reserve South.

[3]From MWD (2021b) based on Palo Verde Irrigation District delivery records. *Mesa* refers to Palo Verde Irrigation District Mesa lands.

[4]From or based upon MWD (2021b).

Reflections

Some of the notable benefits and challenges of the PVID program relate to the field areas that may be fallowed. From the grower's perspective, the fallowing program is designed to allow for a certain level of flexibility. This is because the PVID fallowing program allows for fractions of fields to be fallowed so long as fallowed areas are at least five contiguous acres. This allows growers to fallow portions of their fields that may be particularly problematic (e.g., because of soils, etc.). though there are some additional administrative efforts required by PVID to mark, measure, and maintain records on such sub-field areas.

A noted aspect of the program with regard to the fallowed area is that to help with fallowing enforcement, MWD required easements on some portion of the landowner's land equal to the land area of their commitment to the program. Thus, if a grower failed to comply with the fallowing call, MWD could legally forcibly fallow that area with the easement. This provision did require additional time, expenses, and effort to clear land titles at the onset of the program but was also viewed by some landowners as a benefit, as the cost for the title clean-up was borne by MWD.

In addition to the considerations relating to the program area, the program also requires a notable amount of local administrative effort. The effort is such that PVID has hired a full-time staff member to help MWD administer the program (MWD pays PVID for their administrative role to help manage the program).

Finally, it is notable that the PVID fallowing program fills an important role from the standpoint of water leases. This is because, like the Bard Water District, PVID has an unquantified water right. Meaning that the PVID water users have the right to irrigate a certain amount of land, rather than a right to a specified volume of water. Therefore, the only means of leasing water to other users, e.g., MWD, is through a program where a conservation practice, like fallowing, is implemented and the ΔCU is used to quantify the amount of water that can be leased. Thus, as with other programs, the accuracy of the ΔCU is of importance to all parties involved.

Palo Verde Irrigation District Moderate Deficit Irrigation of Alfalfa Program

In late 2018, a deficit irrigation experiment in PVID's service area was initiated by researchers with the University of California (UC) Division of Agriculture and Natural Resources, UC Davis, and the U.S. Department of Agriculture Agricultural Research Service (USDA ARS). The purpose of the study is to measure the impacts on applied irrigation water, CU, yield, yield quality, soil salinity, and alfalfa plant stand of what has been termed by the researchers as "moderate" deficit irrigation during the summer months (Montazar et al., 2020). The results for the first year or so of the study were published by Montazar et al. (2020), from which the information in the following two paragraphs were taken, unless otherwise cited.

The deficit irrigation strategy in the study is to eliminate one to three irrigation events during the summer (July – September). The number of irrigation events omitted depended upon the irrigation method (border or furrow) and treatment. The summer months were targeted because of the lower crop productivity and water use efficiency (crop production per unit water consumed) relative to other times of the year (A. Montazar, communication, May 26, 2021).

The project, which continues to late December 2021 (A. Montazar, communication, May 26, 2021), is being conducted in four surface irrigated alfalfa fields, which were planted late in 2018. The fields are paired by irrigation method (two border and two furrow, with examples shown in *Figure 21* and *Figure 22*, respectively). The treatments are tailored to the irrigation method. Border irrigation treatments include omitting one and two irrigations, respectively. Furrow irrigation treatments involve omitting two and three irrigations, respectively. There were more irrigations per season for furrow irrigation than border during the study period (Montazar et al., 2020). Each field also includes a section (or multiple sections) irrigated according to the grower's convention.

Figure 21 Photo of a Border Irrigated Study Field (credit, B. Barker).

Figure 22 Photo of a Furrow Irrigated Study Field (credit, L. Perkins).

Technical Analysis

A technical analysis of the PVID deficit irrigation case study is presented in the following sections.

CU Quantification Methods

The researchers are quantifying CU using micrometeorological techniques (TM2) for four study fields. Therefore, this case study differs from the other considered case studies in scope and CU method intensity. Where the other case studies include practical application of conservation measures at a district-level and ΔCU estimation methods based on available data, the PVID deficit irrigation study is a relatively small-scale (field-level) research project specifically using state-of-the-science methods to quantify ET (and thus CU).

CU is quantified as ET in this study using eddy covariance and surface renewal micrometeorological techniques without the need for a water balance analysis (*Figure 23*). These research-grade methods are subject to errors and uncertainties (as are all measurements of ET). These methods are based upon high-frequency meteorological measurements, rather than models, and for the purposes of the present discussion will be referred to as observation methods.[17] Eddy covariance is a common method for estimating ET. Surface renewal, which involves less equipment and less effort to analyze has traditionally been calibrated to eddy covariance sites (e.g., Snyder et al., 1996). Such is the case in the present study (A. Montazar, communication, May 26, 2021). An evaluation of these particular methods is not pursued here. A brief description of each was provided in TM2, which also includes pertinent literature with additional detail on each method.

In this deficit irrigation study, an eddy covariance system (consisting of a sonic anemometer, a net radiometer, and three soil heat flux plates) was installed in the area of each field treated according to the grower's irrigation convention, as shown in *Figure 24* (A. Montazar, communication, May 26, 2021). The systems do not include a gas analyzer or a hygrometer (to measure water vapor). ET is, therefore, computed using the energy balance (Montazar et al., 2020; TM2). These eddy covariance systems are also equipped with fine-wire thermocouples for surface renewal measurements. Paired with the eddy covariance systems are a suite of other sensors. These additional sensors are beneficial to the research, but not directly used for ET estimation, with the exception of a second surface renewal system. This second surface renewal system is a commercial product by Tule Technologies, Inc. These commercial surface renewal systems are also located in the individual deficit irrigation treatment areas and will be used by the researchers to quantify ET for the deficit treatments (A. Montazar, communication, May 26, 2021). The equipment in the grower-convention treatment areas will be used to develop surface renewal adjustments to be applied to the deficit irrigation surface renewal systems.

[17] These methods are not direct ET measurement methods, but rather are methods used to estimate ET based on meteorological measurements, atmospheric physics, and certain assumptions.

Figure 23 Simplified Representation of the Consumptive Use Quantification Approach for the Palo Verde Irrigation District Deficit Irrigation Project.

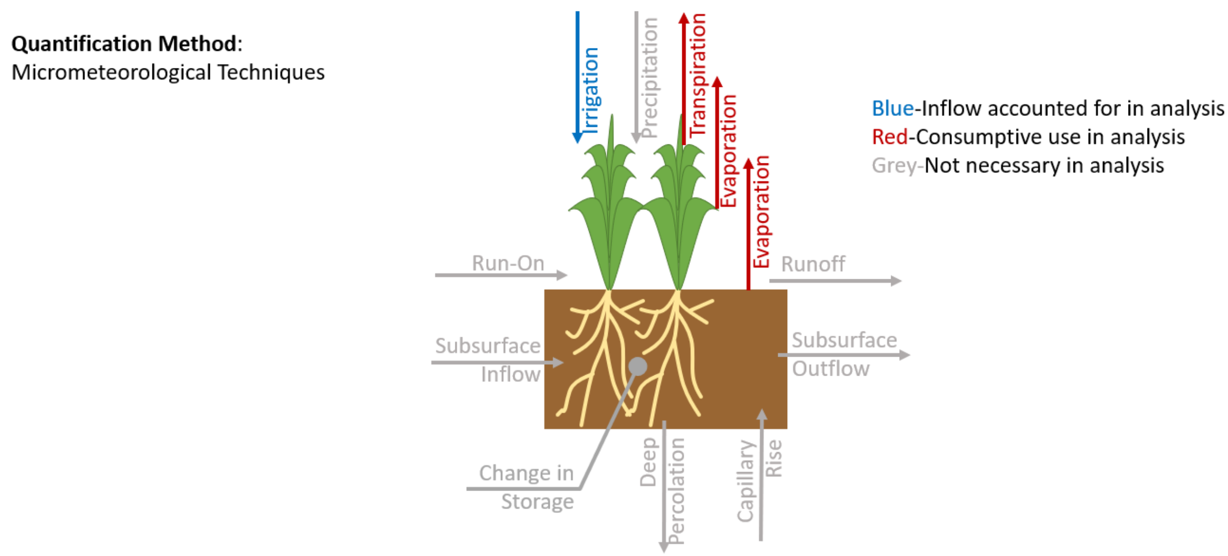


Figure 24 Photo of Eddy Covariance, Surface Renewal Systems and Other Monitoring Equipment (credit, B. Barker).

Applied Water Measurement Methods

A primary measure of water conservation being analyzed and reported by the researchers is the reduction in applied water. This is quantified using PVID records of farm turnout volumes for the study fields (A. Montazar, communication, May 26, 2021). According to a PVID staff member (May 26, 2021), PVID measures farm turnout deliveries at the turnout gate four times per day. The gates are fabricated by PVID and are uniform in dimension. The gates (or a representative gate) have been calibrated for orifice flow measurement.

Yield Measurements

Another primary measure of water conservation being analyzed and reported by the researchers is the change in yield resulting from the deficit irrigation treatments. Yield was measured by collecting samples within a sample frame from 12 locations in each treatment (Montazar et al., 2020). The purpose of these measurements is to relate the change in yield to the change in irrigation and ΔCU (A. Montazar, communication, May 26, 2021). However, as demonstrated in TM2, yield and ET are related, particularly for crops like alfalfa, where the yield is the crop's biomass. Therefore, changes in yield would be expected to be related to changes in CU.

Project End Products

In addition to the scientific knowledge regarding the impacts of this deficit irrigation method, the primary anticipated end product of the study will be an NRCS published conservation practice (A. Montazar, communication, May 26, 2021). This practice will include a mathematical function relating decreases in applied irrigation water (ΔI) from the deficit irrigation practice to impacts in yield (ΔY):

$$\Delta Y = f(\Delta I)$$

where the notation $f(\Delta I)$ simply indicates that ΔY is function of (or related to) ΔI, which function has not been published as of the writing of this document.

In addition to the yield impact vs. ΔI relationship, the relationship of ΔY to ΔCU will be published based on the research (A. Montazar, communication, May 26, 2021):

$$\Delta Y = f(\Delta CU)$$

Ultimately, it may be possible to approximate ΔCU based upon ΔI, but such a relationship would be specific to the irrigation practices of the grower, the soils, and other field conditions (alfalfa stand vigor, disease, and insect pressure, etc.) of each individual alfalfa field in PVID.

Replication and Statistics

One strength of this research study is the replication and possible application of statistical analyses to assess the difference in CU between treatments. It is unknown what statistical tests will be employed by the researchers in their final analyses but, depending on how treatments are defined, the researchers will have three or four replications for each imposed irrigation treatment. This replication and the possible statistical analyses are a benefit of this type of study. The other case studies, which are district-level in nature, do not lend themselves to the use of statistical analysis to test differences in CU. However, such is not practically necessary in those cases. Deficit irrigation, on the other hand, does not lend itself to the relatively simple water balance quantification methods that are employed, for example, in the fallowing cases. Therefore, statistical rigor is important in the development of ΔCU quantification methods for deficit irrigation. It should be acknowledged that, as with some other ET observation methods, micrometeorological measurements are relatively expensive to employ and the size of field plots necessary for this type of study are relatively large. Both of these factors affect the number of replications possible in this type of study.

Since the study is not finished and final statistical tests have not been performed nor provided by the researchers, no further discussion or example results are provided here regarding statistical measures of this case study.

Example CU Results

The full research datasets have not been fully collected or analyzed as of the writing of the present document. However, some initial results were published by Montazar et al. (2020) and other results were provided by A. Montazar for inclusion in this case study.

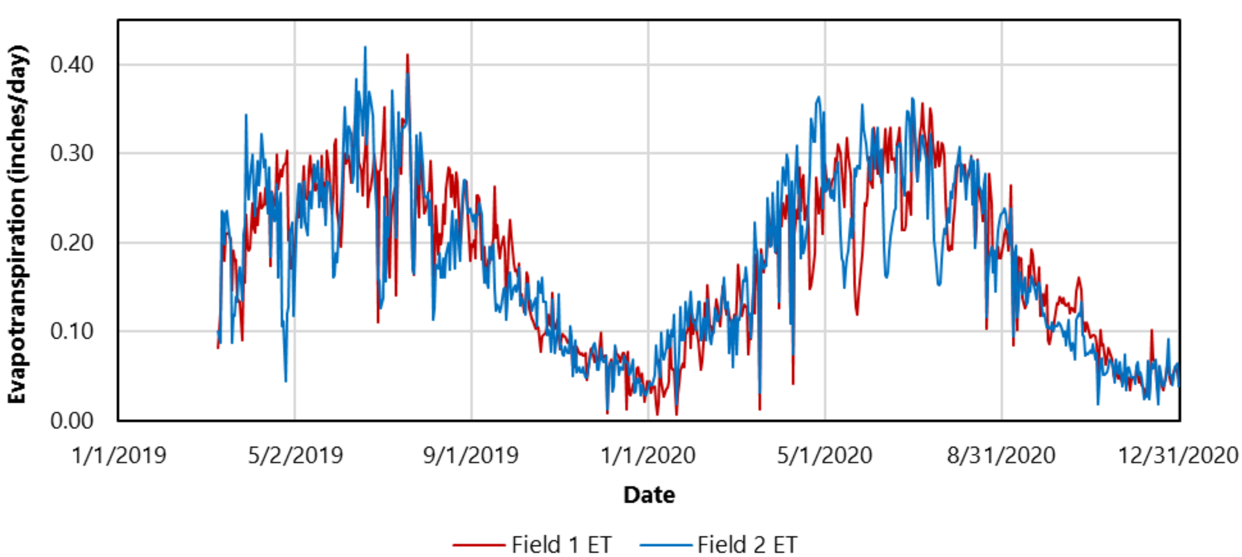
The researchers provided ET results for the grower-convention treatment for two irrigated fields (one furrow irrigated and one border irrigated). Data for the deficit irrigation treatments will be published by the researchers at a later date. Therefore, the present case study analysis does not include an analysis of ΔCU resulting from the conservation practice. However, anecdotally, A. Montazar communicated (May 26, 2021) that the magnitude of ΔCU had been observed to be about 1.8 to 2.0 inches (or 0.15 to 0.17 AF/ac) annually. This anecdotal result is not a final value and is presented for illustrative purposes only.

For the grower-convention irrigation treatment, daily observed ET (ET_{obs}) ranged from near zero to over 0.4 inches per day for the two fields over the period of March 11, 2019 – December 31, 2020 (*Figure 25*). Montazar et al. (2020) also reported ET_{obs} as a ratio of reference ET (ET_o)[18]. Such a ratio is instructive because it is similar to what is referred to as a crop coefficient (K_c) in the common reference ET/crop coefficient modeling method:

$$ET_c = ET_o K_c$$

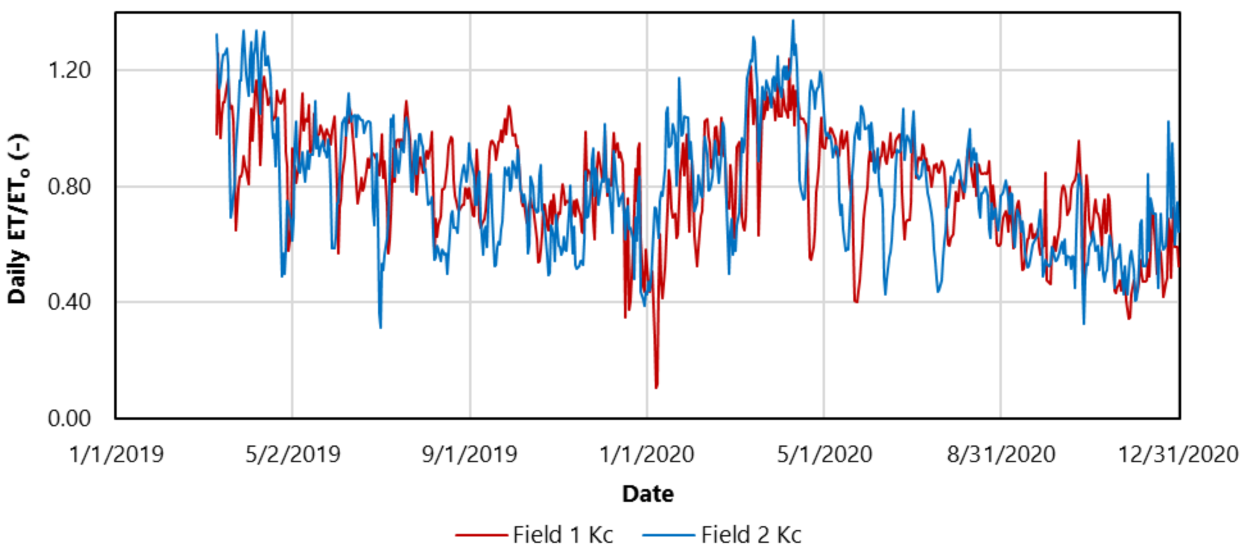
where ET_c is modeled crop ET (TM2; Jensen and Allen, 2016). Therefore, reporting ET_{obs}/ET_o allows for comparison with published K_c values. The latter typically represent conditions of minimal crop stress (TM2), and the former would include any effects of crop stress as discussed by Montazar et al. (2020). The researchers provided ET_{obs}/ET_o for 2019 and 2020. The ET_{obs}/ET_o values have seasonality, reaching their largest values in the spring months (*Figure 26*).

Figure 25 Daily Observed Evapotranspiration (ET) for the Grower Convention Irrigation Treatment for Two Research Fields for March 11, 2019 – December 31, 2020.



[18] Refer to TM2 for a discussion regarding reference ET.

Figure 26 Daily Observed Evapotranspiration (ET) Divided by Short Reference Evapotranspiration (ET_o) for the Grower Convention Irrigation Treatment for Two Research fields for March 11, 2019 – December 31, 2020.



K_c values for the Lower Colorado River Accounting System (LCRAS) were developed by Jensen (1998) and later refined by Jensen (2003). Jensen (1998), in acknowledgement of the fact that alfalfa ET may be less than represented by published K_c values[19], multiplied his alfalfa K_c values by 85% to better represent production field conditions. The later revisions by Jensen (2003) presumably maintained this type of adjustment but the revised alfalfa K_c values had greater peak magnitudes than those presented by Jensen (1998). Jensen's (2003) K_c values[20] for the "Parker-Palo Verde Area" were compared to the 2020 daily ET_{obs}/ET_o (*Figure 27*). The Jensen (2003) K_c magnitudes were similar to the observed values in the spring and early summer months but deviated from the observed in the later summer and fall (*Figure 27*). This observation is independent of the fact that the cutting periods used by Jensen (2003) differ from the observed cutting times in the study fields. It is apparent that both magnitude and K_c timing would need to be modified to better match the observations. Montazar et al. (2020) also discussed the fact that mean ET_{obs}/ET_o values for 2019 were also less than some published K_c values.

The total annual ET_{obs} for the grower-convention treatment in 2020 was about 61 inches in both fields (*Figure 28*). For comparison in the present discussion, Jensen's (2003) K_c values (*Figure 27*) were used to compute ET_c. In this computation, the average of available AZMET and CIMIS reported daily ET_o for stations used by Reclamation (2019b) in *Lower Colorado River Annual Summary of Evapotranspiration and Evaporation* were used (UA, 2021; CDWR, 2021). The calculated annual alfalfa ET_c for the area was estimated to be about 67 inches for 2020. This approximately 10% difference between the observed and modeled annual total ET can be used as an example of the obvious benefits of ET measurement methods over models. However, the expense, expertise, and effort required to make the observations make them impractical for many conditions outside of research.

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[19] Jensen's (2003) justification included the citation of Hill et al. (1983).

[20] The K_c for February 29, 2020 was assumed to be the same as February 28 and March 1 (which were equal), because the Jensen (2003) values were for a non-leap year.

Figure 27 Daily Crop Coefficients (Kc) from Jensen (2003) and from Observed Evapotranspiration Divided by Reference Evapotranspiration from Two Research Fields for 2020.

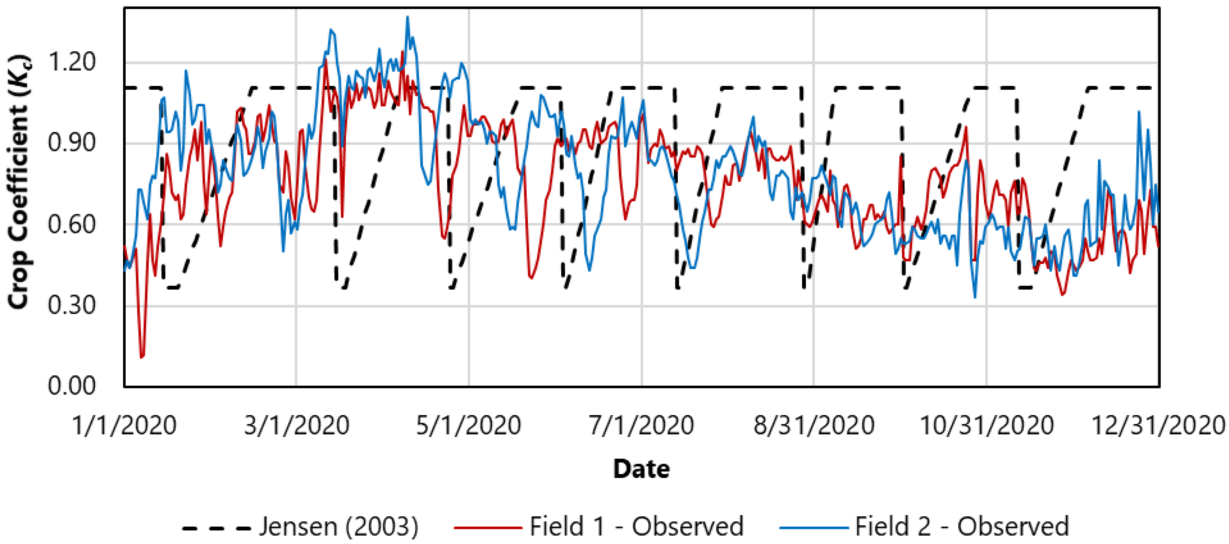
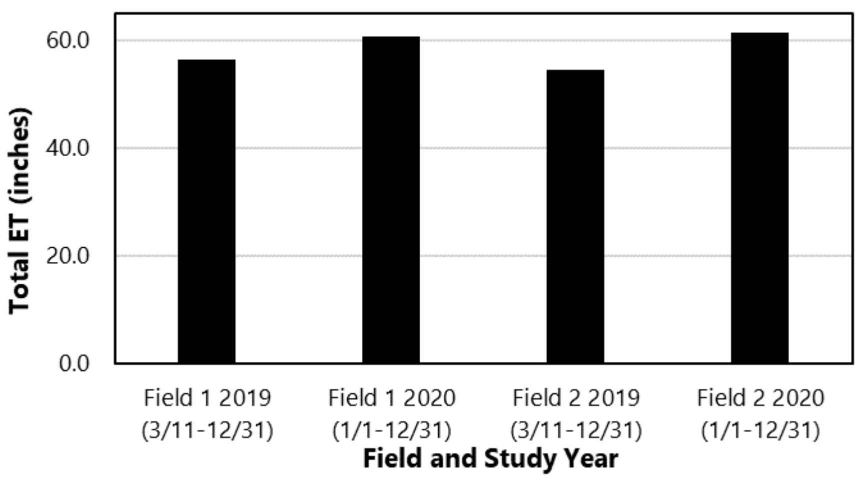


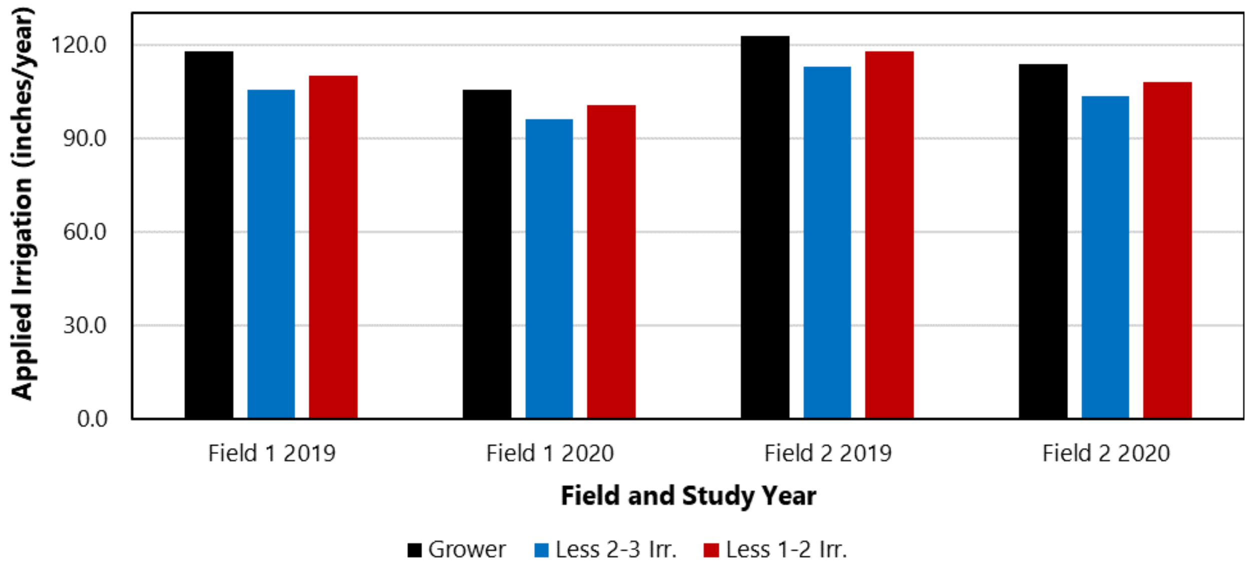
Figure 28 Total Observed Evapotranspiration (ET) for the Grower Convention Irrigation Treatment for Two Research Fields for a Partial Year in 2019 and all of 2020.



Applied Irrigation Water

As mentioned, the research study includes the quantification of reductions in applied irrigation water resulting from deficit irrigation. The reductions in irrigation water ranged from 4.6 to 12.5 inches less than the grower convention per season, depending on the year and season (*Figure 29*).

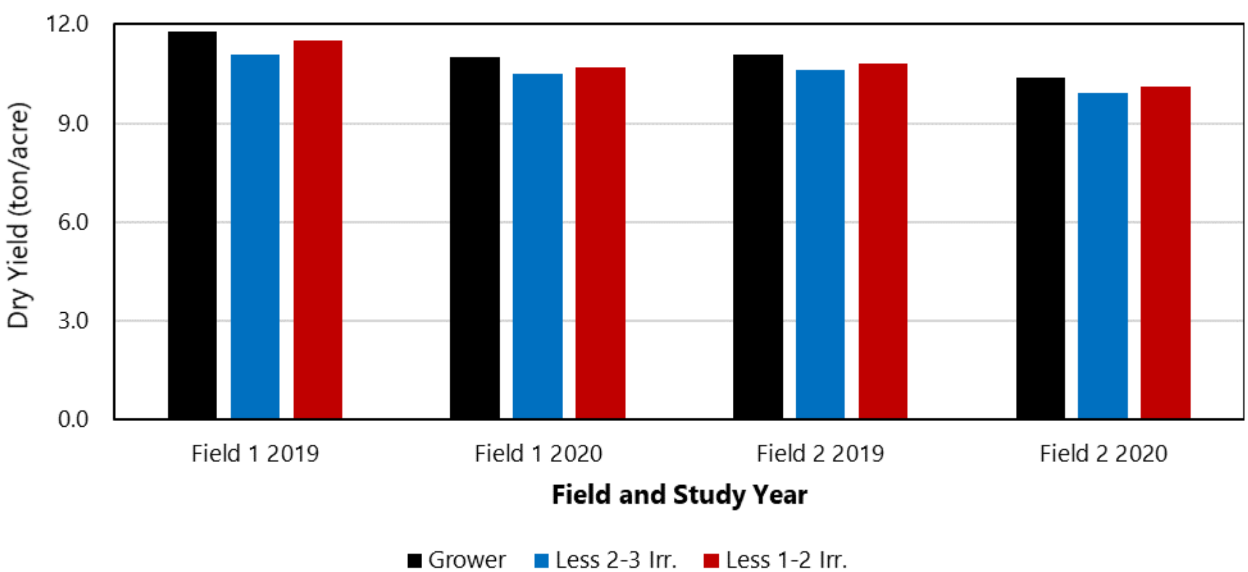
Figure 29 Seasonal Total Applied Irrigation Water for Study Treatments in Two Research Fields for 2019 and 2020.



Crop Yield

A final example result related to *ΔCU* from the study is the impact on yield. As expected, the crop yield appears, visually, to decrease with decreasing irrigation (*Figure 30*). However, it should be noted that the results as presented here do not include statistical tests of difference.

Figure 30 Seasonal Total Dry Yield for Study Treatments in Two Research Fields for 2019 and 2020.



Discussion of Method Assumptions

The *ΔCU* methods used include several assumptions based on the methods used. Some of these assumptions are discussed in the following paragraphs.

Assumption 1: Assumptions of the micrometeorological techniques.

All micrometeorological techniques include certain assumptions that enable the methods to be used to estimate energy fluxes (energy transfer rates per unit ground surface area) and subsequently ET. These assumptions may include the concept that energy transfer is vertical only, and in the case of eddy covariance, that the measurement is made in the proper layer of the atmosphere. It is beyond the scope of the present discussion to consider all of these assumptions. However, it is useful to address the fact that they exist and that, to varying extents, these assumptions impact the accuracy of the measurements. As the only truly more accepted methods for measuring ET include weighing lysimeters, which include vastly greater resources to install and operate, the assumptions and uncertainties associated with micrometeorological techniques are generally accepted by ET researchers.

Assumption 2: The measurement systems have adequate measurement footprints.

All micrometeorological techniques are sensitive to the effects of the land surface of some upwind area, known as a footprint or fetch. The measurement footprint is dependent upon the instrument height and wind speed and direction, among other things (Hsieh, 2000). In the case of the research study, the Tule Technologies surface renewal systems will have a smaller fetch distance than the eddy covariance system and the surface renewal measurements made with that system. This is because the Tule Technologies measurements are located much nearer to the ground. The treatment plots within the study fields are arranged as long strips, running the full field length in the direction of the irrigation application with a shorter dimension (~ 200 feet; A. Montazar, communication May 26, 2021) perpendicular to the irrigation direction (Montazar et al., 2020). It is expected that the fetch will be more sufficient when wind directions are generally parallel to the length of the plots than when wind directions are parallel to the width of the plots. However, because treatment differences are not expected to be large (per communication from A. Montazar, May 26, 2021), and since the measurements are more sensitive to areas relatively near the station than those further away, this may have a small effect. It is particularly expected the Tule Technologies systems will be more likely to have adequate fetch. The footprints are also expected to be shorter (nearer to the measurement station) when the alfalfa is tall than when it has recently been cut (Hsieh, 2000).

Assumption 3: The turnout gate measurements are representative.

The researchers used the PVID records of applied water for the research, rather than making an independent applied water measurement. This was done because the PVID measurements were deemed sufficiently accurate and also to avoid the contention that could arise should the researchers measure a slightly different application rate (A. Montazar, communication, May 26, 2021). This is a practical consideration, as the proposed deficit irrigation practice will likely be adopted by local growers in the near future. However, as with the other case studies, there can be a trade-off between practicality and accuracy.

For example, possible errors could exist if the gate itself or the flow conditions during application differ from those used during the calibration. It is also helpful to understand that any flow measurement will be subject to the precision and accuracy of the method. In this case, the water head measurement at the gate is subject to a certain precision that in turn affects the precision of the flow measurement. Finally, it is also possible that the flow conditions at the measurement times will not be representative of the flow conditions throughout the day. Taking four measurements per day is an attempt to address this concern.

General Observations

There could be some concern under a deficit irrigation program that the CU reductions may be reduced by the need for additional irrigation after resuming irrigation. This could occur in the case where the crop depleted the soil water during the no-irrigation period and then the grower applied additional water to ensure the soil water was replenished. Because the irrigation timing and duration for all treatments are based on the grower-convention part of the field, it is not expected that additional "make-up" water would be applied to the deficit irrigated treatments. Furthermore, it has been observed by A. Montazar (communication May 26, 2021) that there is typically some "overirrigation" during regular events such that it is unnecessary to apply additional water to compensate for extra depleted soil water during the deficit irrigation period.

It is also helpful here to discuss the general applicability of the results of this study. As mentioned, the results of this study will be in the form of functions relating ΔY to ΔI and ΔCU, respectively. It was also speculated above that these relationships could be used to relate ΔCU to ΔI. These relationships will have been developed under the irrigation practices and growing conditions (soils, climate, crop vigor, and health) of PVID and will best represent the study conditions. The researchers will be in the best position to recommend the application conditions of these results. The relationship between ΔY and ΔCU may be expected to be less location-dependent than the ΔY to ΔI relationship. Among other things, this is because the latter is dependent upon the application efficiency, which would vary from location to location and field to field. The ΔY and ΔCU relationship is basically a water use efficiency and may be transferable to areas with similar climate and growing practices. However, such relationships are dependent upon many factors and are still subject to limited transferability (Steduto et al., 2012).

Reflections

Since this case study is really a review of a research study, some of the lessons learned and reflections are different in nature than the other case studies. For example, the primary observation is that the quantification methods used in this study are essentially limited to research settings. The end product relationships (relating ΔY to ΔI and ΔCU), however, are intended for wider application. In such a program, the grower would record and report applied irrigation water quantities and changes in soil water measured by sensors (A. Montazar, communication May 26, 2021).

The applicability of this type of program and any ΔCU quantification relationship that may be developed are important because estimating ΔCU by district water balance or other methods used in the fallowing programs, is not a feasible approach for deficit irrigation. As mentioned, the ultimate end product of this research will be an NRCS conservation practice or guide.

Colorado River Indian Tribes Fallowing Program

The Colorado River Indian Reservation (CRIR) was created in 1865 by the Federal Government for the Indians of the Colorado River and its tributaries. Initially, these were the Mohave and Chemehuevi people, but Hopi and Navajo people were relocated to the Reservation in 1945. The Mohave, Chemehuevi, Hopi, and Navajo Tribes, are collectively, the CRIT. The CRIR is located on both sides of the Colorado River in western Arizona and eastern California, with most of the land in Arizona, as shown on *Figure 31*. The Colorado River Irrigation Project (CRIP), a federal irrigation project operated by BIA, serves approximately 80,000 acres of irrigated farmland, and is located entirely within CRIT's Arizona lands. Small CRIR parcels (in both Arizona and California) receive water by direct pumping from the Colorado River.

Starting in 2016 and continuing to present, CRIT have participated in system conservation (SC) programs to create conserved water for storage in Lake Mead. These include:

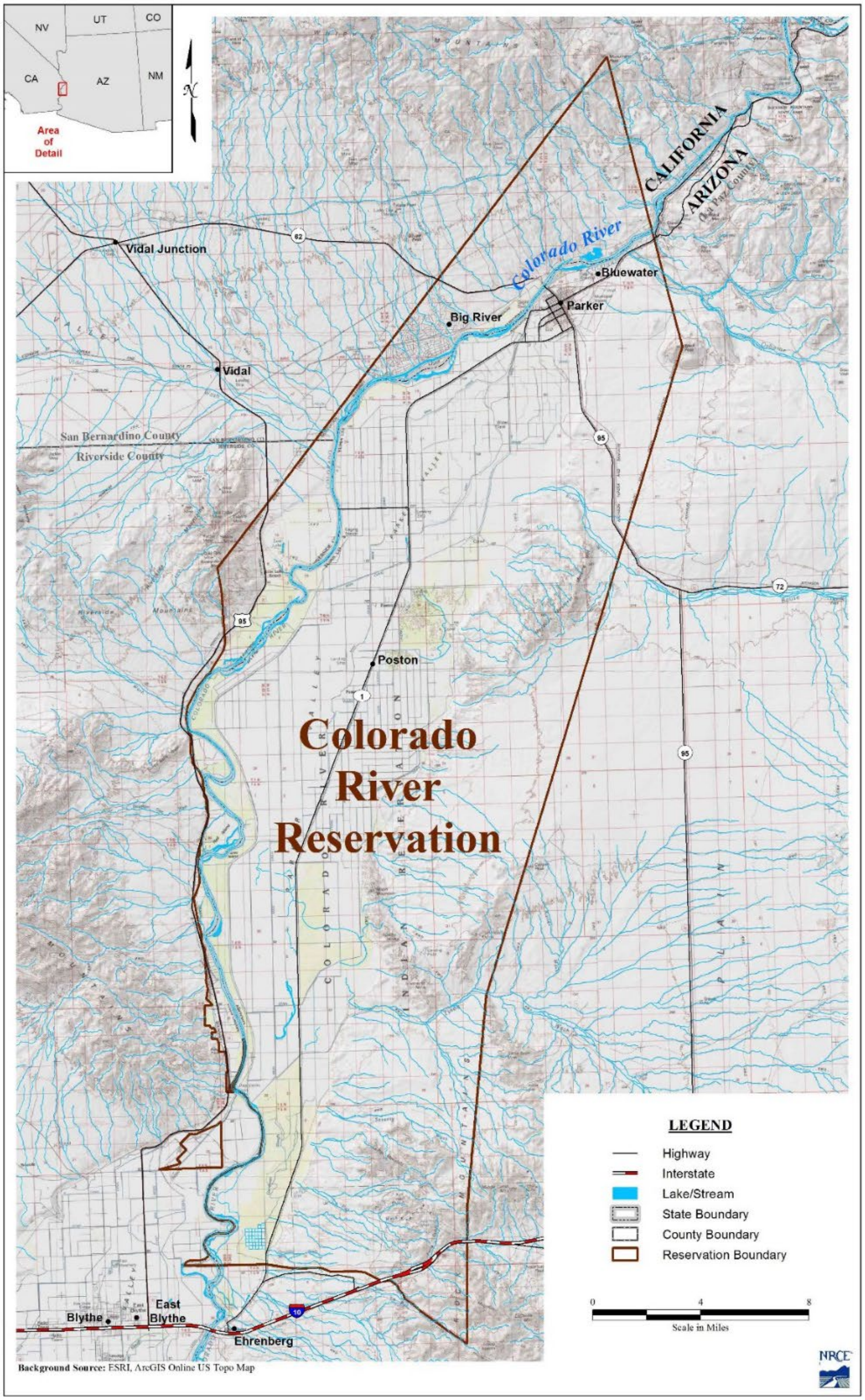
- The Pilot System Conservation Program (PSCP) established by Reclamation, the Central Arizona Water Conservation District (CAWCD), MWD, the Southern Nevada Water Authority (SNWA), and Denver Water[21] (later amended to include the Walton Family Foundation through the Environmental Defense Fund as a third-party contributor).

- CRIT's three-year (2020-2022) System Conservation Agreement (SC Agreement) with Reclamation, the Arizona Department of Water Resources (ADWR), and CAWCD under the State of Arizona's Drought Contingency Plan (DCP). Under this agreement, CRIT has agreed to create 50,000 AFY of CU savings to be stored in Lake Mead as system conservation water during each of the three years of the agreement. Any CU reduction in excess of the 50,000 AFY will be credited to CRIT as Extraordinary Conservation Intentionally Created Surplus (EC-ICS) and stored in CRIT's EC-ICS account in Lake Mead.

Conserved water in each case has consisted of CU reductions due to temporary fallowing of irrigated cropland on CRIT's Arizona lands. By the end of CRIT's current system conservation agreement (end of CY2022), CRIT will have created a total of 214,708 AF of CU savings for storage in Lake Mead. Of this amount, 195,329 AF will be system conservation water and 19,379 AF will be CRIT EC-ICS water. In all instances, except for the creation of EC-ICS, CRIT will have been compensated for its CU reductions under the various system conservation programs in which they have participated.

[21] https://www.usbr.gov/lc/region/programs/PilotSysConsProg/pilotsystem.html

Figure 31 Map of Colorado River Indian Reservation[22].



[22] Additional Sources: California Department of Forestry and Fire Protection, BIA, BLM, CRIT, Arizona State Land Department, Arizona Land Resources Information, USGS NHD, State of Arizona, U.S. Census Bureau, and/or State of California, California Spatial Information Library.

Technical Analysis

A technical analysis of the CRIT fallowing case study is presented in the following sections.

CU Quantification Methods

The primary method used to quantify changes in CU for the CRIT program is the reference evapotranspiration/crop coefficient method (TM2). In each of the water conservation activities in which CRIT has participated, the same methodology has been used to estimate crop CU. The following is summarized from pre-implementation reports provided by CRIT regarding their fallowing programs for system conservation and creation of EC-ICS during Calendar years 2020 and 2021 (NRCE, 2019; NRCE, 2020). *Figure 32* is a map of the CRIR and the locations of fallowed field parcels in the first year (2020) of the SC Agreement.

Field parcels being fallowed were required to have been in active irrigated crop production for at least four of the previous five years (study period) prior to being included in either program. In almost all instances, parcels fallowed had a full five-year irrigation and cropping history and the crop CU was estimated for the full five-year history. On each farm unit, the cropping patterns—meaning the crop type and acreage—for the previous five years were determined by field surveys conducted by the CRIT Water Resources Department[23] and entered into a geographic information system (GIS) database allowing spatially referenced mapping and determination of net irrigated area of each crop.

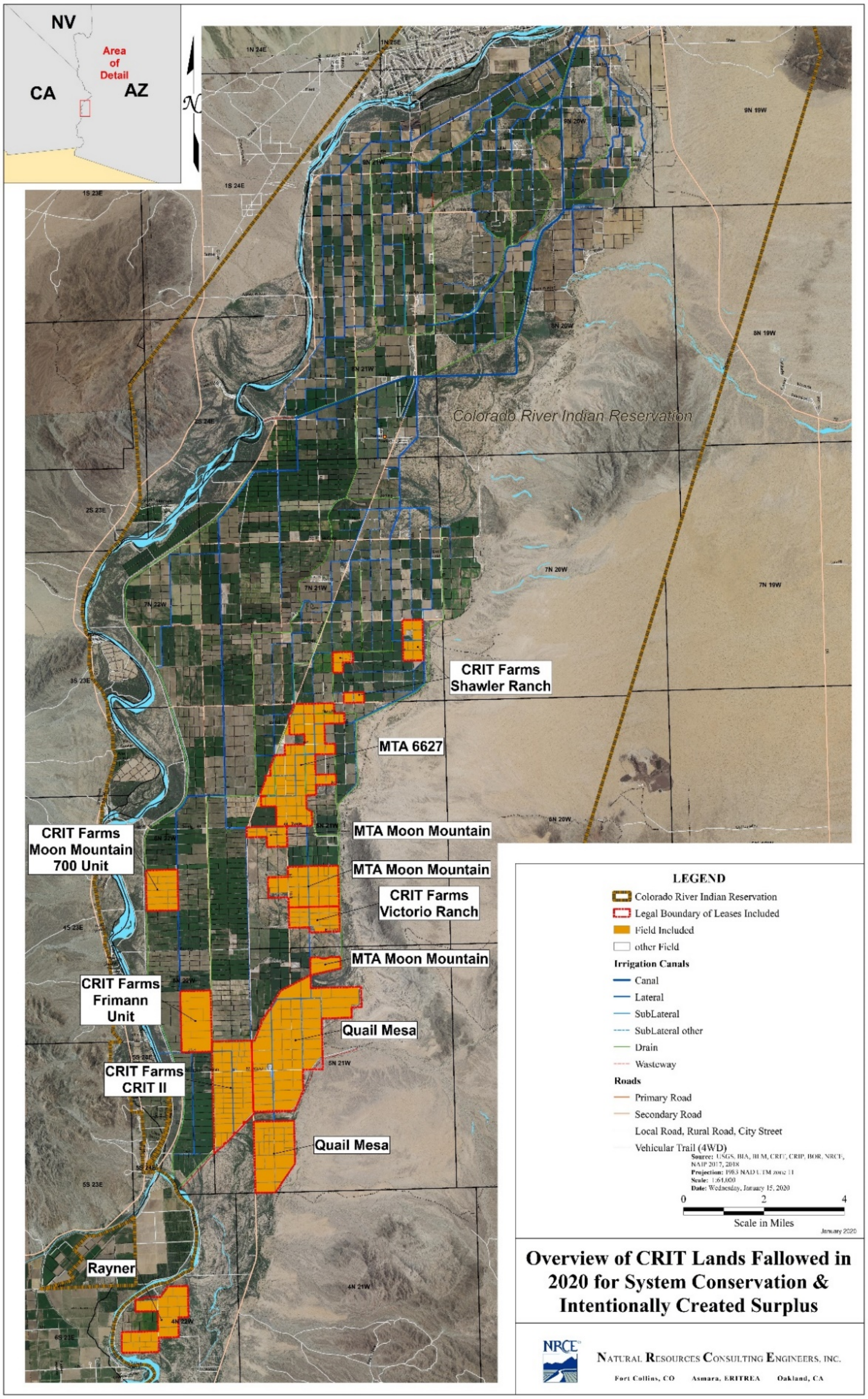
The ET of each crop was computed using the single (mean) crop coefficient-reference ET approach. In this method, reference ET was computed using the ASCE Standardized Reference Evapotranspiration Equation for short reference crop (ASCE, 2005; Jensen and Allen, 2016) and daily weather data collected at one or more local AZMET electronic weather stations operated by the University of Arizona (UA, 2021).

Daily crop coefficients developed by Jensen (1998, 2003) for Reclamation's LCRAS for the Parker Valley were used. Daily crop ET is computed as the product of reference ET and the crop coefficient for that day. Growing season durations of the various crops are implicit in the daily crop coefficients prepared by Jensen (1998, 2003) and were adopted for this analysis.

This method results in daily crop ET estimates for crops growing under ideal, pristine conditions and not short of water, and in some cases, has been termed "potential" crop ET (see TM2). Jensen (1998) recognized that alfalfa crop ET by this method was higher than local estimates and attributed the differences to water and other stresses, delayed baling and removal of hay bales, and other factors, and applied a factor of 0.85 to the alfalfa hay coefficients to obtain more realistic estimates of actual alfalfa ET in the LCRB. Jensen did not adjust crop coefficients for other crops. CRIT used the results from two regional studies that estimated actual crop ET by remote sensing (Clark et al., 2008 at Imperial Irrigation District (IID)); El Haddad and Garcia, 2014 at PVID) to adjust "potential" crop ET estimates from the crop coefficient-reference ET approach. This was done to avoid overstating the actual CU reductions due to temporary fallowing.

[23] With the exception of CRIT's first pilot system conservation implementation agreement when field crop survey data for 2013 were not available and the 2013 cropping pattern on the fallowed farm unit was estimated using the United States Department of Agriculture's (USDA's) National Agricultural Statistics Service Cropland Data Layer (CDL) (NASS, 2010-2015).

Figure 32 Map of Colorado River Indian Reservation and Location of Fallowed Parcels in 2020.



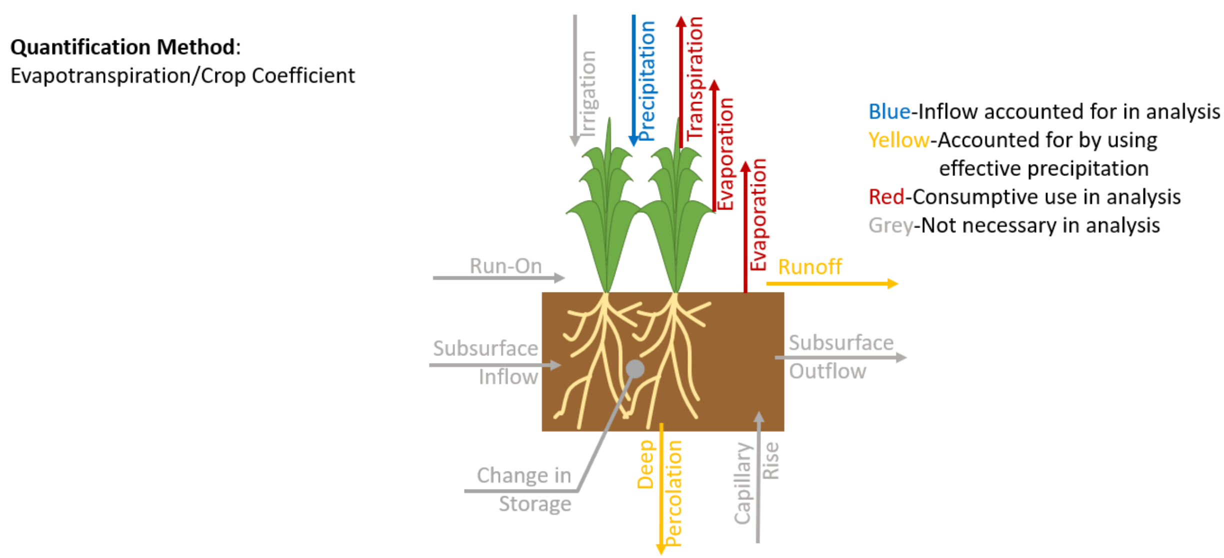
Net crop CU (of applied irrigation water) was computed by subtracting the effective precipitation (the portion of total precipitation that is effectively used by the crop in the ET process) from the crop ET estimates (e.g., *Figure 33*). Effective precipitation was computed using the same method as used in LCRAS, in which a region-specific flat monthly multiplier is applied to total precipitation to estimate effective precipitation (Jensen, 1993). As an example, average annual precipitation measured at the AZMET Parker No. 2 Station was 4.23 inches for the period: 2014-2019. Using the LCRAS method, effective precipitation on the Reservation is about 0.90 inches per year, or about 21 percent of average annual precipitation, for the 2014-2019 period at this location.

For each year of the study period analyzed, a weighted average net crop CU was determined for the farm unit based on acreages of the individual crop types on that unit and the net crop CU of each crop for that year. Using this result, an overall mean unit area net crop CU (in AF/ac) for the study period was determined for each farm unit. This study period average net crop CU was then multiplied by the maximum number of acres irrigated during the four or five years evaluated to determine the total crop CU reduction due to fallowing (ΔCU) as:

$$\Delta CU = A_{max} \times net\ CU_{unit\ area}^{mean}$$

where A_{max} is the maximum net irrigated crop area (in acres) during any year of the study period, and the net CU term is the study period mean unit area net crop CU. Computations were completed on a monthly basis and aggregated to annual totals.

Figure 33 Simplified Representation of the Consumptive Use Quantification Approach for the Colorado River Indian Tribes Fallowing Program.



Diversion Requirements

Under the SC Agreement, CRIT must determine an irrigation diversion requirement at Headgate Rock Dam corresponding to the crop CU reduction at each farm unit participating in the fallowing program. This was estimated by dividing the crop CU reduction by the estimated project irrigation efficiency (product of irrigation delivery system conveyance efficiency and on-farm application efficiency). For the purposes of these analyses, an overall project irrigation efficiency of 53.5% was applied (NRCE, 2017).

For any CU reduction designated as EC-ICS, the associated irrigation diversion is computed using the CU/Diversion ratio for the CRIP using data reported in the most recent published Reclamation Decree Accounting report (per the methodology designated in the Lower Colorado River Basin Drought Contingency Operations (LBOps) Intentionally Created Surplus (ICS) Exhibit S for CRIT.

SC Agreement Conditions

The CU on CRIT's Arizona lands is affected by many factors that are not within the control of the Tribes, including the number of acres planted by lessees, assignees, and allottees, and the crops planted. The SC Agreement required the following in an effort to make sure that a reduction in CU was realized and to limit the amount of water diverted for the Arizona CRIR lands:

- The total irrigated area on Arizona CRIR lands would not exceed 72,871 during the time of SC creation;
- CRIT would use 612,725 AFY as the baseline maximum diversion; and,
- The annual water order requests submitted by CRIT to BIA (under Title 43 Code of Federal Regulations Part 417) contain CRIT's Adjusted Maximum Diversion (which is to be computed as Baseline Diversion minus the required Reduced Diversion Amount, per the SC Agreement) for the year in question.

Irrigated Acreage

Irrigated crop acreage in 2020 was obtained from the annual CRIT Water Resources Department crop survey. The results of the 2020 crop survey are in *Table 13*, below. The total irrigated crop acreage in 2020 was 57,702 acres. The irrigated cropped acreage plus SC/EC-ICS program fallowed lands (10,786 acres) totaled 68,488 acres. This is less than the 72,871-acre limit for irrigated acreage during the SC agreement.

Table 13 Summary of Irrigated Cropland by Crop Type, Fallowed Acreage, and Idle Acreage on CRIT Reservation Lands in Arizona, CY2020.

Crop	Gross Acres
Alfalfa	43,981
Bermuda	2,956
Broccoli	261
Cotton	2,043
Garlic	--
Onion	122
Potato	1,865
Preserve	211
Sudan	2,828
Wheat	3,435
Total Irrigated Land in Production	**57,702**
Fallow (Project)	9,998
Fallow (Rayner)	788
Total Irrigated Land in Production plus SC/ICS Fallowing	**68,488**
Idle Land	7,723
Total	**76,211**

Reduced Diversions

CRIT's original and amended water orders for Colorado River water diversions to Reservation lands in Arizona called for a final 2020 diversion request of 509,390 AF by the CRIP, and a diversion request of 2,628 AF for "Other Diversions" that included direct pumping from the Colorado River and wells, making for a total diversion to CRIR Arizona lands of 512,018 AF. A diversion reduction of 100,706 AF associated with the *⊿CU* due to CY2020 fallowing was estimated (*Table 14*). The adjusted maximum diversion amount for CY2020 should thus be less than or equal to (612,725 – 100,706) 512,019 AF. The diversions, return flows, and CU for the CRIR in Arizona as reported in Reclamation's CY2020 Decree Accounting (Reclamation, 2021a) are contained in *Table 14*. CRIT's total diversion to its Arizona lands in 2020 was 459,026 AF, well less than the Adjusted Maximum Diversion amount and the amount requested of 512,018 AF.

CRIT's 2020 fallowing program met the conditions of the SC agreement to result in a measurable reduction of water use. Field verification by CRIT Water Resources Department, Reclamation, and ADWR supports that identified farm units were fallowed and did not receive irrigation water for all of CY2020.

Table 14 Record of Diversions, Returns, and Consumptive Use for CY 2020 by Colorado River Indian Reservation in Arizona.

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Diversions at Headgate Rock Dam	17,500	30,270	11,150	47,220	57,730	56,080	59,550	57,450	40,820	28,190	23,090	27,900	456,950
Diversions Pumped from the Colorado River and Wells	122	115	129	146	235	225	247	237	200	175	136	109	2,076
Measured Returns	14,664	17,260	13,356	20,734	23,269	22,520	23,402	23,325	20,230	18,090	16,775	17,692	231,317
Unmeasured Returns	969	1,671	620	2,605	3,188	3,097	3,289	3,173	2,256	1,560	1,277	1,541	25,246
Consumptive Use	1,989	11,454	-2,697	24,027	31,508	30,688	33,106	31,189	18,534	8,715	5,174	8,776	202,463

Source: adapted from Reclamation (2021a)

Fallowed Land Verification

During the fallowing period, in order to ensure that any vegetation remaining on the fallowed lands does not consumptively use Colorado River water by drawing water from the Colorado River aquifer, CRIT is required to control and eradicate any green vegetation growth. Weed control is performed using both tillage and chemical means. Records of weed control activity, including date, chemicals used, rates of application, tillage methods, etc. are prepared and maintained. CRIT agreed to provide Reclamation, ADWR, and other applicable entities, with information and updates, when requested, regarding the vegetation eradication program. Stubble from previous cropping is kept on field surfaces to the extent possible to reduce wind erosion (see *Figure 34* of fallowed fields with crop residue and *Figure 35* of a field without residue). CRIT has agreed to grant access to Reclamation and ADWR personnel to perform periodic on-site inspections to verify compliance.

Additionally, CRIT agreed to furnish and install padlocks to lock the farm gate turnouts to fields fallowed to the extent possible to do so. In the event that a turnout serves multiple fields of which not all are being fallowed, other practical mechanisms, including but not limited to, dirt berms in the portion of the irrigation ditch serving the fallowed field, or sealing the on-farm turnouts onto fallowed fields are used to assure that no water deliveries can be made onto the fallowed fields.

Figure 34 Photos of Surface Crop Residue in Fallowed Fields in the Colorado River Indian Tribes' Fallowing Program (Credit: Right: L. Perkins, Left: B. Barker, May 26, 2021).

Figure 35 Photo of Fallowed Field without Surface Residue in the Colorado River Indian Tribes' Fallowing Program (Credit: L. Perkins, May 26, 2021).

Example CU Results

Table 15 below is a summary of CRIT's fallowing in CY2020 under the SC Agreement and the resultant CU estimated reductions (NRCE, 2019). This table includes, for each of nine farm units that were fallowed in CY2020[24], the following:

- Net irrigated field area
- Average crop mix during the study period
- Average unit area net CU for the five-year study period
- Average annual net CU, or ΔCU, for the five-year study period

[24] All of these fields were under the operation of CRIT Farms, the Tribal farming enterprise.

Table 15 Summary of CRIT System Conservation and EC-ICS for CY2020.

Unit	Name	Time Period	Gross Acreage	Max. Net Irrigated Acreage	Ave. Cropping Pattern	Total Net Consumptive Use		Net Consumptive Use Proration		Diversion Reduction Proration		Total Diversion Reduction
						Average AF/ac	Annual AFY	System Conservation AFY	EC ICS AFY	System Conservation * AFY	EC ICS** AFY	Annual AFY
6627	**MTA Farms**	2014-18	1,957.6	1,884.0	80% alfalfa 20% Sudan grass	5.39	10,157	9,450.7	706.2	17,664.8	1,502.6	19,167
6808	**Quail Mesa**	2014-18	3,999.7	3,704.6	58% alfalfa 4% small grain 6% Bermuda (grass hay) 11% Sudan 21% Miscellaneous (onion, garlic, corn, potato)	4.89	18,130	16,869.7	1,260.6	31,532.2	2,682.1	34,214
6693	**MTA Farms**	2014-18	1,343.6	1,183.9	64% alfalfa 1% cotton 6% small grain 13% Bermuda (grass hay) 14% Sudan 21% Miscellaneous (onion, garlic, corn,	4.97	5,886	5,476.3	409.2	10,236.1	870.7	11,107
CRIT Farms	**Victorio**	2014-18	424.7	406.8	60% alfalfa 5% cotton 17% small grain 12% Bermuda (grass hay) 5% Sudan	4.61	1,877	1,746.5	130.5	3,264.4	277.7	3,542
CRIT Farms	**Frimann**	2014-18	674.7	674.7	52% alfalfa 26% cotton 18% small grain 4% Sudan	4.37	2,951	2,745.4	205.2	5,131.7	436.5	5,568
CRIT Farms	**CRIT II**	2014-18	1,265.8	1,238.7	73% alfalfa 19% cotton 6% small grain 2% Miscellaneous (onion, garlic, corn, potato)	5.04	6,247	5,812.4	434.3	10,864.4	924.1	11,788
CRIT Farms	**MTA 700**	2014-18	484.3	465.8	86% alfalfa 7% cotton 7% Bermuda (grass hay)	5.50	2,562	2,383.8	178.1	4,455.7	379.0	4,835
CRIT Farms	**Shawler Ranch**	2014-18	454.9	439.5	69% alfalfa 30% cotton 2% Sudan	5.02	2,206	2,052.9	153.4	3,837.2	326.4	4,164
9035* **	**Rayner**	2013-17	870.7	788.0	52% alfalfa 32% cotton 12% Bermuda (grass hay) 4% Sudan	4.72	3,721	3,462	259	5,770	550.5	6,321
Totals			11,476.0	10,786.0			53,736	50,000	3,736	92,757	7,949	100,706

*System Conservation diversion reduction for Field Units served by the Project is based on Project overall average irrigation efficiency equal to 53.5%.

**ICS diversion reduction for all Units is based on Project CU/Diversion ratio of 0.470 for 2018 using methodology designated in the LBOps ICS Exhibit S for CRIT.

***Estimates in this table for 9035 are based on 2013-2017 USGS cropping data with the area under a linear move sprinkler system removed; System Conservation diversion reduction using an overall average irrigation efficiency for direct pumping from River equal to 60%

- Proration of *ΔCU* between SC and EC-ICS for each farm unit
- Proration of the associated diversion reduction between SC and EC-ICS for each farm unit
- Total diversion reduction on each farm

The last row of the table contains totals for CY2020. CRIT proposed to fallow a net irrigated field area of 10,786 acres to produce a total *ΔCU* of 53,736 AF (50,000 AF to SC and 3,736 AF to EC-ICS). The associated diversion reduction is a total of 100,706 AF.

Discussion of Method Assumptions

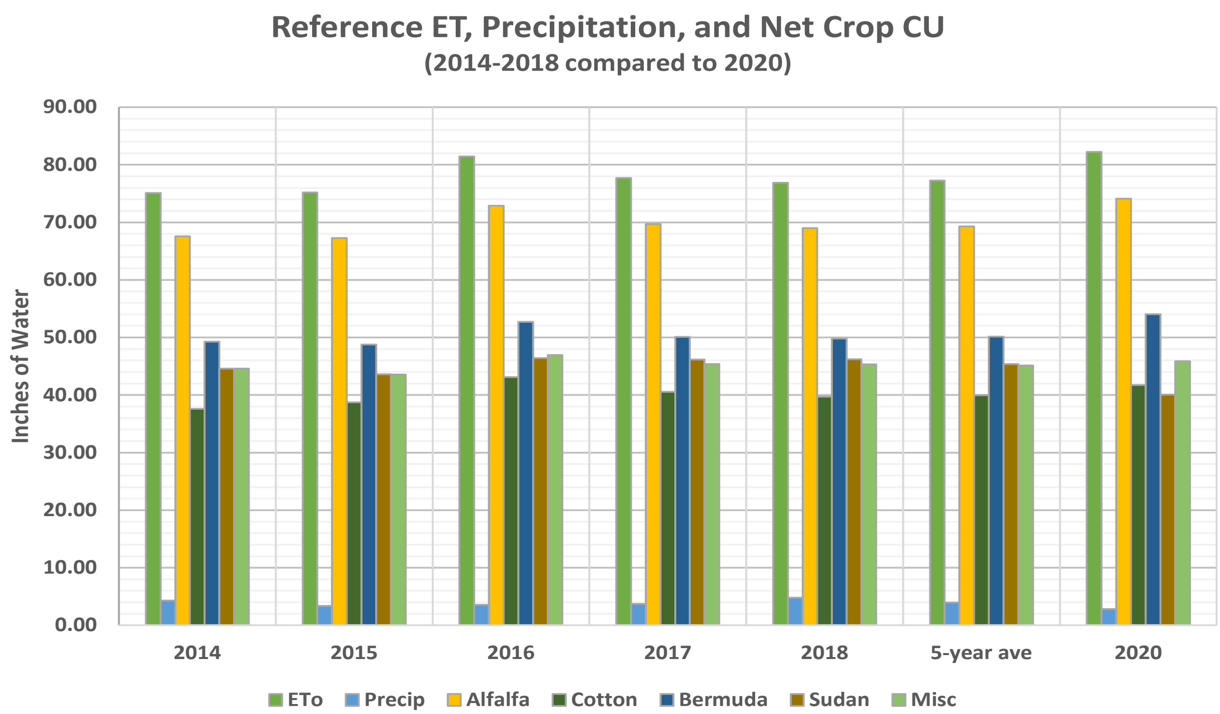
The *ΔCU* method includes several assumptions, which are either explicit or implicit in the method. The primary assumptions are discussed below.

Assumption 1: The four- or five-year study period average CU of crops grown on the fallowed fields is representative of the CU that would have occurred on the fallowed fields during the year or years of fallowing.

This assumption essentially has two parts—both the crop mix that would have been grown and the climate during the fallowing period are assumed to be represented by the crop mix and the climate of the study period used to determine *ΔCU*. Significant deviations in either of the cropping pattern or the climate of the fallowing period from the annual range of crops or climate occurring during the study period may result in either an over- or under-estimation of *ΔCU*. The crop mix that would have been present on the fallowed fields during the fallowing period is unknown. However, CRIT cropping is heavily dominated by perennial crops such as alfalfa and Bermuda grass hay, and the percentage of these crops across the Reservation has been relatively stable over the past 5-8 years, based on crop surveys prepared by the CRIT Water Resources Department.

Climate variability on a seasonal and annual basis does occur. Rather than evaluating each parameter, a comparison of the short crop reference ET, precipitation, and the net CU of the major crops allows assessment of whether there may be potential impacts from assuming the study period average climate condition is representative of the fallowing period climate. *Figure 36* is a graphical comparison of total annual reference ET, precipitation, and the net CU of alfalfa, cotton, small grains, Bermuda grass hay, Sudan grass, and miscellaneous winter crops for each year of the study period, the five-year average (2014-2018), and for the fallowing period (2020). Minor differences are observable, but in this instance are considered negligible. There may be other cases where a four- or five-year average is not considered representative of the fallowing period. In such instances, a normalizing factor such as the ratio of reference ET for the study period to that of the fallowing period could be computed and applied on a monthly basis to adjust the longer-term averages to the conditions of the fallowing period (e.g., Allen and Torres-Rua, 2018). Such adjustment would necessarily be *post facto* and would require flexibility in the terms and conditions of the SC agreement.

Figure 36 Comparison of Study Period (2014-2018) versus Fallowing Period (2020) Reference ET, Precipitation, and Net CU of Major Crops on the Colorado River Indian Reservation.



Assumption 2: The factors applied to reduce the computed "potential" crop ET to actual crop ET are reasonable and appropriate adjustments and result in actual crop ET that is representative of actual field conditions.

As discussed in TM2, it is well known that the crop coefficient-reference ET approach (whether single mean crop coefficient or dual crop coefficient) produces crop ET estimates considered to be "potential" crop ET because the crop coefficients used are typically developed under experiment station conditions whereby most stresses (water, pest, or disease) are carefully managed to minimize or eliminate the impacts of such stresses in crop water use. As noted above, Jensen (1998) recognized that alfalfa crop ET by this method was higher than local estimates and applied a factor of 0.85 to the alfalfa hay crop coefficients to obtain more realistic estimates of alfalfa ET in the LCRB. CRIT used the results of two relatively large-scale studies, one at PVID and one at IID to develop adjustment factors for other crops. The purpose of this effort was to avoid an overstatement of the actual *ΔCU*. A more rigorous evaluation of this approach, including a remote sensing ET modeling for CRIP lands, may be advisable.

Assumption 3: The CU from the fallowed fields (and possibly the irrigation and drainage ditches serving the fallowed land) is negligible.

This assumption is discussed in both the Bard Water District Seasonal Fallowing Program *Discussion of Method Assumptions* and the Palo Verde Irrigation District Forbearance and Fallowing Program *Discussion of Method Assumptions* sections.

Assumption 4: Any carryover effects of fallowing on CU are negligible.

This assumption is directly related to the assumption that the CU from fallowed land and the associated ditches is negligible (see the previous assumption). This assumption is valid so long as evaporation from the fields and the dried-up ditches can be considered negligible during the fallow period.

Reflections

A benefit of the approach taken to compute *ΔCU* under CRIT's fallowing program is the computation of crop CU and estimation of the associated diversion reduction prior to fallowing implementation. Also of benefit, is the fact that the computation methodology is independent of what is occurring on the remainder of the irrigated lands on the part of the Reservation in Arizona during the fallowing period. For each year of the study period analyzed, a weighted average net crop CU was determined for each farm unit based on acreages of the individual crop types on that unit and the net crop CU of each crop for that year. There were instances on some farm units during some years when fields on the unit may have been idle. These were not included in the calculated net crop CU for that unit for that year (i.e., both irrigated acres and CU on the idle parcel would be zero). The overall average net crop CU was calculated based only on the net irrigated and cropped acreage during the study period.

A potential drawback of the CRIT methodology that is very important to note, however, is that due care must be applied to develop crop CU estimates representative of the actual field conditions. This includes use of representative high-quality weather data, a state of the science crop ET estimating method (such as the single mean crop coefficient-reference ET method used that is based on ASCE's Standardized Reference ET Equation), accurate crop survey data, etc. The component of this due diligence that can and should be improved in the very near future is the cross-comparison of net crop CU under CRIT's methodology with actual crop ET estimates that will become available under the OpenET project (OpenET, 2021).

The comparison of the *ΔCU* under this methodology to Reclamation Decree Accounting requires a reasonably accurate assessment of irrigation efficiency to convert the *ΔCU* to an associated diversion amount. This diversion amount is actually the diversion reduction CRIT is required to show in its annual water order under terms of the SC Agreement, and as previously explained, is subtracted from the maximum baseline diversion to determine an adjusted maximum diversion amount. This maximum diversion amount is then directly comparable to Decree Accounting results. Parties to the agreement can track diversions monthly and annually to ensure there is a reduction in CRIT's diversions and water use due to the fallowing. The irrigation efficiency in this case is the ratio of net crop CU to total water diverted. All sources of the total CU other than net crop CU should be removed to the extent possible. The development of this ratio is most often accomplished with a water balance and requires extensive, high-quality data on crops, acres irrigated, water measurement at diversions, spills, drains, etc. This was accomplished at CRIT but there is considerable room for improvement of the data and the results. It is expected that as CRIT make water conservation improvements, the project irrigation efficiency will improve.

Other observations/lessons learned include:

- The maximum baseline diversion of 612,725 AF is approximately 50,000 AF less than CRIT's annual Colorado River water right allocation to CRIR lands in AZ of 662,402 AF. This condition was imposed in the agreement (among other conditions) to ensure that there would be a measurable reduction in CRIT's water use. The impact of not being able to draw upon this 50,000 AF was to cause CRIT Farms to idle additional land not in the fallowing agreement (of the 7,723 acres of idle land shown in *Table 13* above, approximately 3,990 acres were under CRIT Farms management and put into short term idle). CRIT Farms is adjusting its crop mix to lower water use crops to accommodate the restriction. However, access to divert and use the 50,000 AF imposed reduction would have alleviated CRIT Farms' need to perform additional short-term idling of irrigated cropland. CRIT's fallowing program performance has been demonstrated in 2020 and, so far, in 2021 with diversions and CU well less than what was actually proposed as can be verified in Reclamation annual Decree Accounting reports.

- The fallowing program at CRIT has focused on maximizing the CU yield from fallowing and thereby has focused on fallowing farm units with high percentages of alfalfa in the crop mix that are approaching the end of their useful stand life. Some of these units had multiple field parcels with glyphosate-resistant genetically modified (GMO) alfalfa. In fallowing such stands, CRIT management has found considerable extra diligence is required to eradicate the stand and keep the parcel free of green vegetation.

- In the development, implementation, and evaluation of its fallowing program, CRIT has had to work with multiple agencies to be successful: Reclamation, ADWR, CAWCD (the parties to the agreement); and BIA (at the national, regional, and local office levels, e.g., Colorado River Agency). There were multiple instances of delays with reviews, comments, and feedback due to the number of entities reviewing and agreeing to terms and conditions. There were also the inevitable communications breakdowns that resulted in misunderstandings and actions that negatively impacted the Tribes and their lessees.

- Recent studies commissioned by CRIT Tribal Council show there may be multiple opportunities to improve the overall irrigation efficiency of the Colorado River Irrigation Project (Franzoy, 2017; NRCE, 2017). Project irrigation efficiency is the combination of conveyance efficiency and on-farm efficiency. The Franzoy (2017) report refers to a systematic study of the Project, which provided details of infrastructure, e.g., leaky gates and check structures, eroded earthen canal prisms, and other large Project infrastructure, requiring significant capital investment to rehabilitate or replace. Improving such infrastructure will improve Project conveyance efficiency. The NRCE (2017) report presents the results of water balance analyses using Project data for the period June 2011-December 2015 to identify inefficiencies on the Project (at both the conveyance and on-farm levels) and opportunities for improving efficiency and conserving water. The Project has low on-farm efficiencies due to high seepage loss in on-farm ditches and a high volume of deep percolation losses of water applied to farm fields. On-farm improvements are the responsibility of the landowner or lessee. These delivery system and on-farm system inefficiencies have resulted in a Project efficiency of approximately 50%, meaning half of CRIT's diversions are returned to the River as Project return flows. CRIT has strong interest in addressing Project inefficiencies at both the delivery system and on-farm levels. CRIT's objectives are to make water available for expanded irrigation or alternate economic uses and benefits to the Tribes, while also maintaining an irrigated agriculture land base and a healthy environment along the Colorado River. To this end CRIT is using some of its compensated system conservation to fund improvements on the Project.

Mohave Valley Irrigation and Drainage District Fallowing Program

MVIDD is in western Arizona. The district is non-contiguous being positioned around lands of the Fort Mojave Indian Reservation (MVIDD, 2016; *Figure 37*). MVIDD's service area is about 31,500 acres with about 7,000 acres of farmland that can be irrigated and about 380 acres of golf course (MVIDD, 2016).

MVIDD's irrigation water is from wells in the Colorado River alluvial aquifer. MVIDD is comprised of individual farm-level conveyance systems, with wells discharging into lined head ditches (*Figure 38*), rather than a single, large, shared canal system.

In 2020, MVIDD began a fallowing program for system conservation (MVIDD, 2019). For this program, an enrollment process was created whereby participating farmers voluntarily enter into an agreement with MVIDD to fallow land that had been verified as actively cultivated in three or more of the five most recent years (MVIDD, 2020b). The fallowed areas or parcels are limited to 10 or more acres each (MVIDD, 2020b). Upper limits are specified for both the amount of land that can be irrigated and the total annual irrigation diversions for the district during the fallow periods. The proposed fallowed area was approximately 1,200 acres in 2020 and over 1,300 acres in 2021 (MVIDD, 2019, 2020b). The proposed system conservation volume was 6,137 AF in 2020 and 6,778 AF in 2021 (MVIDD, 2019, 2020b).

Figure 37 Map of the Mohave Valley Irrigation and Drainage District (Provided by MVIDD).

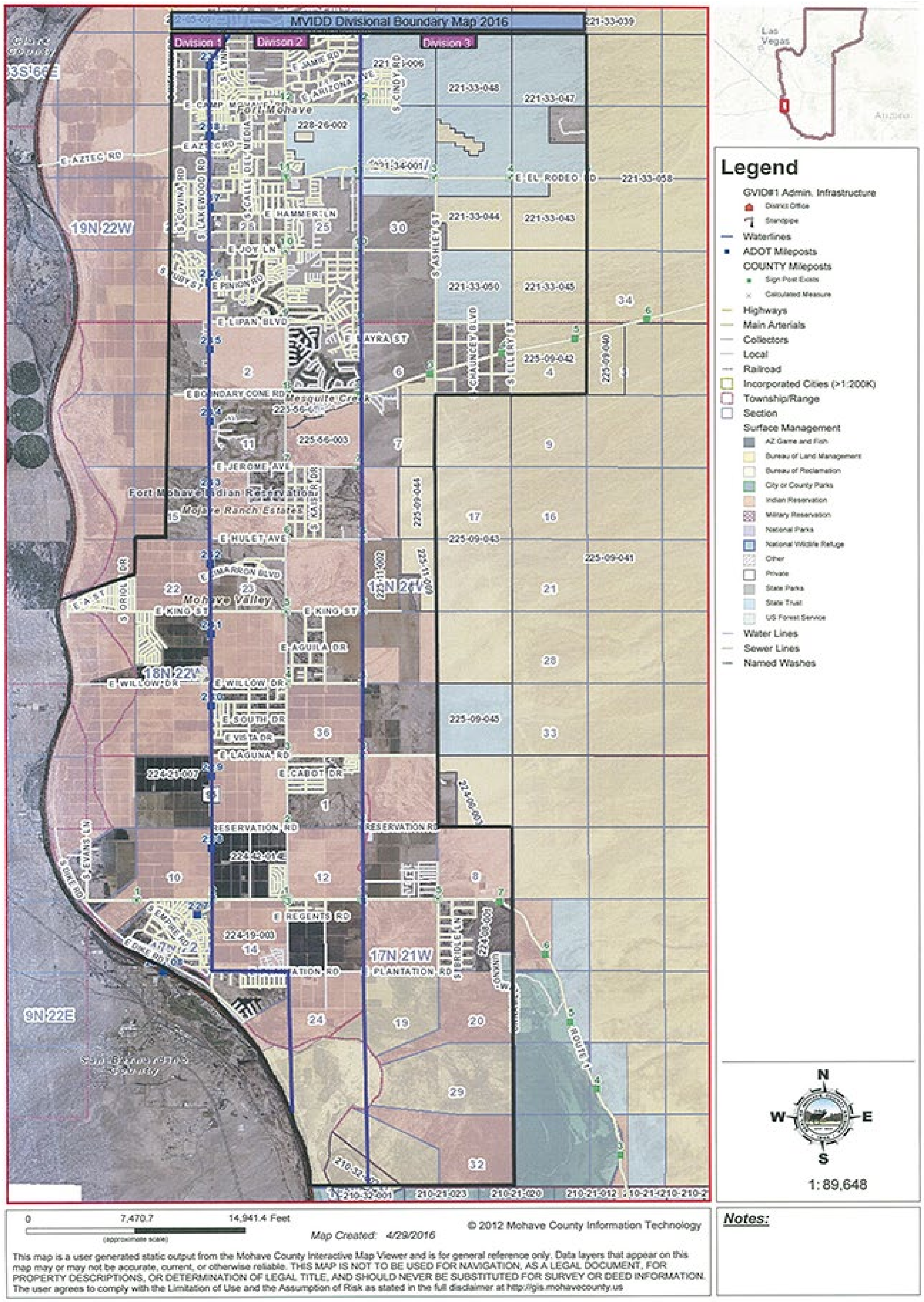


Figure 38 Photos of Irrigation Infrastructure in the Mohave Valley Irrigation District (credit: L. Perkins, May 27, 2021).

Technical Analysis

A technical analysis of the MVIDD fallowing case study is presented in the following sections.

CU Quantification Methods

The CU reduction estimates for the MVIDD fallowing program are estimated using the reference evapotranspiration/crop coefficient method and spatial crop surveys (Land IQ, 2020; see also TM2). MVIDD contracted with Land IQ (Sacramento, CA) to conduct the CU analysis.

Crop Surveys

Crop surveys were performed by Land IQ (2019, 2020) using a remote-sensing-based analysis for the five recent years (2014-2018 for 2020 and 2015-2019 for 2021). The surveys were performed only for fields that were intended to participate in the fallowing program (1,214 acres total in 2020[25] and 1,344 acres in 2021[26]). They used remote sensing techniques and both satellite imagery (Landsat) and aerial imagery (National Agricultural Imagery Program, NAIP) for the analysis. Care was taken to consider only irrigated areas. The geospatial Crop Data Layer from the National Agriculture Statistics Service (NASS) was used for validation (Land IQ, 2020; https://nassgeodata.gmu.edu/CropScape/). Land IQ (2020) reported the accuracy of their surveys to be better than 97% based on experience in California and provided justification that the accuracy at MVIDD was expected to be at least that based on the relatively few crops grown in the district.

Evapotranspiration and Crop Water Use Modeling

The ET modeling performed by Land IQ (2020) was done using the reference-ET-crop-coefficient method:

$$ET_c = ET_o K_c$$

[25] Later reduced to 1,196 acres (MVIDD, 2019).

[26] The program included 1,348 acres (MVIDD, 2020b).

where ET_c is modeled crop ET, ET_o is short reference ET, and K_c is used to represent a specific crop and crop growth conditions (TM2; Jensen and Allen, 2016). For this analysis, "quality control[led]" ET_o was obtained from the individual in charge of AZMET (Land IQ, 2019). They used mean ET_o for two to three AZMET stations in the Mohave Valley, depending on data availability. They obtained K_c values from a common source, the Food and Agriculture Organization of the United Nations Irrigation and Drainage Paper No. 56 (Allen et al., 1998) and from consultation from "…professors at University of California, Davis ([R.L.] Snyder, [communication], 2016)" (Land IQ, 2019).

CU was based on the ET of applied water (ET_{AW}), which was computed by subtracting effective precipitation, or that portion of precipitation that contributes to the crop water requirement (e.g., SCS, 1993). Effective precipitation was computed using a piecewise polynomial function and precipitation data from the same AZMET source as the ET_o (Land IQ, communication, September 2, 2021).

Reduction in CU

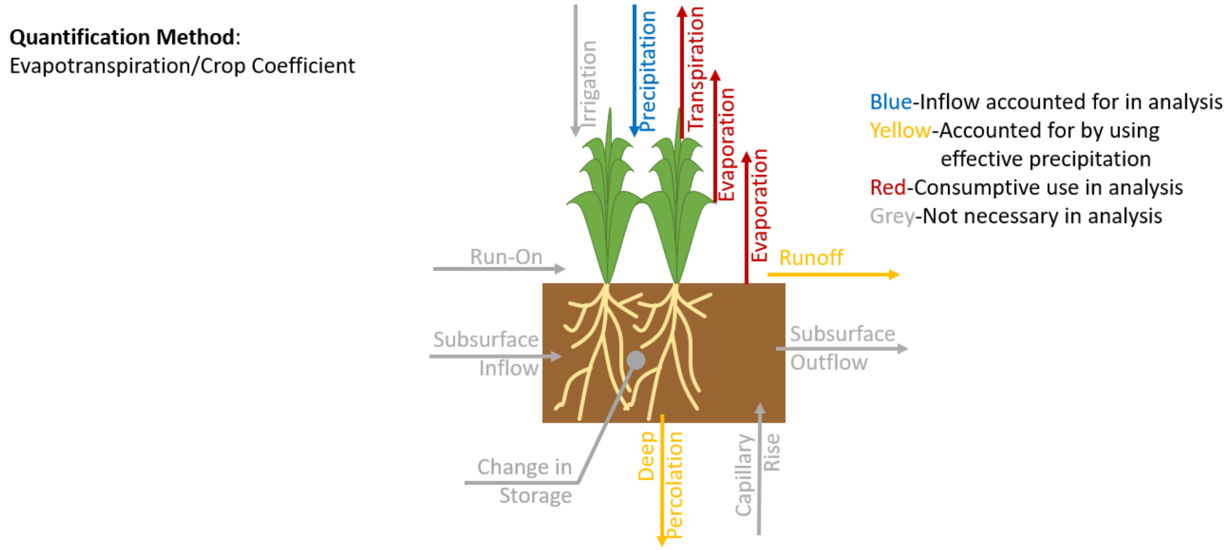
As with other fallowing programs, ΔCU was computed as the difference in CU quantified for crops (as represented by ET_{AW}) that may have been grown on the fields had they not been fallowed, as represented by the analysis described above (Land IQ, 2019, 2020). The fallowed fields were assumed to have zero CU. This was done for each participating landowner, with ET_{AW} or ΔCU for each year being computed as area weighted averages based on the crop surveys. Average ΔCU values were then computed across years for each grower and the five-year average ΔCU was totaled for the district.

Reduction in Diversion

The fallowing program has a limit on MVIDD diversions for irrigation, as described above (MVIDD, 2019, 2020b). To compute this, MVIDD used the mean total irrigation diversion for MVIDD from the Decree Accounting for 2014-2018 for 2020 and for 2016-2019[27] for 2021 (MVIDD, 2019, 2020b). These were 29,725 AF and 29,312 AF, respectively (MVIDD, 2019, 2020b). MVIDD (2019, 2020b) then subtracted a 7 AF/ac diversion allowance for each fallowed acre to obtain a diversion limit. For 2020, this was 29,725 AF – (1,196 ac × 7 AF/ac) = 21,353 AF. For 2021, this was 29,312 AF – (1,348.62 × 7 AF/ac) = 19,872 AF.

[27] The four years with the greatest diversion for MVIDD in Reclamation (2021a) from 2015-2019 (MVIDD, 2020b).

Figure 39 Simplified Representation of the Consumptive Use Quantification Approach for the Mohave Valley Irrigation and Drainage District Fallowing Project.



Example CU Results

Crop Surveys

The crops identified by Land IQ (2020) were alfalfa, other hay (including Bermuda), Sudan, and fallowed land, with alfalfa being the predominant crop (*Table 16*). The relative proportions of the various crops identified by Land IQ (2020) were similar to those reported in the 2019 and 2020 district crop reports (MVIDD, 2020a, 2021; *Table 17*).

Table 16 Summary of Crop Surveys for Fields to be Fallowed (Land IQ, 2019, 2020).

Crop Year	Program Year	Crop						
		Alfalfa	Alfalfa (Poor and Partial Year)	Other Hay (Including Bermuda)	Fallow	Sudan	Sudan Followed by Alfalfa	Total
		------- *Irrigated Area (acres)* -------						
2014	2020	1,162			19		34	1,214
2015	2020	1,123			19	36	36	1,214
	2021	1,118			154	36	36	1,344
2016	2020	1,161			19			1,180[1]
	2021	1,128		110	107			1,344
2017	2020	1,195		19				1,214
	2021	1,269		75				1,344
2018	2020	1,195		19				1,214
	2021	1,269		75				1,344
2019	2021	1,097	35	212				1,344

[1]Sum does not equal the full 2020 surveyed area of 1,214 acres.

Table 17 Summary of Mohave Valley Irrigation and Drainage District Crop Reports for 2019 (Before the Fallowing Program) and 2020 (First Year of the Fallowing Program) (MVIDD, 2020a, 2021).

Crop Year	Crop					
	Alfalfa	Other Hay (Including Bermuda and Ryegrass)	Hemp	Small Grain	Vegetables	Total
	------- "Farmed" Area (acres) -------					
2019	3,172	575			14	3,761
2020	2,215	436	51	394		3,095

Evapotranspiration and Crop Water Use

The modeled ET_c and ET_{AW} for the identified crops were computed and summarized as annual totals (Land IQ, 2020, 2021; Table 18). The computed ET_{AW} was similar in magnitude to ET_c as a result of the relatively small effective precipitation.

Table 18 Summary of Modeled Crop Evapotranspiration and Evapotranspiration from Applied Water for Mohave Valley Irrigation and Drainage District (Land IQ, 2020, 2021).

Crop Year	Crop			
	Alfalfa[1]	Other Hay (Including Bermuda)	Fallow	Sudan
	------- Annual Crop Evapotranspiration (inches) -------			
2014	62.1	62.3	0.0	37.0
2015	63.3	63.5	0.0	38.4
2016	62.8	62.7	0.0	38.3
2017	63.5	64.0	0.0	38.8
2018	66.6	67.0	0.0	41.3
2019	63.3	64.0	0.0	39.2
	------- Annual Evapotranspiration from Applied Water (inches) -------			
2014	59.6	59.8	0.0	35.1
2015	60.6	60.8	0.0	37.8
2016	59.6	59.5	0.0	35.6
2017	61.0	61.5	0.0	37.9
2018	65.0	65.5	0.0	40.9
2019	58.6	59.3	0.0	38.6

[1]Prorated when applied for partial years and reduced to 2/3 of this value for "poor" condition alfalfa.

Total Reduction in CU

The total ΔCU for the full program in MVIDD was estimated to be 6,137 AF for 1,196 acres of fallowed land in 2020 (MVIDD, 2019). Total ΔCU was estimated to be 6,778 AF for 1,349 acres of fallowed land in 2021 (MVIDD, 2020b).

Total Diversion

The total MVIDD agricultural irrigation diversion in the Decree Accounting for 2020 was 19,458 AF, which was 2,077 AF less than the limit of 21,535 AF described by MVIDD (2019). This is a difference of a little less than 10%.

Discussion of Assumptions

The *⊿CU* method includes several assumptions, which are either explicit or implicit in the method. Some of the primary assumptions are discussed below.

Assumption 1: The CU for the fallow fields, or at least the *⊿CU* for the fallow fields, would be similar to the CU in those same fields, on average, in five previous years.

This assumption is discussed in the *Discussion of Method Assumptions* section of the Colorado River Indian Tribes Fallowing Program case study. Two aspects of this assumption relating to MVIDD will be considered here. The first is that the crops that would be grown on the fallowed fields would be similar to those grown in previous years; the second is that other factors affecting CU would be the same in the fallowing year as the mean of the quantification years.

Regarding the crops grown, the surveyed crop mix was similar across many of the survey years in the fields to be fallowed (*Table 16*). The crop mix, based on MVIDD crop reports was similar in 2019, before the fallowing program, and 2020, a program year (*Table 17*). Though, there was about 445 acres (~14% of the reported area) of crop types not grown in 2019 that were grown in 2020. It is uncertain whether any of the program participants would have elected to grow crops that differed from their respective recent histories had they not fallowed their fields. Another consideration is the growth of alfalfa. Alfalfa is a perennial crop that is grown for several years before it is removed. Project participants may have strategically enrolled fields with aging alfalfa stands as opposed to randomly selecting fields to fallow regardless of the crop or stand age.

In addition to the crop mix considerations, other conditions may or may not have varied notably between the five-years used to estimate *⊿CU* and the fallowing year. These conditions include weather, pest pressure, and management, among others. For the present discussion, only weather is considered specifically. One benefit of using an average as opposed to the estimated *⊿CU* is that an average may better represent typical conditions and reduce the uncertainty involved with assumptions, measurement, and modeling methods in any one year. Furthermore, it can be expected that the annual variability in ET for a given crop will not be too great (e.g., SCS, 1993). Though *⊿CU* as being discussed here is actually ET less effective precipitation, the ET is of much greater magnitude than precipitation and, therefore, this justification has some merit. It is also possible, however, that the methods used to estimate *⊿CU* for a given year are sufficiently accurate to be more representative than a mean across years. Using the range of *⊿CU* (ET_{AW}) values presented in *Table 18*, alfalfa *⊿CU* ranged within -4% to +7% of the mean for 2014-2019. Similarly, the *⊿CU* for other hay ranged from – 3% to +7% of the mean, but Sudan *⊿CU* ranged from -7% to +9% of the mean. The actual *⊿CU* for 2020 could have been within or outside of this range (assuming the modeling method was accurate).

Assumption 2: The crop coefficients and effective precipitation methods used are representative of the conditions in MVIDD.

A difficulty in applying K_c values to quantify *⊿CU* is that published K_c values are often representative of crops under little stress in research conditions (e.g., TM2). This means that when applying published K_c values, the resulting ET_c will be an overestimate of actual production conditions unless adjustments are made. For example, Jensen (1998) reduced his recommended K_c values for alfalfa in the Lower Colorado River Basin by multiplying the values by 85% to account for production conditions. The reported actual K_c values in the PVID deficit irrigation case study are further evidence of the difference between research station and production field conditions; wherein the observed alfalfa K_c values were less even than Jensen's (2003) values used for LCRAS. This concept is further corroborated by the discussion in *Standard Conditions vs. Non-Standard Conditions* section of TM2.

Land IQ (2019, 2020) used K_c values based on communications from university faculty and from Allen et al. (1998), the latter of which, if properly adjusted for climate, would be considered "potential" values. Whether or not these values were reduced to represent actual conditions was not specified. For validation, Land IQ compared their results to the 2013 *Lower Colorado River Annual Summary of Evapotranspiration and Evaporation* (Reclamation, 2019a). Comparing ET_c or ET_{AW} estimates with other sources is good practice. It is noted that 2013 was outside of the years included in the Land IQ analysis but the 2014 analysis from Reclamation (2019b) was likely not available for the Land IQ (2019) analysis.

For the present discussion, the *Lower Colorado River Annual Summary of Evapotranspiration and Evaporation* or similarly named reports for 2010 – 2014 (Reclamation, 2014, 2016, 2018, 2019a,b) were considered for comparison (*Table 19*). As also observed by Land IQ (2019, 2020) for 2013, the alfalfa ET_{AW} from Reclamation was similar to that computed by Land IQ, about 64 inches per year versus about 61 inches per year, respectively. The difference may be caused by differences in ET_o, K_c, or effective precipitation, though the latter should be small (*Table 18*), particularly considering the differences observed for the overlapping analysis year, 2014. The difference for Sudan was a little greater in magnitude and proportion. The Land IQ ET_{AW} for Bermuda was notably greater than the estimate of Reclamation. However, according to Land IQ (communication, September 2, 2021), the difference is related to the "Bermuda grass growing season" being "incorrect in the past." It must be remembered that the comparisons in *Table 19* have little overlapping periods of record. Furthermore, with the exception of alfalfa, the Reclamation ET_{AW} values have not been reduced to represent production conditions. This comparison is an illustration of the differences that exist in methods, but in both cases a comparison to estimates of actual production field ET_{AW} would be beneficial.

Finally, regarding the impact of the effective precipitation methods used, it is important to consider the magnitude of precipitation in MVIDD. For example, in 2010 - 2019, there was an average of about 5.2 inches per year of precipitation averaged across the available records for the three AZMET stations and three NOAA climate stations[28] (NOAA, 2021a,b; UA, 2021; *Table 19*). For the one overlapping year in the Reclamation and Land IQ analyses, 2014, there was only 3.3 in. of precipitation. This was less than the difference between the ET_{AW} between the Land IQ (2019) and Reclamation (2019b) analyses. Effective precipitation is expected to be much less than the full quantity of precipitation (Jensen, 1993).

[28] The three AZMET stations were Mohave, Mohave 2, and Ft. Mohave, CA. The former two stations were used by Reclamation (2019) and all three by Land IQ (2019, 2020). The two NOAA stations were Bullhead City, AZ and Laughlin, NV and were used by Reclamation (2019b).

Table 19 Comparison of Crop Evapotranspiration of Applied Water for Select Crops for Mohave Valley Irrigation and Drainage District from Reclamation and Land IQ for 2010 – 2019.

Year	LCRAS ET_{AW} (in.)[1]			MVIDD ET_{AW} (in.)[2]			Precipitation[4] (in)
	Alfalfa	Bermuda/ Grass[3]	Sudan[3]	Alfalfa	Other Hay/ Bermuda	Sudan	
2010	62.0	53.3	40.7	--	--	--	9.4
2011	62.6	53.2	40.6	--	--	--	4.0
2012	65.4	55.7	41.8	--	--	--	6.8
2013	65.1	55.0	42.0	--	--	--	4.3
2014	63.6	54.6	41.6	59.6	59.8	35.1	3.3
2015	--	--	--	60.6	60.8	37.8	4.8
2016	--	--	--	59.6	59.5	35.6	4.9
2017	--	--	--	61.0	61.5	37.9	3.7
2018	--	--	--	65.0	65.5	40.9	2.5
2019	--	--	--	58.6	59.3	38.6	8.8
Average	63.7	54.4	41.3	60.7	61.1	37.7	5.2

[1]Source: Reclamation (2014, 2016, 2018, 2019a,b). Names similar to sources.
[2]Source: Land-IQ (2019, 2020). Names similar to sources.
[3]Jensen (1998) did not apply any reductions to the crop coefficients for Bermuda or Sudan and so too, the crop coefficients of Jensen (2003) would also not have this adjustment.
[4]Sources: AZMET Mohave, Mohave 2, and Ft. Mohave, CA stations (UA, 2021) and NOAA (2021) Bullhead, AZ and Laughlin, NV stations.
[4]The average for 2010 - 2014 was 5.5 in. and for 2014 - 2019 was 4.7 in.

Assumption 3: The CU from the fallowed fields and possibly the irrigation and drainage ditches serving the fallowed land is negligible.

This assumption is discussed in the *Discussion of Method Assumptions* sections of the other three fallowing case studies. Some additional commentary for MVIDD is provided here.

Because effective precipitation was subtracted from ET_c in computing ΔCU, the effect of precipitation on evaporation is technically accounted for. It has also been demonstrated that the total annual precipitation is relatively small (3.6 inches in 2020). Effective precipitation can be expected to be only a small portion of this (Jensen, 1993). It is reasonable to assume that deep percolation from precipitation is negligible. Given that the fields are leveled according to a site visit participant, it is likely that surface runoff is also negligible. Therefore, the fraction of precipitation that is not effective would likely be evaporated whether in an irrigated or a fallowed field.

Assumption 4: CU from conveyance ditches is negligible.

This assumption is that changes in CU occur only on irrigated land or that any other ΔCU is negligible. Technically, there is evaporation from field ditches, though the magnitude of the evaporation is expected to be small, and the wetted area of field ditches is also small compared to the minimum size of the fallowed fields (10 acres; MVIDD, 2019, 2020b). Furthermore, because the field ditches are concrete lined, the evaporation from the ditches will be essentially entirely from the water surface when the ditch is conveying water or during drying after an irrigation. Any evaporation or ET that may occur from ditch water that may leak through the turnout gates is prevented from entering the fallowed field by sealing the gates with silicone (*Figure 40*).

Figure 40 Photo of a Locked and Sealed Field Turnout Gate Serving a Fallowed Field in the Mohave Valley Irrigation District (credit: B. Barker, May 27, 2021).

Assumption 5: Any carry-over effects of fallowing on CU are negligible.

This assumption is directly related to the assumption that the CU from fallowed land and the associated ditches is negligible. This assumption is valid so long as evaporation from the fields and the dried-up ditches can be considered negligible during the fallow period.

Assumption 6: The diversion capacity of the fields can be represented by a set per-acre value.

To determine a maximum allowable annual diversion, MVIDD applied a per-acre diversion rate of 7 AFY/ac to all fallowed lands. This is convenient because it is the maximum irrigation duty allowed to irrigators in MVIDD (MVIDD, 2019, 2020b). Implicit in using this value is an assumed district-average combined conveyance and irrigation application efficiency. For example, in 2020, the total ΔCU was estimated to be 6,137 AF / 1,196 ac = 5.13 AF/ac (MVIDD, 2019). The total irrigation efficiencies would then be 5.13 AF/ac / 7 AF/ac × 100% = 73%. Similarly, for 2021, the total irrigation ΔCU would be 6,778 AF / 1,349 ac = 5.03 AF/ac (MVIDD, 2020b). The corresponding total irrigation efficiency would be 5.03 AF/ac / 7 AF/ac × 100% = 72%. It is expected that the conveyance efficiencies for the systems should be high because they are all short-run, concrete lined ditches (e.g., Brouwer et al., 1989). This still bespeaks a relatively high application efficiency for basin irrigated fields (compare to Brouwer et al., 1989). However, the turnouts, as shown in *Figure 40*, appear to typically have large flow capacities, possibly 10 – 20 cfs. Large turnout flow rates allow for relatively rapid movement of water across the field. This rapid distribution of water has the potential to result in relatively high application uniformity and consequently the potential for relatively high application efficiencies. Though, such may be possible as the fields are typically laser leveled according to a grower. The implication of an overestimated effective irrigation efficiency, if such existed, would be either an underestimate of the necessary diversion reduction or a possible overestimate of the ΔCU. The former is based on MVIDD administrative diversion limits. The latter has already been discussed. Conversely, the opposite implications would exist if the effective irrigation efficiency happened to be underestimated.

Reflections

The MVIDD fallowing program, as with the other case studies, has had both challenges and benefits. One challenge with the fallowing program is that it has been observed by a grower that participated in the site visit that the longer the fallowing duration, the more effort (and expense) is required when the field is brought into production again. This is reportedly largely related to the difficulty of cultivating the dry soil following fallowing. One effort to protect the fallowed fields in MVIDD is to leave crop stubble in the field to reduce wind erosion (*Figure 41*). One grower also expressed interest in the establishment of cover crops that could be killed without herbicide prior to the fallowing period for the soil stewardship value. This is because there is concern regarding the impact that applying chemicals during fallowing has on soil health.

The fallowing of a field is not seen entirely as a cost, as there may be some advantages that can be obtained from the program. For example, one of the participants pointed out that growers could use the fallowing period to convert fields from conventional production to organic production. However, this would require a move away from requirements to apply herbicide during the fallowing period to eliminate any vegetation. This is a three-year process that can have economic disadvantages because crops are grown without conventional inputs but cannot be certified organic. In addition to this, there was some expressed interest in developing a more tailored fallowing program by using seasonal fallowing.

In addition to some of the specific challenges and benefits of the program, there are concerns about the impact of other water users on the program's ΔCU. Specifically, there is still concern from some participants when idle land that is not in the program is brought back into irrigated production and, thus, could offset some of the ΔCU from the fallowing program. This is because at any given time and for various reasons, there is some land in MVIDD that is currently out of production. If this land were to be irrigated during the fallowing program, it could negate the conservation effects of the program.

Another concern with idle land was that if such land were enrolled in the program, it would not result in actual ΔCU relative to recent conditions. For this reason, fields had to be irrigated in three of five recent years to be included in the fallowing program.

Finally, it was reported that initial concerns regarding the fallowing program included socio-economic concerns and fear about loss of water entitlements. Education was key. This program is in the early stages of development and there is landowner interest in continued creative development and refinement of the system.

Figure 41 Photo of a Fallowed Field with Crop Stubble to Reduce Wind Erosion in the Mohave Valley Irrigation District (credit: B. Barker, May 27, 2021).

Synopsis and Recommendations

The six case studies presented in this technical memorandum include a variety of conservation activities, temporary fallowing, seasonal fallowing, deficit irrigation, and large-scale conveyance system improvements (*Table 20*). The reader may likewise benefit from a comparison of *Figure 6*, *Figure 7*, *Figure 10*, *Figure 19, Figure 23*, and *Figure 33*, which are simplified representations of the CU quantification methods for each respective case study. The CU, or *ΔCU*, methods applied in the different participating projects vary and are subject to available data and resources. There are pros and cons associated with each method for which commentary was primarily provided in the respective *Discussion of Method Assumptions* sections for the case studies. Many of the interconnected considerations and decisions related to the selection of a CU quantification method for the different conservation activities have been summarized in a decision tree (*Figure 42*).

The decision tree was developed in an attempt to condense the results and observations from the case studies into a single summary. While this simplified summarization is not comprehensive, it is helpful as an illustration of the very challenges that led to this Pilot Study effort. When viewing, or seeking to apply the tree, it is important to consider the following:

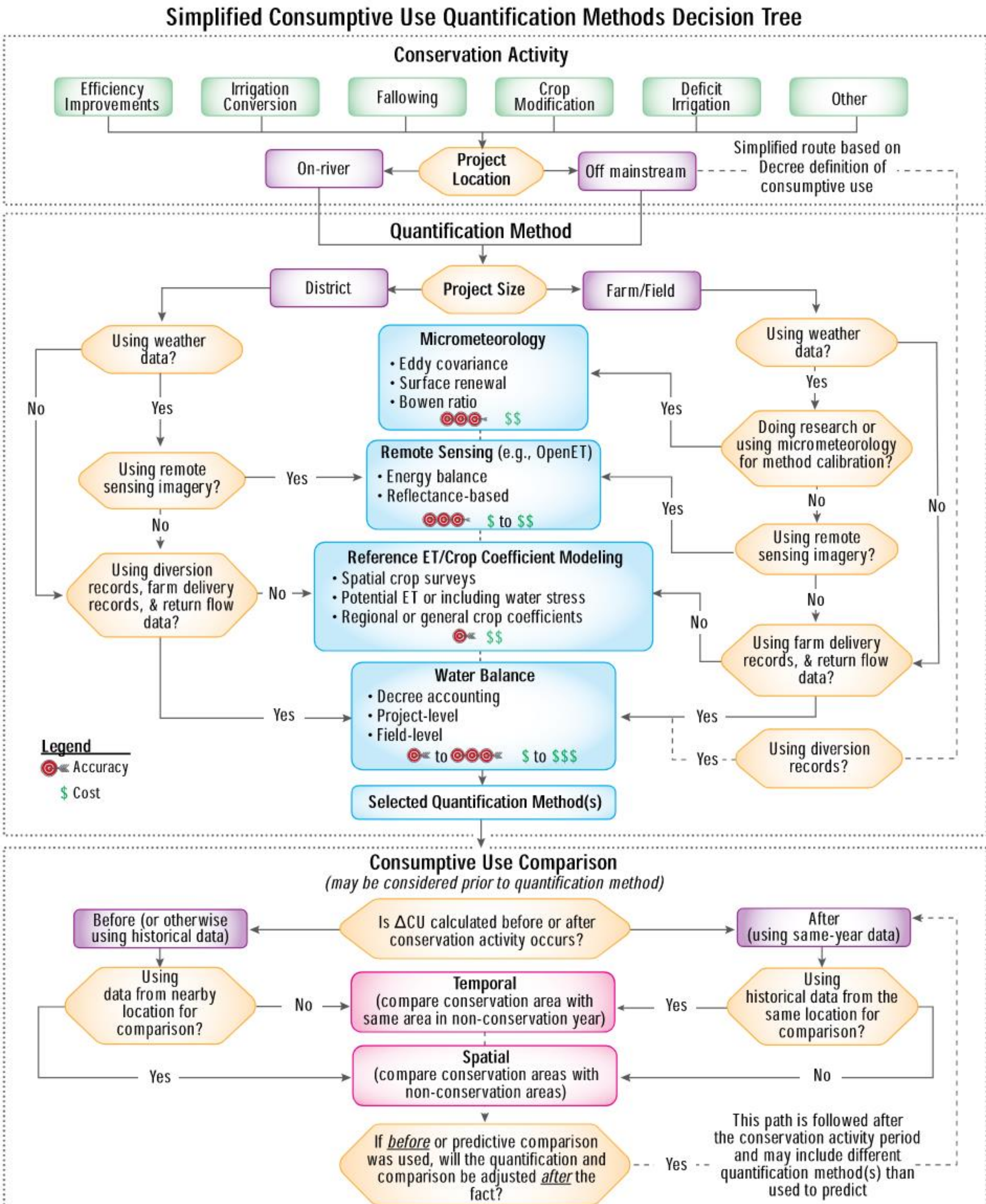
- The user must be aware of what options are practical or possible for each conservation activity. The decision tree is not the expert, it is a simplified summary based largely on the cases studied. As a future effort, the concepts from the tree could be combined with others into an electronic decision support tool that could be applied by users more directly.
- There is no single correct path for a given conservation method. Rather, the paths outlined in the tree represent things that practitioners should consider.
- Not all of the important decision factors are represented in the tree. Most notably, the decision tree does not include any direct references to non-technical aspects of a conservation agreement.
- Multiple CU quantification methods may be applied in a single study. For example, ET modeling methods could be used in conjunction or comparison with water balance methods.

Table 20 Summary of Case Study Conservation Measures and Consumptive Use Quantification Methods.

Potential Case Study	Location		Conservation Activity			Quantification Method			Comparison Method[1]		Time Period	
	On-/Off Mainstream	State	Deficit Irrigation	Fallowing	Efficiency Improvements	Water Balance	Micrometeorology	Reference ET	In Time	In Space	Single Year	Multi-Year Mean
GRIC System Modernization[2]	Off-Mainstream	AZ			•	•			•			•
Bard Water District Seasonal Fallowing Program[3]	On-Mainstream	CA		•		•				•		•
PVID Forbearance and Fallowing Program[3]	On-Mainstream	CA		•		•				•	•	•
PVID Moderate Deficit Irrigation Program[4]	On-Mainstream	CA	•			•	•	•		•		•
CRIT Fallowing Program[5]	On-Mainstream	AZ		•		•		•	•			•
MVIDD Fallowing Program[6]	On-Mainstream	AZ		•		•		•	•			•

[1]Method used to identify the change in consumptive use relative to conditions without the conservation method. The methods either compare the same area "in time" or effectively compare areas of conservation with areas not under conservation ("in space").
[2]Comparison on per-acre basis.
[3]Based on Decree Accounting Reports.
[4]Developing empirical relationship between irrigation deficit and yield.
[5]Specifically accounted for non-ideal growing conditions.
[6]Used remote sensing-based crop surveys.

Figure 42 Simplified Decision Tree for Selection of Consumptive Use Quantification Methods.



Notes:

This is a simplified representation based on the case study analyses, it is not a comprehensive guide for selecting quantification or comparison methods, though it may be helpful in identifying general technical considerations for method selection.

The logic steps are not absolute (e.g., micrometeorology is not strictly limited to field-scale research). In some instances, using multiple quantification or comparison methods may be more appropriate than just using one.

The effect of a comparison method is dependent upon similarity between the compared conditions (e.g., applying a comparison method for areas or time periods affected by water shortage).

- The decision statements on the tree are not necessarily absolute. For example, micrometeorology is not limited to field-level analyses or research applications. However, when applied practically, micrometeorology is likely to be paired with another CU technique (e.g., calibrating ET models).
- The effect of a comparison method is dependent upon similarity between the compared conditions. For example, this may be particularly a challenge when applying a comparison method for time periods when the comparison areas or times may be affected by water shortage. In such a case, the decision must be made whether to compare to water short conditions or non-water shortage conditions.

The tree can be applied to the case studies as follows:

- **GRIC Irrigation System Modernization:** This is an *Efficiency Improvement* project. This type of project requires some sort of *Water Balance*, be it a flow balance, or a ponding test, etc. to quantify CU. In this case, if there are no flow records, the practitioner would not use *Reference ET/Crop Coefficient Modeling* as the user should understand that that is not an applicable method. The CU comparison is done using data for the studied years, so the *After* timeframe would be selected with a *Temporal* comparison (comparing the same area in time).

- **Bard Seasonal Fallowing:** This is a *Fallowing* project applied at the *District* level. In the analysis, no weather data is being directly used in the quantification, nor is any remote sensing imagery. Flow data from the Decree Accounting report was utilized. This path correctly identified the *Water Balance* quantification method. The CU comparison is done using a combination of data for the studied years and previous (historical) years. So, really, both the *Before* and *After* timeframes apply with a *Spatial* comparison because the total fallowed area in the Unit is compared to the total irrigated area in the Unit.

- **PVID Forbearance and Fallowing:** This is similar to the Bard program, but the CU comparison is done separately using data for the studied year and data for previous (historical) years. Still, both the *Before* and *After* timeframes would be selected. The adjustment or "true-up" *After* the fact is also applied.

- **PVID Moderate Deficit Irrigation:** This is a *Deficit Irrigation* project applied at the *Field* level. In the analysis, weather data have been used, and it is a research project. *Micrometeorology* was correctly identified as the CU method. The comparison would be considered *After*-the-fact because data from the study years is used in quantification. The comparison would also be a *Spatial* comparison because the ΔCU is computed between plots. In future application, this comparison could be considered *Before* (i.e., predictive) when applied outside of the study itself.

- **CRIT Fallowing and MVIDD Fallowing:** These are *Fallowing* programs applied at the *District* level. However, the quantification could also be considered to be at the *Field* level. Weather data were used in the analysis, but remote sensing data were not used to estimate ET (remote sensing was used for crop identification for MVIDD) and micrometeorology was not used. Since flow records were not used for the CU directly, *Reference ET/Crop Coefficient Modeling* was correctly identified as the CU quantification method. The comparison was made using historical data from the same area in a predictive fashion (*Before* timeframe) and the comparison was temporal because CU for each participating field was compared with estimates of CU for past years from the same field. The CU comparison at CRIT was made *a priori* as one of the initial steps in the review and approval of CRIT's fallowing proposal by the respective parties to the fallowing agreement(s). This facilitated "up front" certainty in the process for the entity implementing the fallowing, for the entity funding the system conservation, and by the entity performing the accounting of water use.

One thing not fully captured in the decision tree is the full set of assumptions associated with each quantification method. Such assumptions are very situation dependent, as demonstrated in the case study discussions. For example, the Bard and PVID fallowing programs had similar CU methods, both based on the Decree Accounting reports. However, the two programs had a mix of similar and different assumptions. In an attempt to address some of the assumptions used in the two studies, including the shared assumption that the district-wide CU was representative of the fallowed ΔCU, the MVIDD and CRIT fallowing programs employed crop ET modeling. However, the methods used in these latter two programs also included certain qualifying assumptions, including some that were the same as for Bard and PVID and some additional ones as well.

One example of an assumption in the MVIDD and CRIT cases was the need to translate the CU estimates into diversion quantities for agreement purposes and comparison with the Decree Accounting. For CRIT this was done by using a universal irrigation efficiency. For MVIDD, the per-acre water duty was used. An additional assumption was that the modeled CU was an accurate representation of actual CU. This was a concern because the modeling methods used typically result in ET greater than realized for production conditions. A method that was applied in the CRIT analysis to address this concern was to adjust ET results downward based on results from remote sensing energy balance ET modeling studies in the region. More direct incorporation of remote sensing methods could be a logical next step in the progression of CU quantification methods (i.e., those used by PVID/Bard to those used by CRIT/MVIDD, and so forth).

Steps in this progression are cost dependent. For example, the quantification methods used by MVIDD and CRIT are likely more costly to employ than those used in the Bard and PVID programs because of the effort required (e.g., consultants were employed for both MVIDD and CRIT quantification efforts). Remote sensing methods are typically more expensive still. This is captured, in essence, by the accuracy and cost representations on in the decision tree. For each project, there is a practical balance between cost and accuracy.

One example of a trade-off between cost and accuracy is the employment of micrometeorological methods in the PVID deficit irrigation study. For example, these methods are not subject to the same assumptions that were included in the methods used for the fallowing programs (though there are theoretical and operation assumptions when using micrometeorology, TM2). Micrometeorological methods have the benefit of being directly sensitive to the conditions in the measurement locations. However, these methods themselves are research-grade and require expense, expertise, and effort that may not be reasonable in practice for all conservation programs. The challenge, then, for a study like the PVID deficit irrigation study is the generalization of the results. For example, that particular project will ultimately result in mathematical relationships that can be applied to estimate yield reduction from adopting the practice. The relationships, in turn, may also allow for the estimation of CU reductions. However, such relationships may need to be generalized using reference ET or by conducting a similar experiment in other areas of the LCRB to increase transferability.

In addition to the need to consider assumptions associated with the quantification methods, the user must also consider data availability. This again is not fully captured in the decision tree. For example, the GRIC project is an off-mainstream project, so, based on the Decree definition, CU = diversions, because there are no return flows to the Colorado River. Therefore, *⊿CU* could be quantified based on diversions (as represented using supply flows in the case study). However, there was a data availability challenge for historical (pre-improvement) flow records. This challenge is not unique to GRIC. It is common for data quality and availability to improve in time. For an efficiency project (especially off mainstream where CU is equal to diversions), it can be difficult or impossible to accurately estimate CU without flow measurements. For certain conservation activities (particularly on the Colorado mainstream), ET modeling techniques can be used to address the challenge resulting from a lack of certain measurements. However, even modeling methods require input data of some sort (e.g., weather data and cropping patterns).

Another related challenge faced in the GRIC case study was the comparability of before-and-after conditions to estimate *⊿CU*. This challenge is a universal difficulty in quantifying *⊿CU*. For the GRIC project, even without data record limitations, it is still necessary to make assumptions of similarity between years before and after the project improvements because factors other than the improvements may affect *⊿CU*. For the fallowing programs, these similarity assumptions were typically made in space (the fallowed fields would perform similarly to other fields in the area) though they were made in time also for MVIDD and CRIT (the fallowed fields would perform similarly to the same fields in the past). For the deficit irrigation study, the assumption of similarity will be in the applicability of the relationships developed at PVID, relating yield changes to *⊿CU* and to changes in irrigation application, to other areas of the LCRB.

The principle of similarity will always be necessary, since it is impossible to both implement and not implement a conservation activity in the same space and time. The assumption of similarity can be strengthened by including spatially and/or temporally accurate CU estimates. For example, by including remote-sensing-based ET models (RS-ET models). Such models are becoming increasingly affordable to implement and some RS-ET model output products are becoming publicly available (Open-ET, 2021). These products are subject to their own associated sets of assumptions and accuracies (TM2). However, they provide spatial estimates of actual crop ET, which can be of use in quantifying *⊿CU*. These products may also provide, as shared in a communication from the Arizona Department of Water Resources, a consistent methodology for estimating CU to be applied to projects in different areas.

One example of how remote sensing products could be used to improve *⊿CU* estimates, including supporting similarity assumptions, would be to analyze such products for a study area or district for years prior to any conservation program. A statistical analysis could be used to identify whether CU (and crop types) in fields that would later participate in the conservation program were significantly different than CU (and crop types) for fields that would not participate. If no difference is observed, the RS-ET models could be applied in years of conservation to quantify *⊿CU* based on comparison between the participating fields and non-participating fields. Using RS-ET models for comparisons in space was also applied in the Upper Colorado River Basin by Allen and Torres-Rua (2018).

A variation of the spatial RS-ET model analysis mentioned above would be to perform the same type of analysis but compare CU across several non-conservation years for fields that would participate in the conservation program. That is, perform the comparison in time. This would allow for identification of interannual variability in CU. The user could then use the mean CU for a determined number of non-conservation years in comparison with CU for one or more conservation years to estimate *⊿CU*. Using the ratio of CU to Reference ET could be used to assist in this comparison as was done by Allen and Torres-Rua (2018) in the Upper Colorado River Basin. Adaptation would be necessary for predictive analyses, such as MVIDD and CRIT provide.

The statistical analyses just described and the comparisons using reference ET to normalize comparisons could also be applied with adaptation to non-remote-sensing methods, like the water balance estimates of PVID and Bard. The RS-ET-model approaches described above could also be incorporated as either primary or secondary CU estimation methods. For example, the CU quantification for the CRIT fallowing program was adjusted based on the results of RS-ET modeling studies. However, incorporating longer period RS-ET model results and performing on-going analyses, including application during conservation periods could improve the CRIT methods. The inclusion of multiple CU estimation methods could benefit any of the projects considered herein, particularly the on-mainstream projects. RS-ET modeling could be used as a second or primary CU method for any of the projects. A second CU estimation method would not be limited to RS-ET models. For example, the reference-ET-based methods used for MVIDD and CRIT could be directly compared with the district-wide water balance approach used for Bard and PVID. When using multiple methods, invariably each method would result in a different estimate of *ΔCU*. However, having more than one estimate would allow the involved parties to investigate the causes of differences and decide which method(s) they would use ultimately use.

In addition to CU methods, the number of years included in an estimate of *ΔCU* is also important. For example, according to MWD, PVID estimates of CU are typically based on Decree Accounting results for the year in question. The Bard estimates of CU for 2020 also included the year in question, but it was incorporated in a mean with the four preceding years. For CRIT and MVIDD, the mean *ΔCU* was computed using up to five past years and for GRIC, two years prior to the improvements and two years after were used to characterize *ΔCU*.

These different periods of analysis were the result of several considerations. These considerations included the availability of data (e.g., only two years were available after improvements for GRIC). Another consideration was practicalities (e.g., the inclusion of two years prior to improvements for GRIC was a group decision made to keep the required effort reasonable, among other things). The analysis period was also dependent upon the project intent. For example, the PVID and Bard analyses were applied after-the-fact and so, including the data for the year of conservation was possible. However, the CRIT and MVIDD methods were designed to be used prior to the conservation activity. Therefore, a predictive estimate was needed and in both cases the mean of several past years was selected as the predictor. The benefit of using the current year's data for quantification for conservation activities like fallowing programs is evident. However, in cases where a forecast of the conservation activity is needed or in cases like GRIC's project, where the conservation activity provides a clear before-and-after type of condition, including multiple years in the analysis can provide a more robust estimate.

From a statistical standpoint, when using a mean across years as a predictor, the more years included, the better the prediction. This is subject to the condition that including more years does not mean including years with irrelevant crop, management, or irrigation practices and so forth (in general, the same considerations could be applied when comparisons are made in space). Where possible, efforts should be made to normalize data included in interannual or spatial means. For example, using reference ET, as described above, or by dividing estimates by irrigated area as in the GRIC and Bard cases and both PVID cases, or by excluding areas or times that have non-representative conditions. For example, if crops or irrigation methods changed 10 years ago, it may be inaccurate to extend an analysis back into that time. The discussion regarding permanent crop CU at Bard is another example. Including cropping patterns and other relevant practices in any temporal or spatial statistical analyses (e.g., as described in the recommendations for using RS-ET models above) can help identify periods or locations that should be excluded from CU quantification. Because a historical mean may differ from the actual conditions in a conservation year a prudent practice would be to include a correction using data for the conservation year after the conservation year is over. The PVID fallowing program is an example of this. The need for such an adjustment may be a collective decision of the various project parties.

In addition to technical considerations and improvements, it is important to consider the desires of the parties involved in a conservation activity. This includes the conserving parties and the beneficiary parties (e.g., funding parties or regulators). The varying interests will drive the type of quantification and comparison methods used and what is to be quantified. The selection of a comparison method and baseline for determining ΔCU is an example. Do the parties want an upfront (predictive) quantification, or should the quantification represent the conservation period? Or should the comparison be made upfront and corrected, or "trued-up" after the fact? Should the comparison be made in space (e.g., conservation field to neighboring fields), or in time (conservation period to non-conservation period), or both (e.g., the Bard method is implicitly both)? What periods or areas should be considered for a baseline? Should multiple baselines be used or multiple comparisons be made? For example, for CRIT and MVIDD, ΔCU is estimated, but a diversion reduction and corresponding diversion cap are also quantified as additional metrics of conservation.

Decisions on methods should be agreed upon collectively. Such processes should be transparent and should allow for adaptation and improvements as resources, technologies, etc. become available or the state of the science advances. When agreeing upon a set of quantification and comparison methods, it is important to acknowledge also that CU methods should be reviewed and changed as necessary. Agreements on quantification methods will likely be concurrent with other factors, payment, legal, etc. in a conservation program. Although not directly related to quantification, it is helpful to consider some of the lessons learned in the case study *Reflections* presented previously. For example, the ability of a district or participant to take advantage of a conservation program for purposes beyond water conservation (e.g., for system improvement construction at Bard, or the desire to use fallowing to transition to organic production at MVIDD). Conversely, negative impacts must also be considered like socio-economic impacts on communities, potential impact on other water resources (e.g., groundwater at GRIC), or the impact of the conservation practice on regular crop production (e.g., increased impact of chemical application on fallowed field soil health with time at MVIDD).

In closing, each of the studied cases have employed ΔCU methods that are in some way different than those applied by the others. The methods used vary in cost and expertise required to employ them and the availability of information. None of the ΔCU methods would be applicable in all cases and therefore, no "best" option is identified herein as multiple methods, or combinations may be equally valid, and cost and other non-technical factors must be considered. However, certain principles can be learned from each. The importance of data collection, e.g., regarding crops grown and grower practices, flow measurements, and weather, to name a few, is evident for all of the cases. Each of the ΔCU methods described has some advantage over the others, each could also benefit from refinement. The accuracy of quantification methods is important to all parties involved in a conservation program. The need to continue improving ΔCU methods, even for programs that seem highly developed or mature is important. For all cases, the ever-improving CU quantification methods, technology, and data products should be evaluated and incorporated in a continuous process. No ΔCU quantification methodology should be considered final or closed to improvement particularly as conditions (e.g., climate, infrastructure, political, management, cropping, irrigation methods), quantification and measurement technologies, and other information change.

Workshop #3 Participants

Almost 50 people participated in Workshop #3. *Table 21* is a list of the workshop attendees.

Table 21 Workshop #3 Participants

Funding Partners

Reclamation	Central Arizona Water Conservation District	Metropolitan Water District of Southern California	Southern Nevada Water Authority
Dan Bunk Jeremy Dodds John Shields Nohemi Olbert KayLee Nelson	Deanna Ikeya	Bill Hasencamp Aaron Mead Larry Lai Michael Yu Nadia Hardjadinata	Seth Shanahan Casey Collins

Agricultural Districts/Cities

Imperial Irrigation District	Yuma Mesa Irrigation and Drainage District	Mohave Valley Irrigation and Drainage District	Coachella Valley Water District	Mojave Water Agency
Dylan Mohamed Ben Brock	Mike Crowe	Kerri Hatz Michael Pearce Vince Vasquez	Robert Cheng	Anna Garcia

Tribal Representatives

Bureau of Indian Affairs	Fort Mojave Indian Tribe	Colorado River Indian Tribes	Ak-Chin Indian Community	Quechan Tribe
Jonathan Cody Johnita Whiteman Cherry Bustos Gary Colvin Davetta Ameelyenah Catherine Wilson	Russell Ray	Guillermo Garcia Dillon Esquerra	Brenda Ball	Jay Weiner Frank Venegas

State Agencies

Arizona Department of Water Resources	University of California Cooperative Extension	Colorado Water Conservation Board	San Juan Water Commission	Colorado River Commission of Nevada
Rabi Gyawali	Ali Montazar	Michelle Garrison	Aaron Chavez	Warren Turkett

Consultants/Attorneys/Other

NRCE	Jacobs	Noble Law	Moyes Sellers & Hendricks	Pima-Maricopa Irrigation Project
Tom Ley Ryan McBride Burdette Barker	Lela Perkins Chris Kurtz Armin Munevar	Meghan Scott	Jason Moyes	David DeJong

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Appendix: Workshop 3 Presentation Slides

BUREAU OF RECLAMATION

Exploration of Quantification Methods for Agricultural Water Savings in the Lower Colorado River Basin

Workshop #3

September 22, 2021

Welcome/Introductions

Workshop #3 Agenda

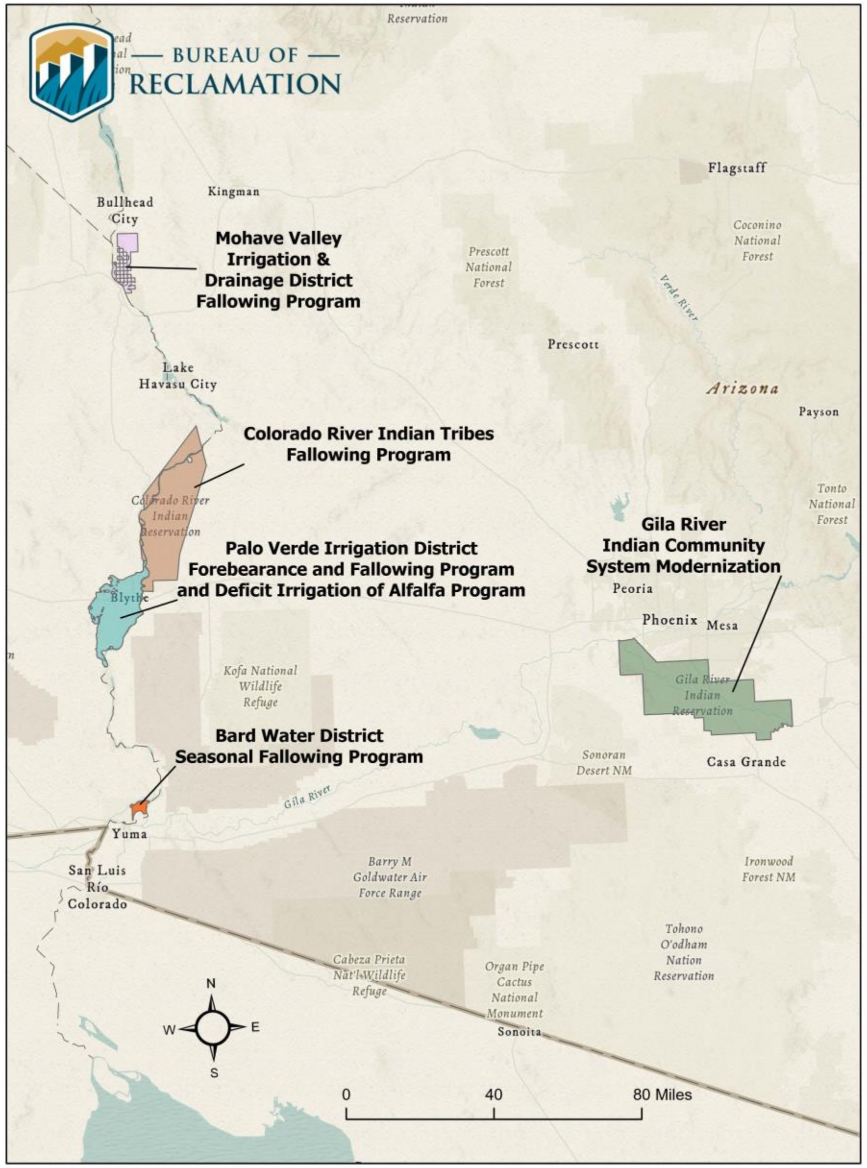
- Welcome and Introductions
- Background/Acknowledgements
- Case Study Summaries
- Decision Tree Summary
- Synopsis and Discussion
- Wrap-up and Next Steps

Background and Pilot Study Objectives

- The 2012 Basin Study identified strategies to address the evolving supply-demand imbalance
- The subsequent Moving Forward effort identified quantification of agricultural conservation water savings as a challenge
- Using case studies:
  - Explore methods currently in use to quantify agricultural water conservation
  - Evaluate methods for consistency and accuracy with Reclamation's Lower Colorado River water accounting methods
  - Recommend approaches to improve methods of quantifying agricultural water conservation in the Lower Basin

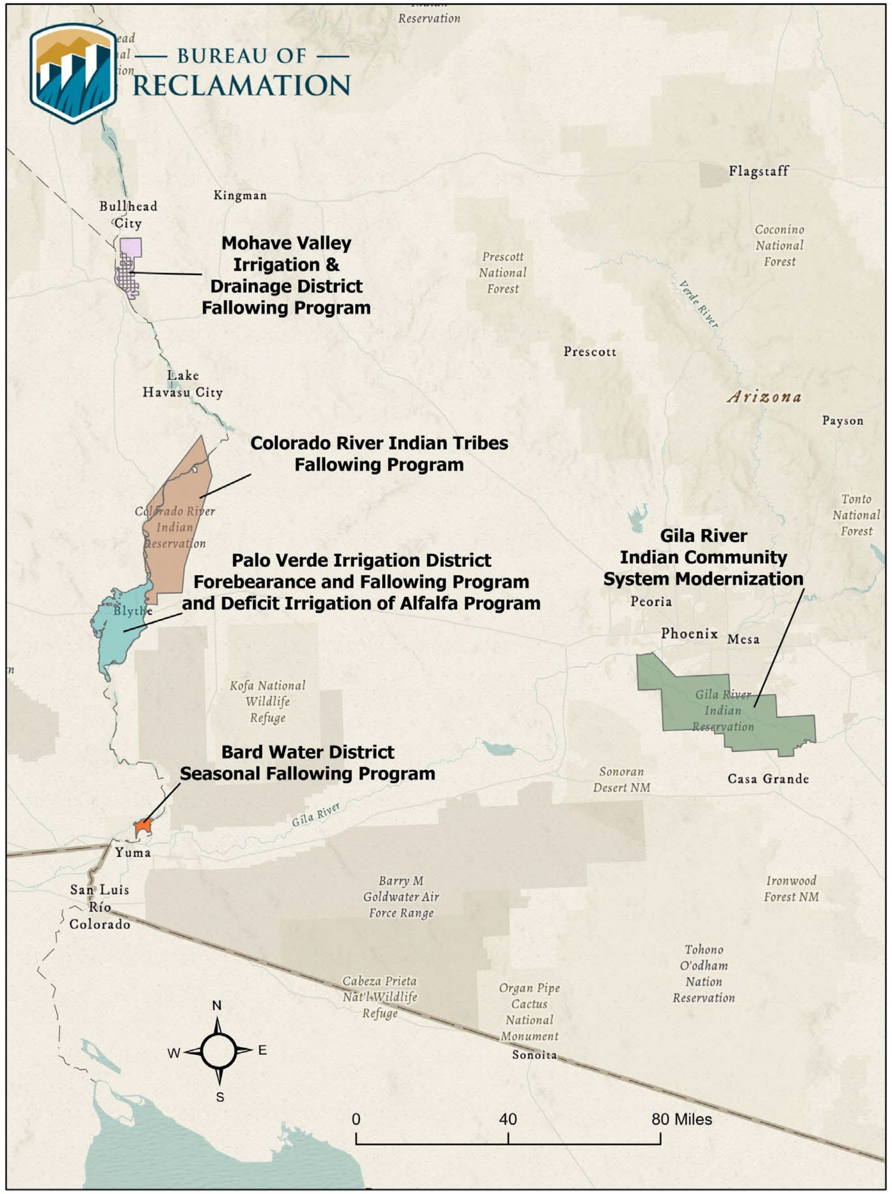
Case Studies Selected for Evaluation

- Gila River Indian Community System Modernization
- Bard Water District Seasonal Fallowing Program
- Palo Verde Irrigation District Forbearance and Fallowing Program
- PVID Partial Year Deficit Irrigation of Alfalfa Program
- Colorado River Indian Tribes Fallowing Program
- Mohave Valley Irrigation and Drainage District Fallowing Program



Case Studies Selected for Evaluation

Case Study	Location		Conservation Activity					Quantification Method			
	State	On-/ Off Mainstream	Deficit Irrigation	Irrigation Conversion	Fallowing	Crop Modification	Efficiency Improvements	Water Balance	Micrometeorology	Reference ET	Remote Sensing
PVID Forbearance and Fallowing Program	CA	On-Mainstream			X			X			
PVID Partial Year Deficit Irrigation of Alfalfa Program	CA	On-Mainstream	X					X	X	X	
CRIT Fallowing Program	AZ	On-Mainstream			X			X		X	
Mohave Valley IDD Fallowing Program	AZ	On-Mainstream			X			X		X	
Bard Water District Seasonal Fallowing Program	CA	On-Mainstream			X			X			
GRIC System Modernization	AZ	Off-Mainstream					X	X			



Case Study Evaluation Process

- In-person field visits and interviews
- Review of documentation
- Relationship of the conservation activity and quantification method to Reclamation's Colorado River Decree Accounting
- Identification of challenges and lessons learned
- Consideration of the accuracy of methods used in the project
- Consideration of costs and complexity of program implementation
- Opportunities for improvement of the quantification method(s)

Acknowledgements

- Gila River Indian Community (GRIC)
  - David DeJong, Pima-Maricopa Irrigation Project (P-MIP) Director
  - Christopher Blackwater, Bureau of Indian Affairs (BIA)
  - Kyle Varvel, BIA
  - Bill Eden, P-MIP Senior Civil Engineer
  - Mark Moore, Gila River Irrigation and Drainage District (GRIDD)
  - Delbert Johnson, GRIDD
- Bard Water District (Bard)
  - Nick Bahr, Bard General Manager
  - Bill Scott, Board Director
  - Jerry Nakasawa, Board Vice President
  - Meghan Scott, Bard Legal Counsel
- Palo Verde Irrigation District (PVID)
  - Ned Hyduke, General Manager
  - JR Echard, Operations Manager
  - Jack Seiler, Board President
  - Ryan Seiler, Grower
  - Grant Chaffin, Grower
  - Kim Bishoff, District Controller
- Palo Verde Irrigation District (PVID) (cont'd)
  - Paula Hayden, PVID Fallow Coordinator
  - Ali Montazar, University of California
- Colorado River Indian Tribes (CRIT)
  - Amelia Flores, Chairwoman
  - Tommy Drennan, Councilman
  - J.D. Fisher, Councilman
  - Anisa Patch, Councilwoman
  - Devin Heaps, Water Resources Director
  - Guillermo Garcia, Hydrologist
  - Miguel Gonzales, CRIT Farms
  - Rebecca Loudbear, CRIT Attorney General
- Mohave Valley Irrigation and Drainage District (MVIDD)
  - Kerri Hatz, MVIDD General Manager
  - Charles (Chip) Sherrill, Chairman
  - Vince Vasquez, Board Director
  - Michael Pearce, MVIDD Legal Counsel
  - Chris Stall, Land IQ, Consultant

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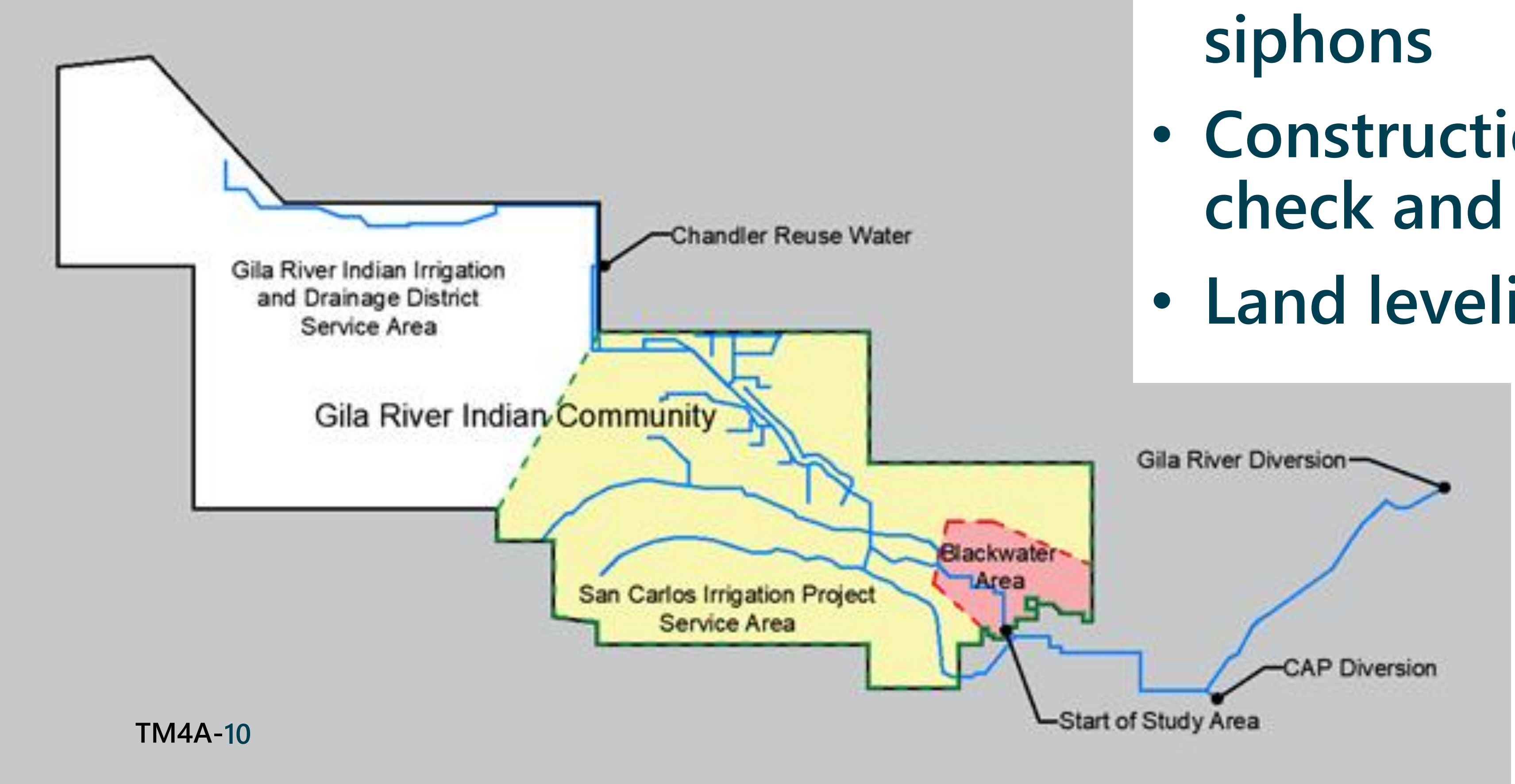
Gila River Indian Community System Modernization

Pima-Maricopa Irrigation Project

- Goals: efficiency, reliability, modernization
- Reconstruction and concrete lining of all main canals and most laterals
- Reconstruction of pipelines and siphons
- Construction or reconstruction of check and drop structures
- Land leveling

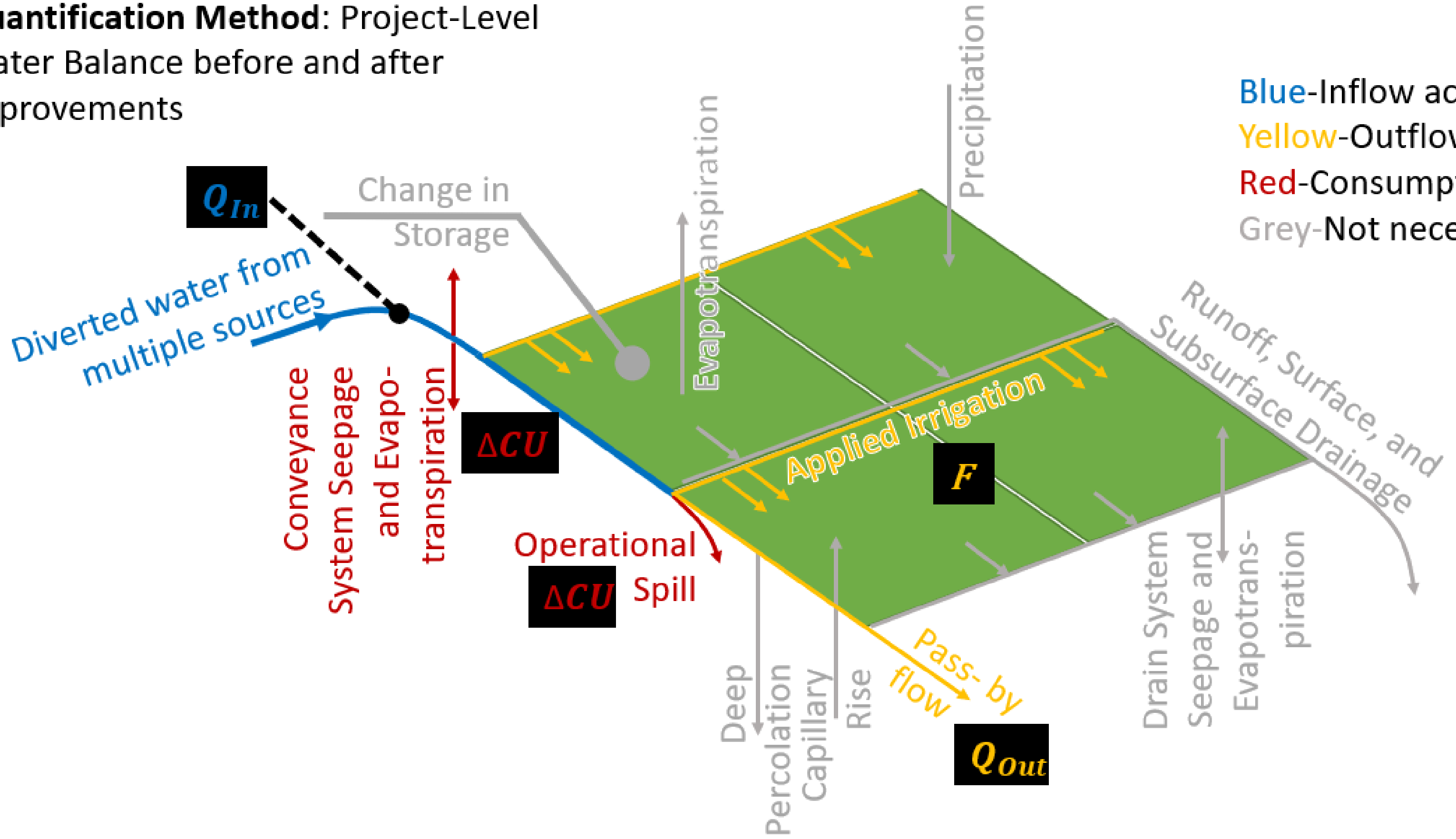


CU Quantification

Simplified Representation of the Project-Level Water Balance Approach for Quantifying Consumptive Use Reductions for the P-MIP Infrastructure

Quantification Method: Project-Level Water Balance before and after improvements

Blue-Inflow accounted for in analysis
Yellow-Outflow accounted for in analysis
Red-Consumptive use in analysis
Grey-Not necessary in analysis



$$\frac{\Delta CU}{A_{Irr}} = \frac{Q_{In}^{Before} - Q_{Out}^{Before}}{A_{Irr}^{Before}} - \frac{Q_{In}^{After} - Q_{Out}^{After}}{A_{Irr}^{After}}$$

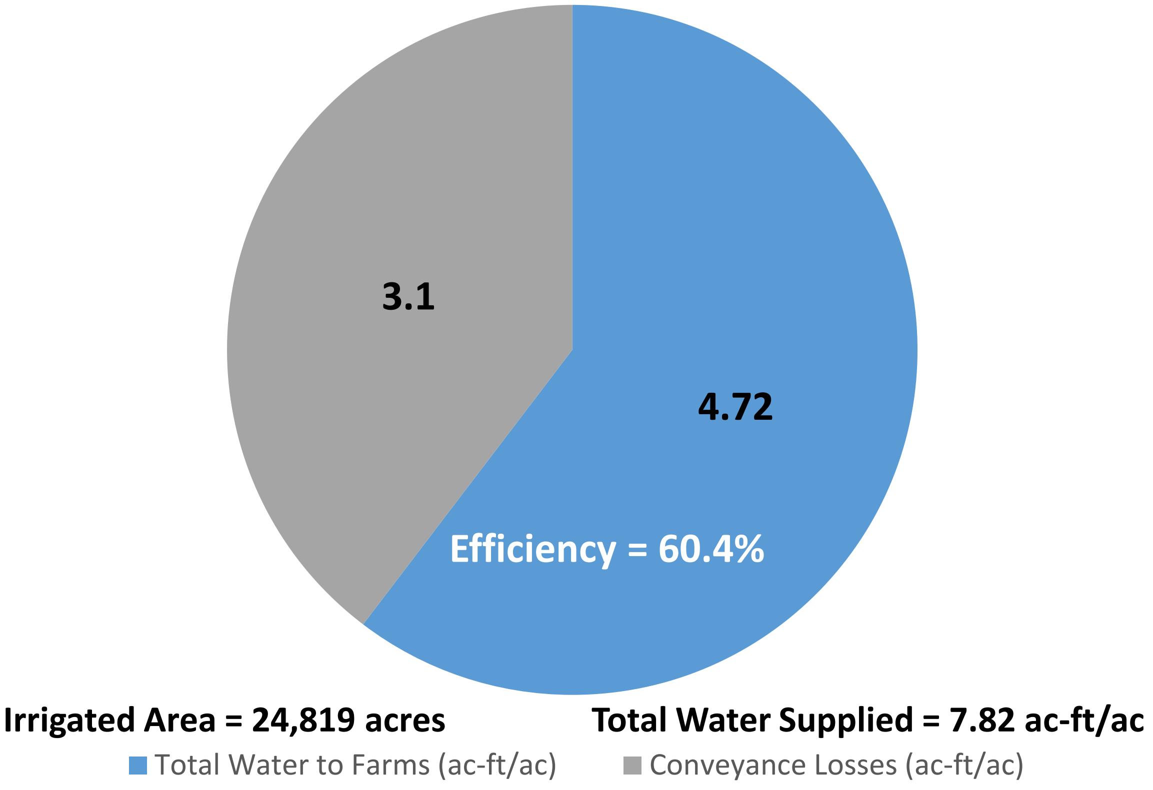
$$\frac{\Delta L_{Conv}}{A_{Irr}} = \frac{Q_{In}^{Before} - Q_{Out}^{Before} - F^{Before}}{A_{Irr}^{Before}} - \frac{Q_{In}^{After} - Q_{Out}^{After} - F^{After}}{A_{Irr}^{After}}$$

CU Quantification

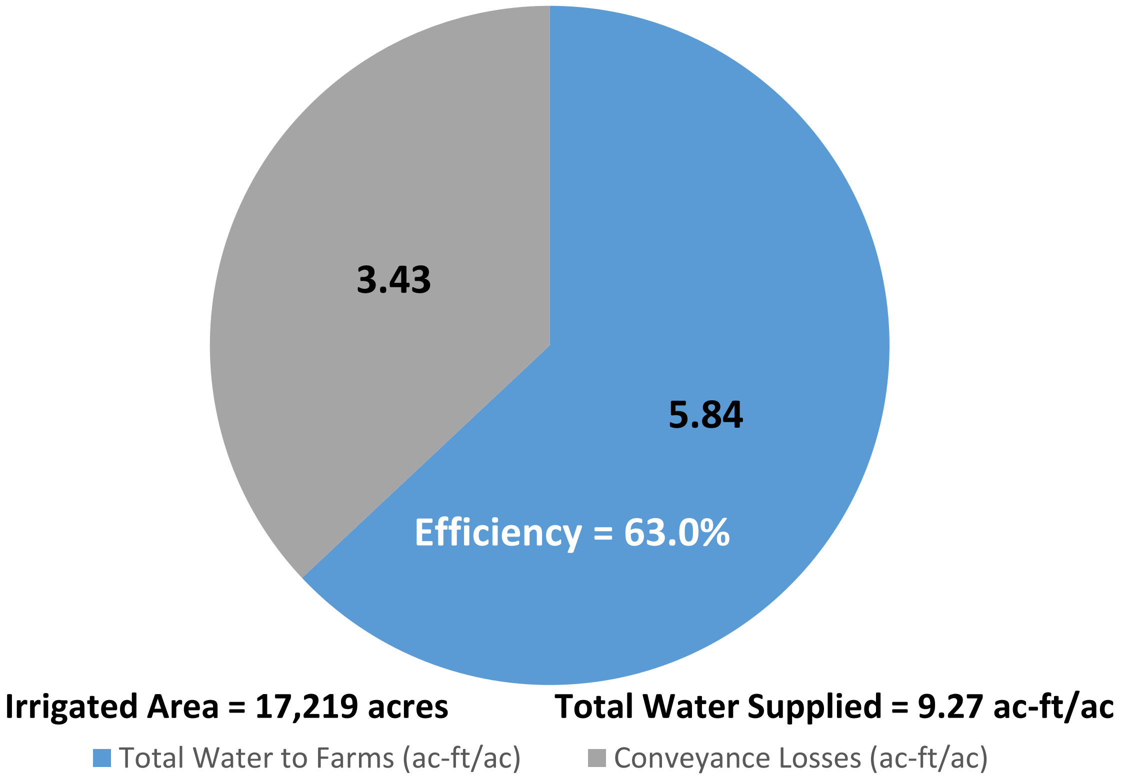
- P-MIP system can be considered an off-river water user
- CU reduction can be quantified by comparing diversions records before and after improvements
- Since P-MIP build-out is not completed, it was decided that ΔCU would be evaluated for sub-areas of the P-MIP

CU Results (P-MIP Service Area)

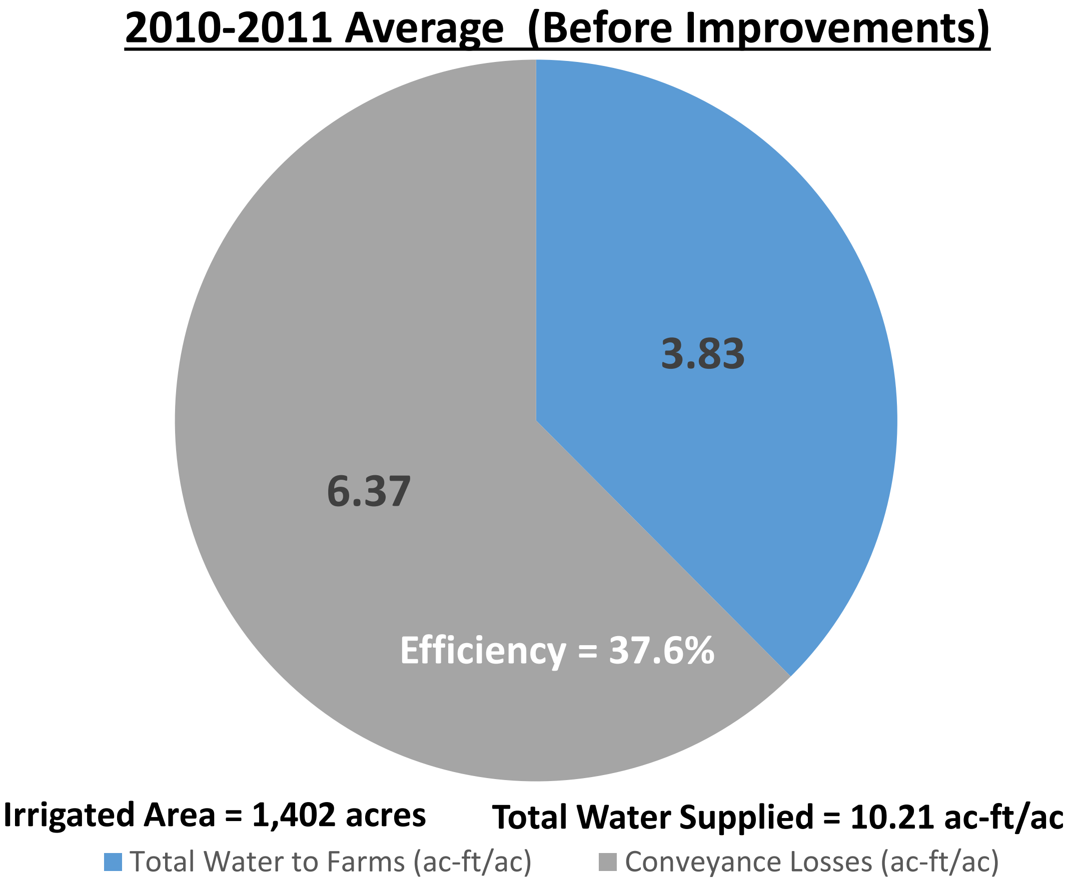
2010-2011 Average (Before Improvements)

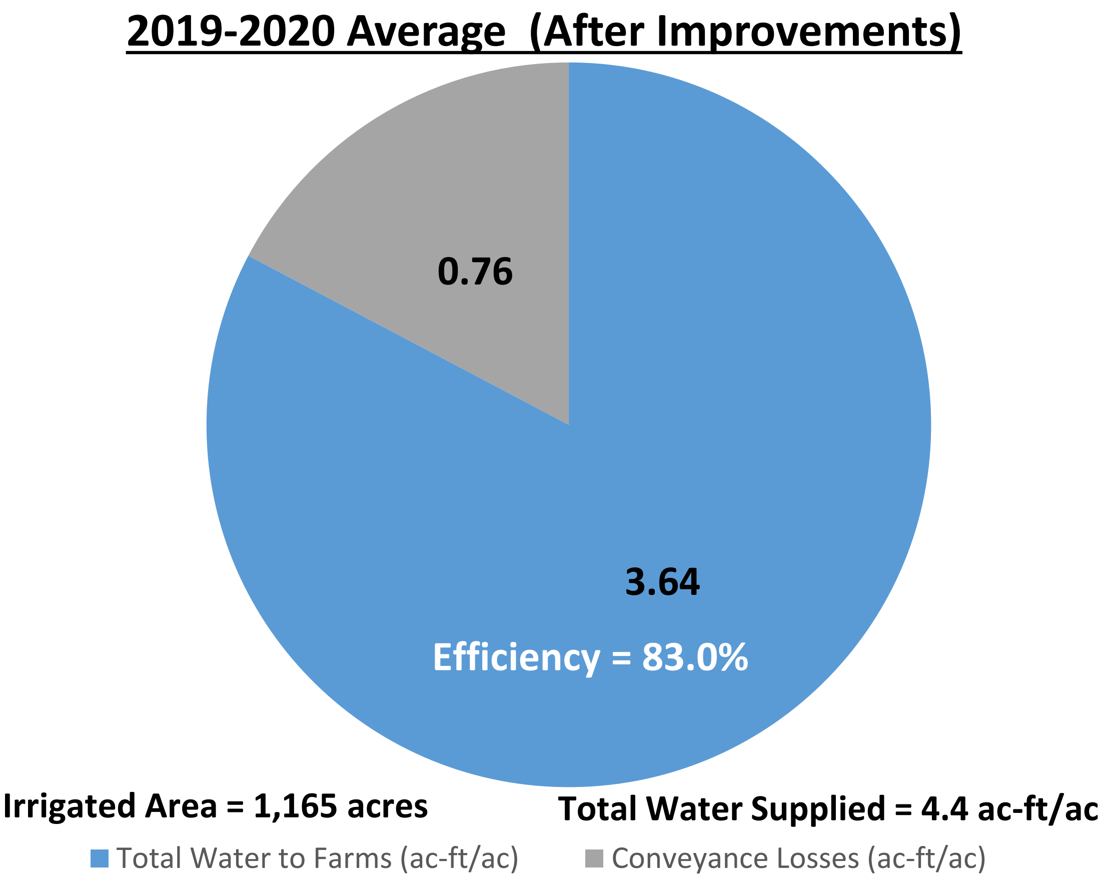


2019-2020 Average (After Improvements)



CU Results (Blackwater Area)





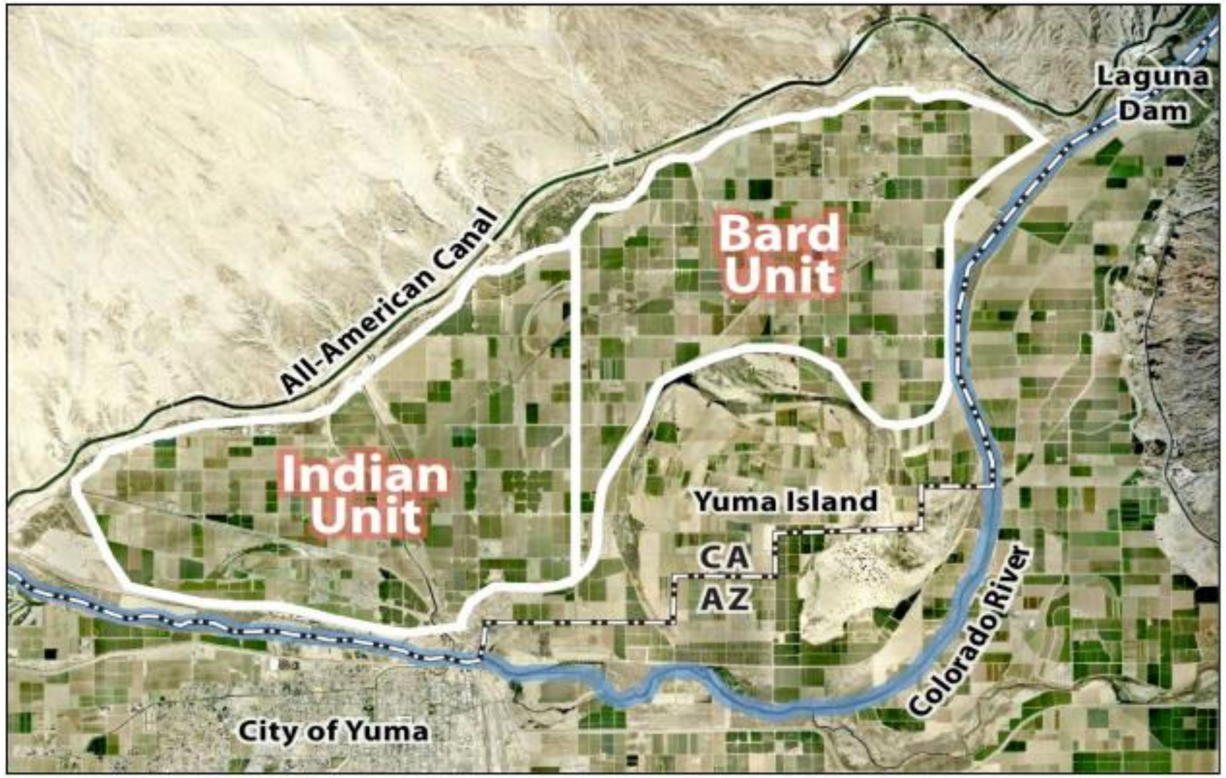
Reflections

- P-MIP is a large project made possible by reliable and consistent funding
- GRIC is committed to providing a resilient, reliable and efficient irrigation system
- Changes in system management also provides potential efficiencies in administrative effort and expense
- Quantifying changes in CU is challenging due to lack of available pre-improvement data
- Anecdotal evidence of decreased groundwater recharge from the canals now that they have been lined

Bard Water District Seasonal Fallowing Program

Bard Water District Seasonal Fallowing Program

- Applies only to Bard Unit from April 1 through July 31
- Up to 3,000 acres can be fallowed each year (minimum of 10 contiguous acres for each area)
- MWD pays each grower a flat rate based upon the area fallowed
- MWD covers administrative costs and a per-acre rate for district infrastructure improvements
- Conserved water available for use by MWD

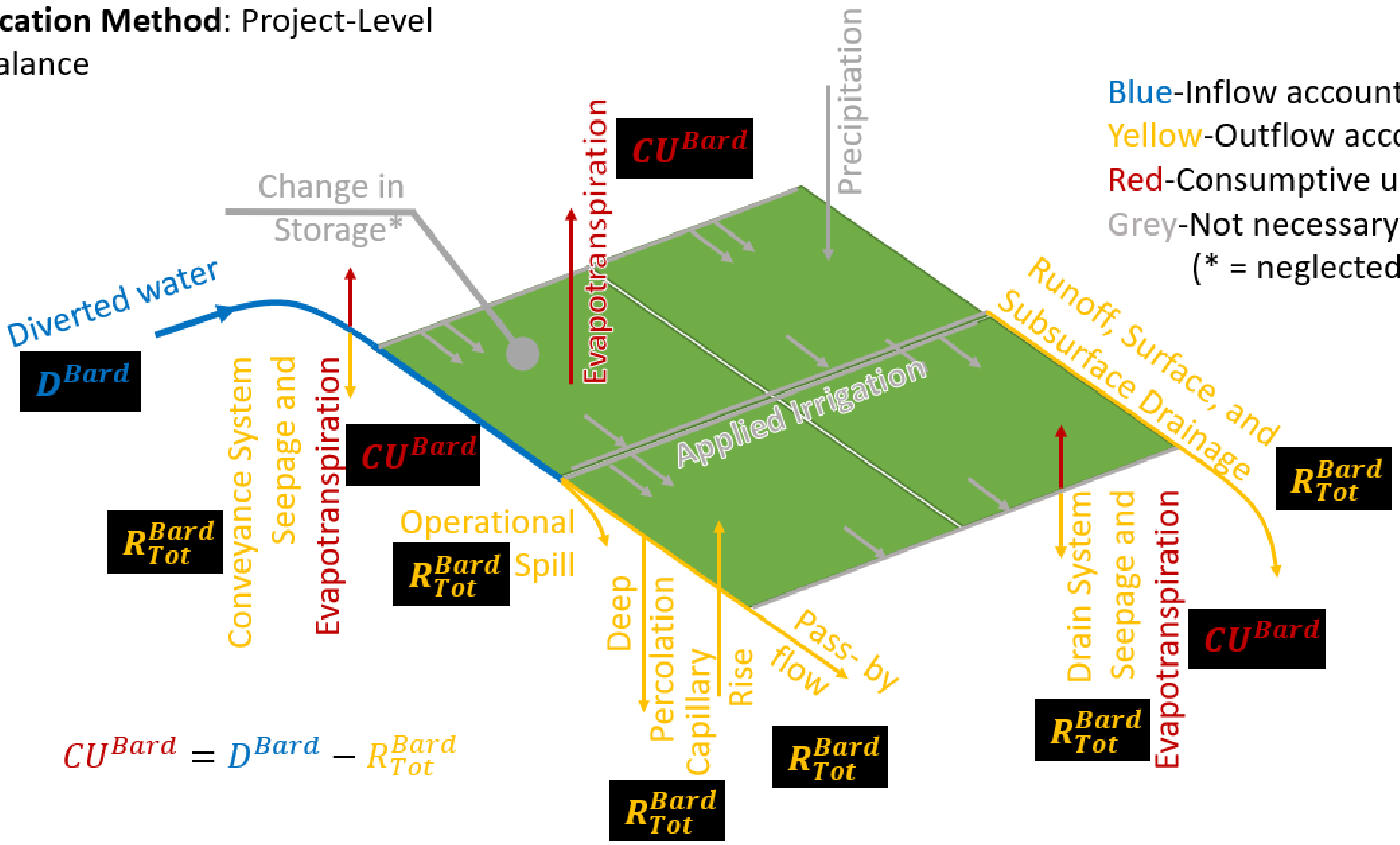


Map of Bard Water District

CU Quantification

Simplified Representation of the Project-Level Water Balance Approach for Quantifying Consumptive Use Reductions for the Bard Water District Seasonal Fallowing Program

Quantification Method: Project-Level Water Balance



Blue-Inflow accounted for in analysis
Yellow-Outflow accounted for in analysis
Red-Consumptive use in analysis
Grey-Not necessary in analysis
(* = neglected)

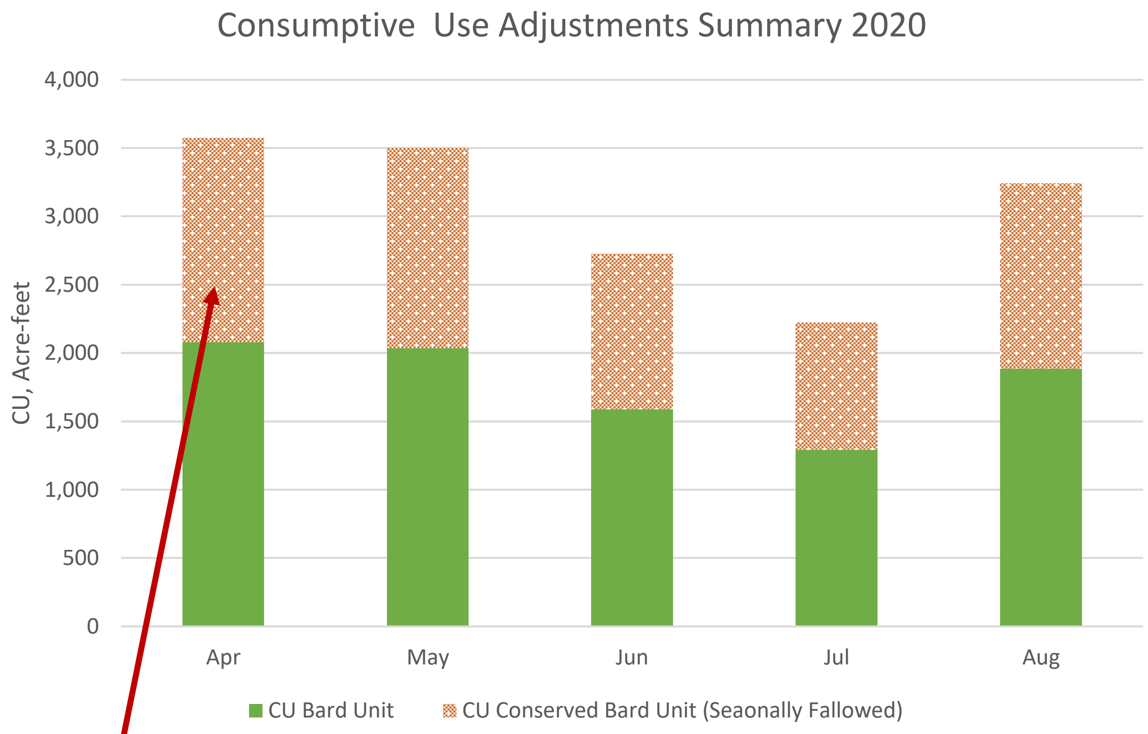
$$CU^{Bard} = D^{Bard} - R_{Tot}^{Bard}$$

CU Quantification

- ΔCU based upon Reclamation's Decree Accounting
- Diversions, unmeasured return flows, and a portion of the measured return flows are reported by Unit
- Delineation of irrigated lands likely represents the most time-consuming task for CU quantification

CU Results

Year	Area Fallowed (acres)	Reported CU Factor (AF/ac)
2016	509	1.87
2017	1,641	2.32
2018	973	1.99
2019	1,984	2.14
2020	2,749	2.32
Area-Weighted Mean	1,571	2.21
------------- 2020 ΔCU -------------		
2020 Fallowed Area (ac)		2,749
2020 ΔCU (AF)		6,075



Conserved CU

Reflections

- From the grower's perspective, fallowing can be considered like one of several potential crops in a crop rotation
- Program can be logistically favorable
  - Timing
  - Less productive land
- Reduced water deliveries during the fallowing period can help facilitate improvement projects, like canal lining
- Software program modifications were required to facilitate the fallowing program
- The Bard Unit has an unquantified water right - a program is the only means of leasing water to other users

Reflections

- MWD is presently developing a revised method for quantifying ΔCU for the program, which will include precipitation and estimates of ET
- Accuracy of the ΔCU is of importance to all parties involved
- Current program is considered by some to be the "right" size to appropriately balance potential impacts on agronomics and the local economy

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Palo Verde Irrigation District Forbearance and Fallowing Program

PVID Forbearance and Fallowing Program

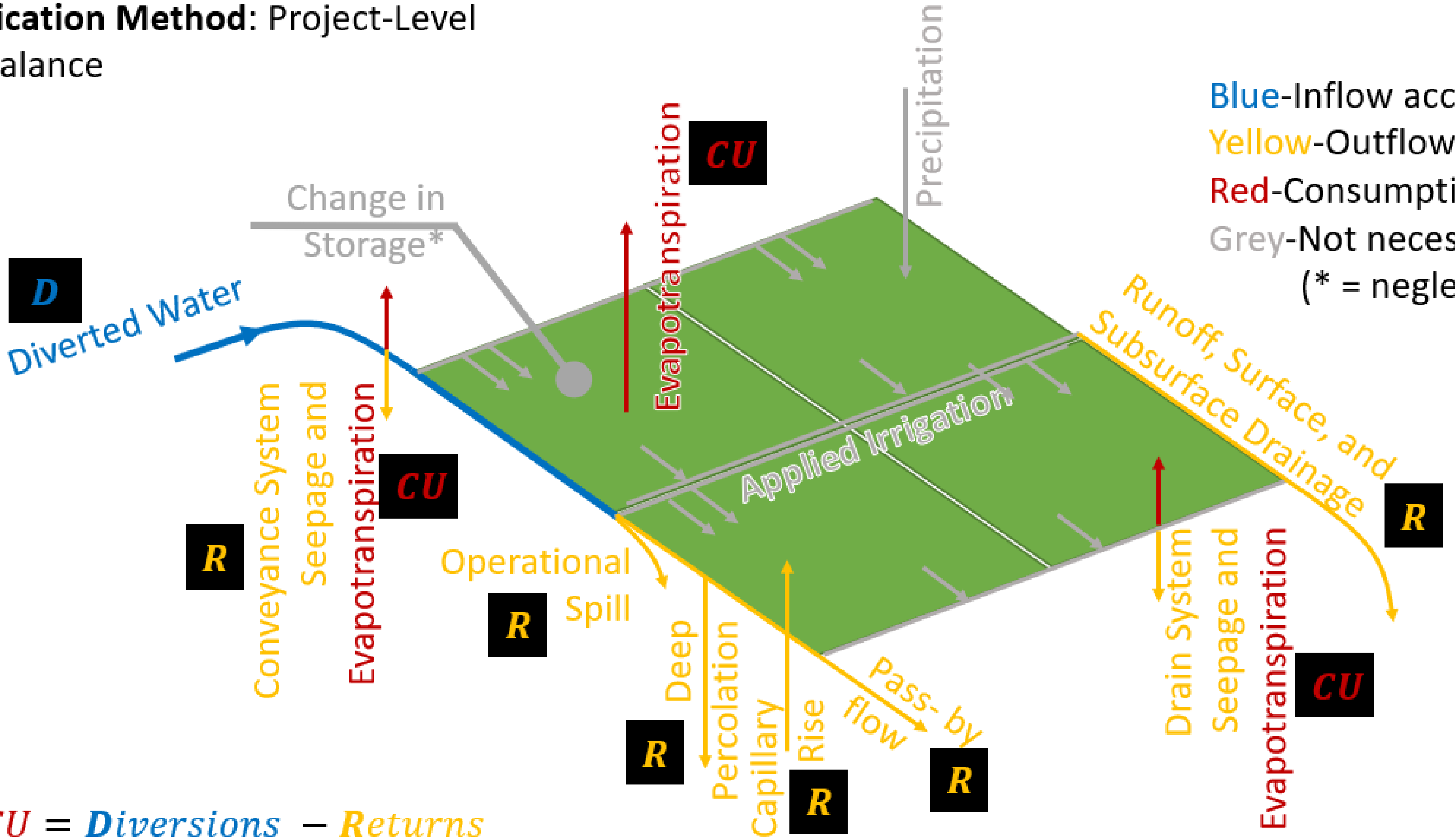
- Program began in 2004
- 35-year agreement with MWD
- Payments based on acreage fallowed
- $6M for local community improvement programs
- Conserved water available for use by MWD
- Amount of land in program each year is determined by MWD
- Minimum of 5 acres – portions of fields can be fallowed

CU Quantification

Simplified Representation of the Project-Level Water Balance Approach for Quantifying Consumptive Use Reductions for the PVID Fallowing Program

Quantification Method: Project-Level Water Balance

Blue-Inflow accounted for in analysis
Yellow-Outflow accounted for in analysis
Red-Consumptive use in analysis
Grey-Not necessary in analysis
(* = neglected)



$$CU = Diversions - Returns$$

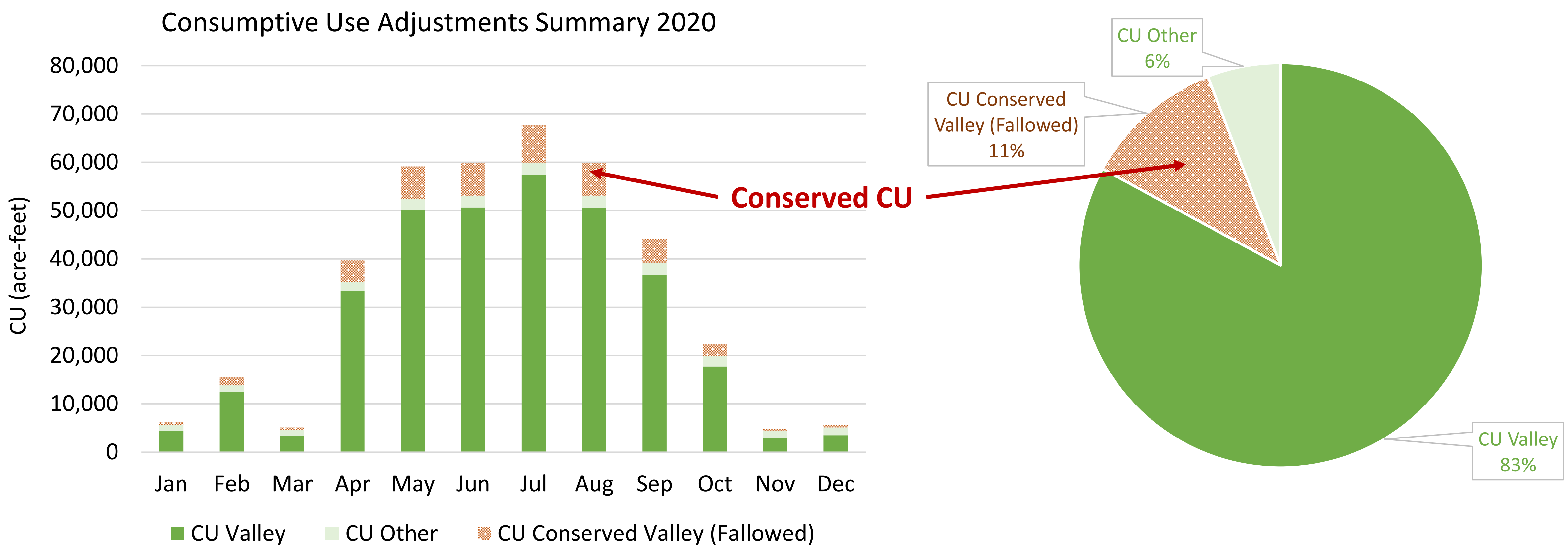
$$CU_{Valley} = CU_{Total} - CU_{Mesa} - CU_{Pumped} - CU_{PVER} - CU_{PVER-So} - CU_{DUCA}$$

Some components of CU are estimated directly.

CU Quantification

- ΔCU based upon Reclamation's Decree Accounting
- CU quantified over various historical periods using measured diversions, measured return flows, and estimates of unmeasured return flows
- Estimated by subtracting out CU of areas outside of the Valley

PVID Forbearance and Fallowing



Reflections

- Allows growers to fallow portions of their fields that may be particularly problematic
- MWD required an easement equal to the area committed to the program
- Program requires a notable amount of administrative effort
- Only means of leasing water to other users is through a program where a conservation practice, like fallowing, is implemented
- Accuracy of the ΔCU is of importance to all parties involved

Palo Verde Irrigation District Partial Year Deficit Irrigation of Alfalfa Program

Partial Year Deficit Irrigation of Alfalfa Program

- Initiated by researchers with UC Agriculture and Natural Resources
- Purpose is to measure the impacts on applied irrigation water, CU, yield, yield quality, soil salinity, and alfalfa plant stand of “moderate” deficit irrigation during the summer months

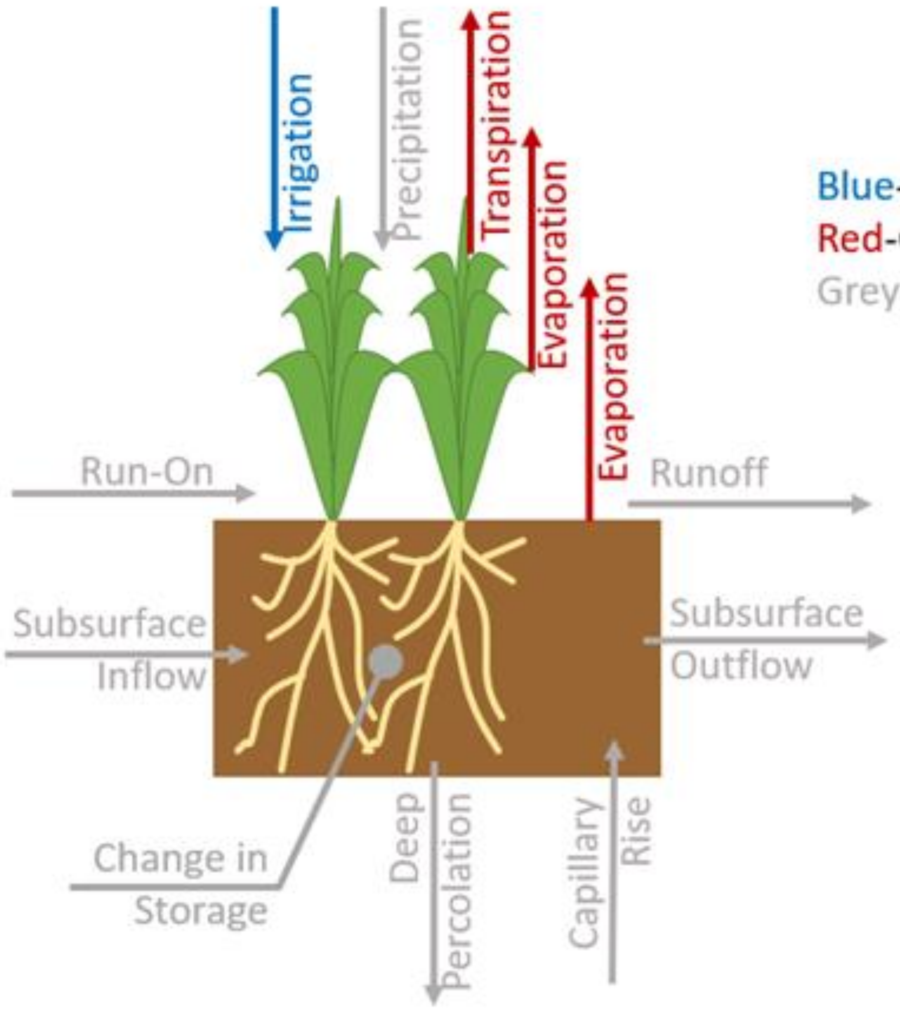
Partial Year Deficit Irrigation of Alfalfa Program

- Strategy is to eliminate one to three irrigation events during the summer (July – September), depending on the irrigation method (border or furrow) and treatment
- Summer months targeted because of the lower water use efficiency relative to other times of the year

CU Quantification

Simplified Representation of the Consumptive Use Quantification Approach for the Palo Verde Irrigation District Deficit Irrigation Project

Quantification Method:
Micrometeorological Techniques

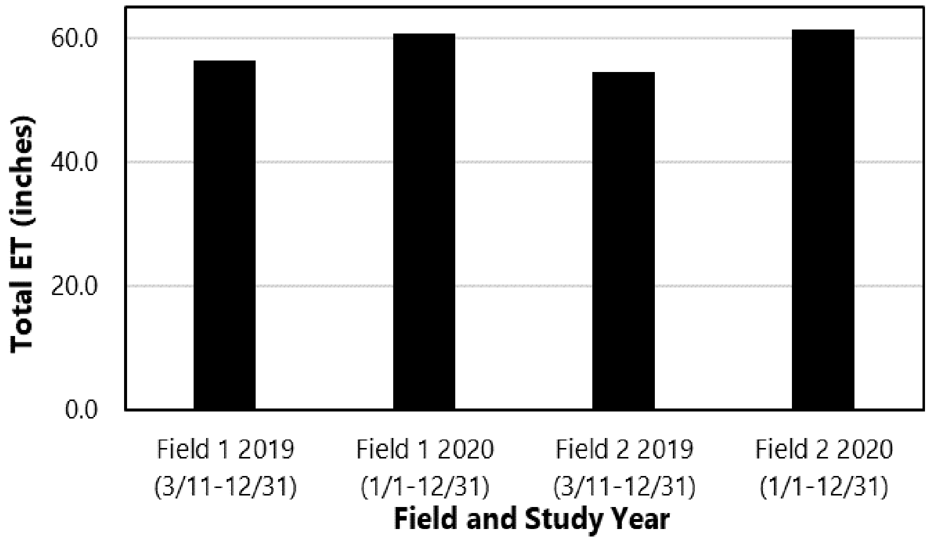


Blue-Inflow accounted for in analysis
Red-Consumptive use in analysis
Grey-Not necessary in analysis

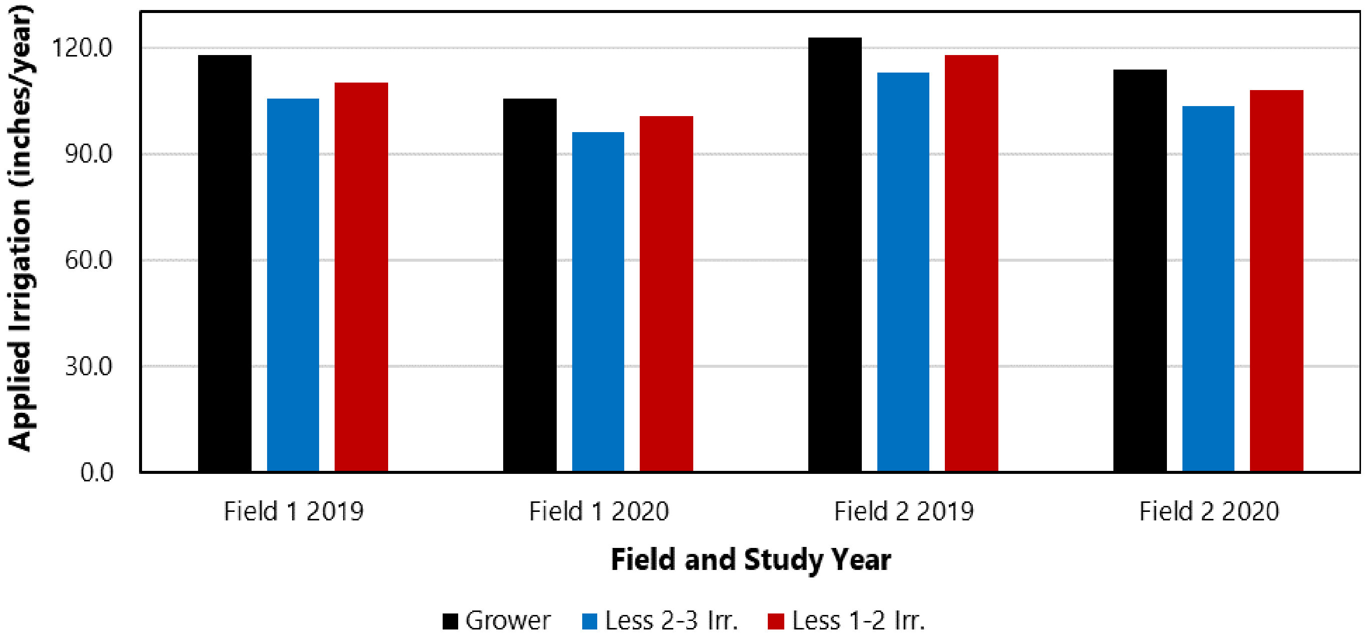
CU Quantification

- CU is quantified as ET using eddy covariance and surface renewal micrometeorological techniques
- Primary measures of water conservation
  - Reduction in applied water
  - Change in yield
- Replication and possible statistical analyses

CU Results



Total Observed ET for the Grower Convention Irrigation Treatment for Two Research Fields for a Partial Year in 2019 and all of 2020



Seasonal Total Applied Irrigation Water for Study Treatments in Two Research Fields for 2019 and 2020

Reflections

- Quantification methods used in this study are limited to research settings
- Ultimate end-product of this research will be a NRCS conservation practice or guide

BUREAU OF RECLAMATION

Colorado River Indian Tribes Fallowing Program

CRIT Fallowing Program

- 3-year program (2020-2022)
- 50,000 AFY of CU savings to be stored in Lake Mead as system conservation water
- Any excess is credited and stored in CRIT's EC-ICS account in Lake Mead
- Conserved water due to temporary fallowing of irrigated cropland

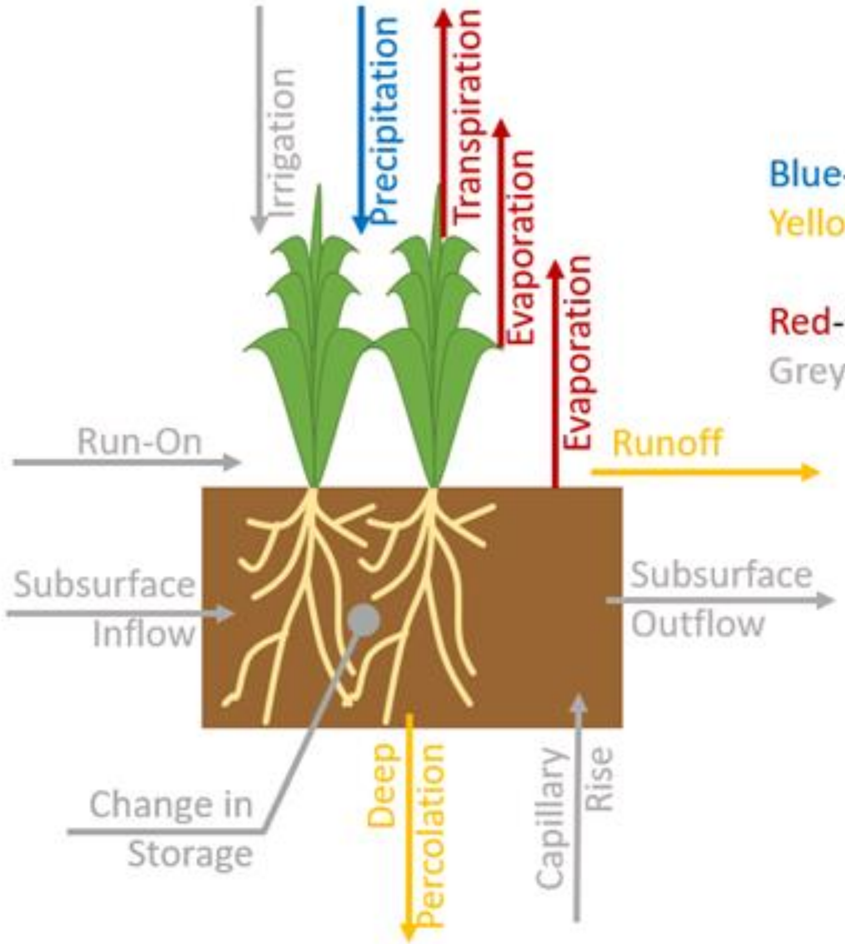
CRIT Fallowing Program

- Field parcels required to have been in active irrigated crop production for at least four of the previous five years
- Cropping patterns determined by field surveys
- Spatially referenced crop mapping system in GIS environment

CU Quantification

Simplified Representation of the Consumptive Use Quantification Approach for the CRIT Fallowing Program

Quantification Method:
Evapotranspiration/Crop Coefficient

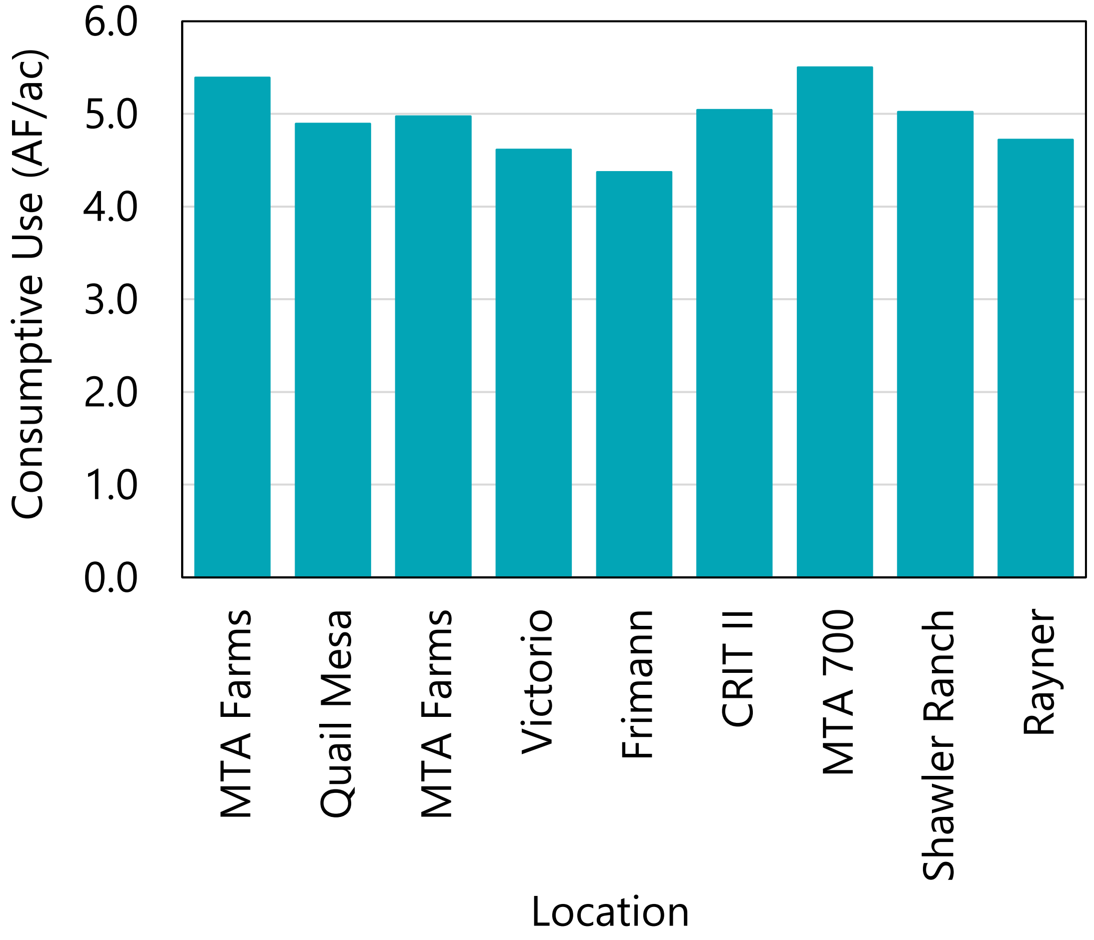


Blue-Inflow accounted for in analysis
Yellow-Accounted for by using effective precipitation
Red-Consumptive use in analysis
Grey-Not necessary in analysis

CU Quantification

- *Δ*CU based upon reference evapotranspiration/crop coefficient method
- ET of each crop was computed using the single (mean) crop coefficient-reference ET
- Daily crop coefficients for Reclamation's LCRAS for the Parker Valley were used
- Factors applied to account for "non-standard" growing conditions

CU Results



Year	Fallowed Land (acre)	Predicted Decrease		Maximum Diversion	
		Consumptive Use (ac-ft)	Diversion (ac-ft)	Predicted (ac-ft)	Decree Accounting (ac-ft)
2020	10,786	53,736	100,706	512,018	459,026

Reflections

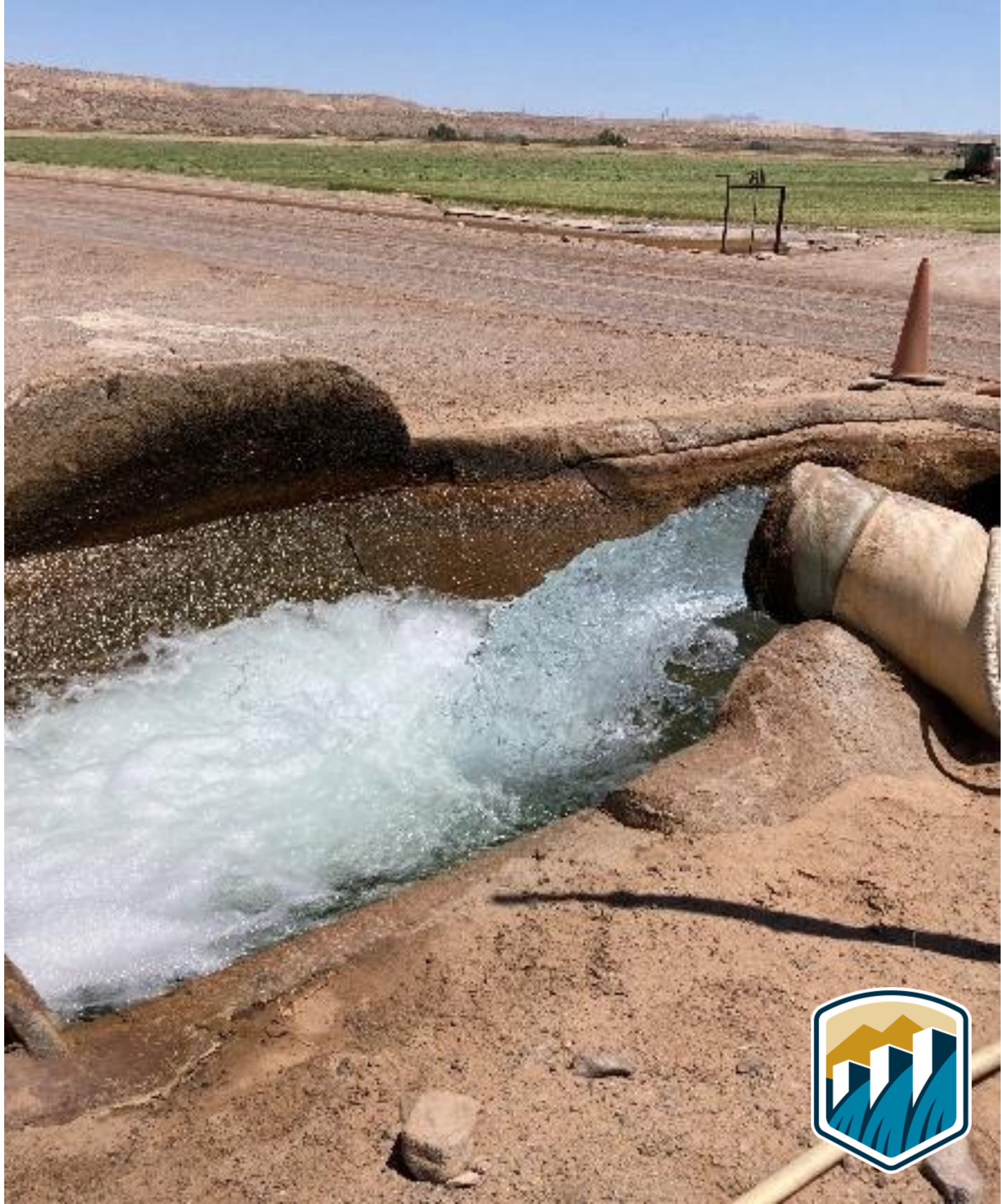
- Crop CU and estimation of the associated diversion reduction is computed prior to fallowing implementation and is independent of what is occurring on the remainder of the Reservation
- Care must be applied to develop crop CU estimates representative of the actual field conditions
- Comparison of the ΔCU to Reclamation Decree Accounting requires a reasonably accurate assessment of irrigation efficiency
- Agreement conditions caused CRIT Farms to idle additional land
- Extra diligence is required to eradicate GMO alfalfa stand and keep the parcel free of green vegetation
- Required coordination with multiple agencies resulted in delays and miscommunications

BUREAU OF RECLAMATION

Mohave Valley Irrigation and Drainage District Fallowing Program

MVIDD Fallowing Program

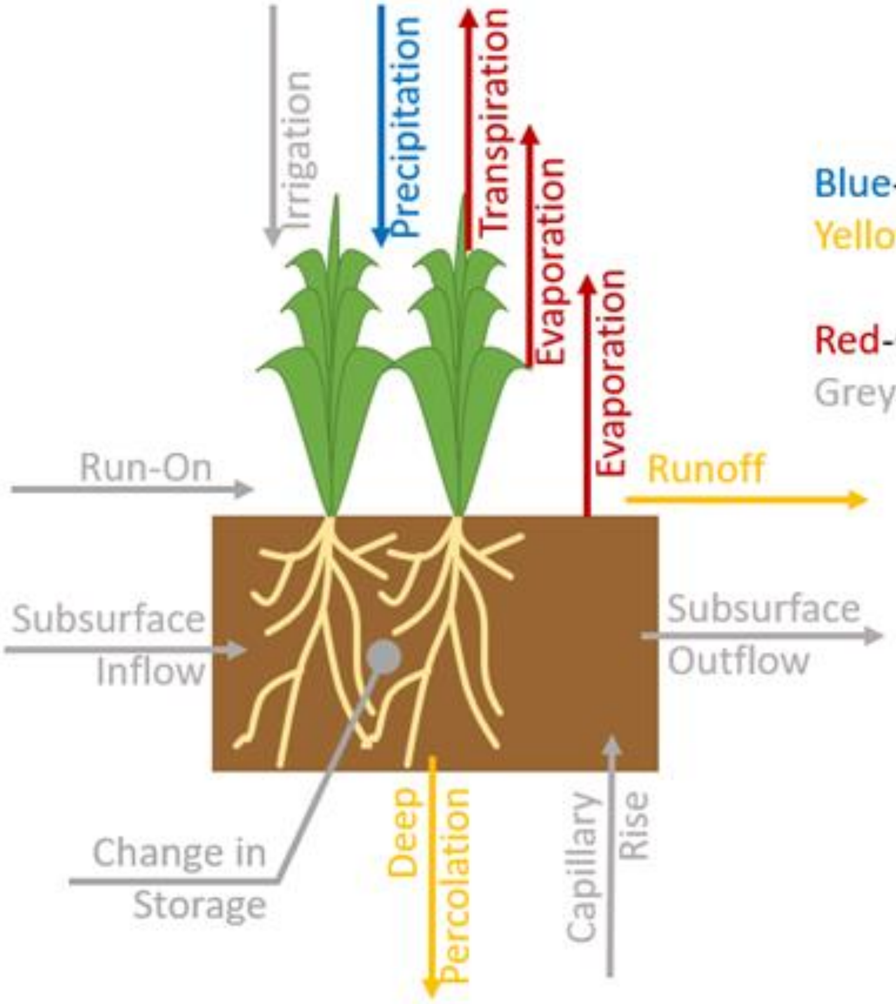
- MVIDD began a fallowing program in 2020 for System Conservation
- Land had to be actively cultivated in at least three of the five most recent years
- Minimum of 10 acres per participant
- Fallowed area was about 1,200 acres in 2020 and over 1,300 acres in 2021



CU Quantification

Simplified Representation of the Consumptive Use Quantification Approach for the MVIDD Fallowing Project

Quantification Method:
Evapotranspiration/Crop Coefficient

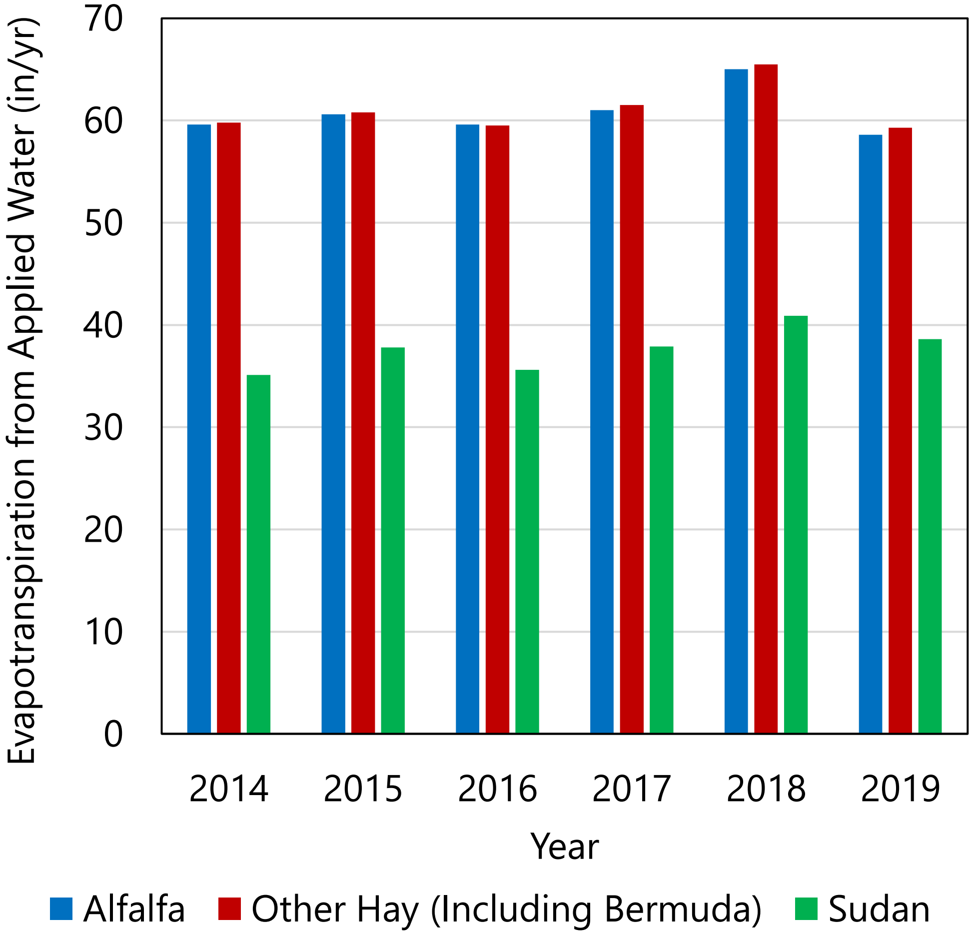


Blue-Inflow accounted for in analysis
Yellow-Accounted for by using effective precipitation
Red-Consumptive use in analysis
Grey-Not necessary in analysis

CU Quantification

- *Δ*CU based upon reference evapotranspiration/crop coefficient method and spatial crop surveys
- Estimated *Δ*CU:
  - *2020:* 6,137 AF on 1,196 acres of fallowed land (5.13 AF/ac)
  - *2021:* 6,778 AF on 1,349 acres of fallowed land (5.03 AF/ac)

CU Results



Year	Fallowed Land (acre)	Predicted Decrease		Maximum Diversion	
		Consumptive Use (ac-ft)	Diversion (ac-ft)	Predicted (ac-ft)	Decree Accounting (ac-ft)
2020	1,196	6,137	8,372	21,353	19,458
2021	1,349	6,778	9,440	19,872	---

Reflections

- The longer the fallowing duration, the more effort (and expense) is required to bring the field into production again
- Interest in the establishment of cover crops for soil stewardship value
- Growers could use the fallowing period to convert fields from conventional production to organic production
- Interest in a seasonal fallowing program
- Concerns about the impact of other water users on the program's ΔCU
- Initial socio-economic concerns and fear about loss of water – education was key

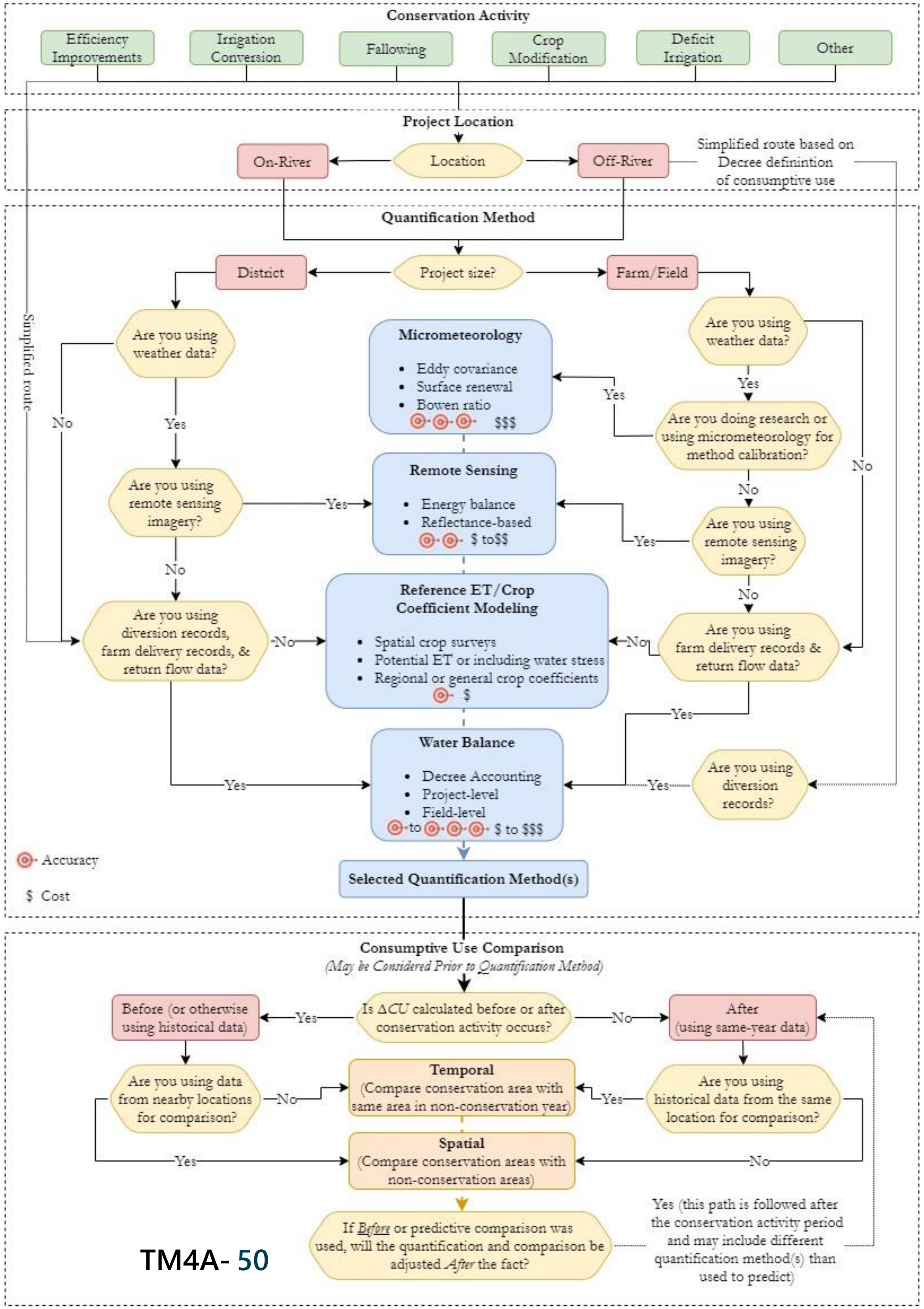
BUREAU OF RECLAMATION

Synopsis and Discussion

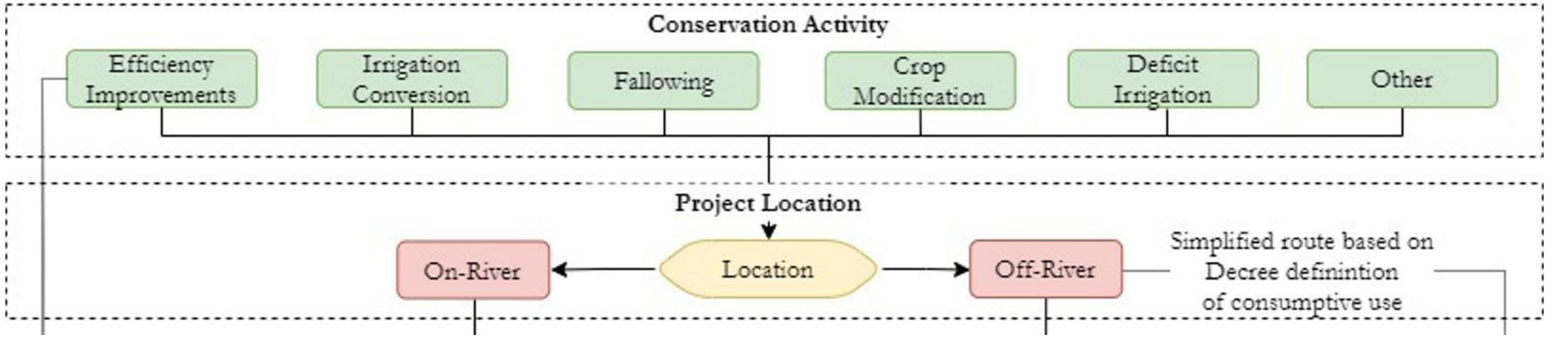
Case Study	Location		Conservation Activity			Quantification Method			Comparison Method[1]		Time-Period		Other Comment
	On-River/ Off Mainstem	State	Deficit Irrigation	Fallowing	Efficiency Improve-ments	Water Balance	Micromet-eorology	Reference ET	In Time	In Space	Single Year	Multi-Year Mean	
GRIC System Modernization	Off Mainstem	AZ			•	•			•			•	Comparison on per-acre basis
BWD Seasonal Fallowing	On-river	CA		•		•				•		•	Based on Decree Accounting reports
PVID Forbearance and Fallowing	On-river	CA		•		•				•	•	•	Based on Decree Accounting reports
PVID "Moderate" Deficit Irrigation	On-river	CA	•				•					•	Developing empirical relationship between irrigation deficit and yield
CRIT Fallowing	On-river	AZ		•				•	•			•	Specifically accounted for non-ideal growing conditions
MVIDD Fallowing	On-river	AZ		•				•	•			•	Used remote-sensing-based crop surveys

[1]Method used to identify the change in consumptive use relative to conditions without the conservation method. The methods either compare the same area (field or district) "in time" or effectively compare areas of conservation with areas not under conservation ("in space").

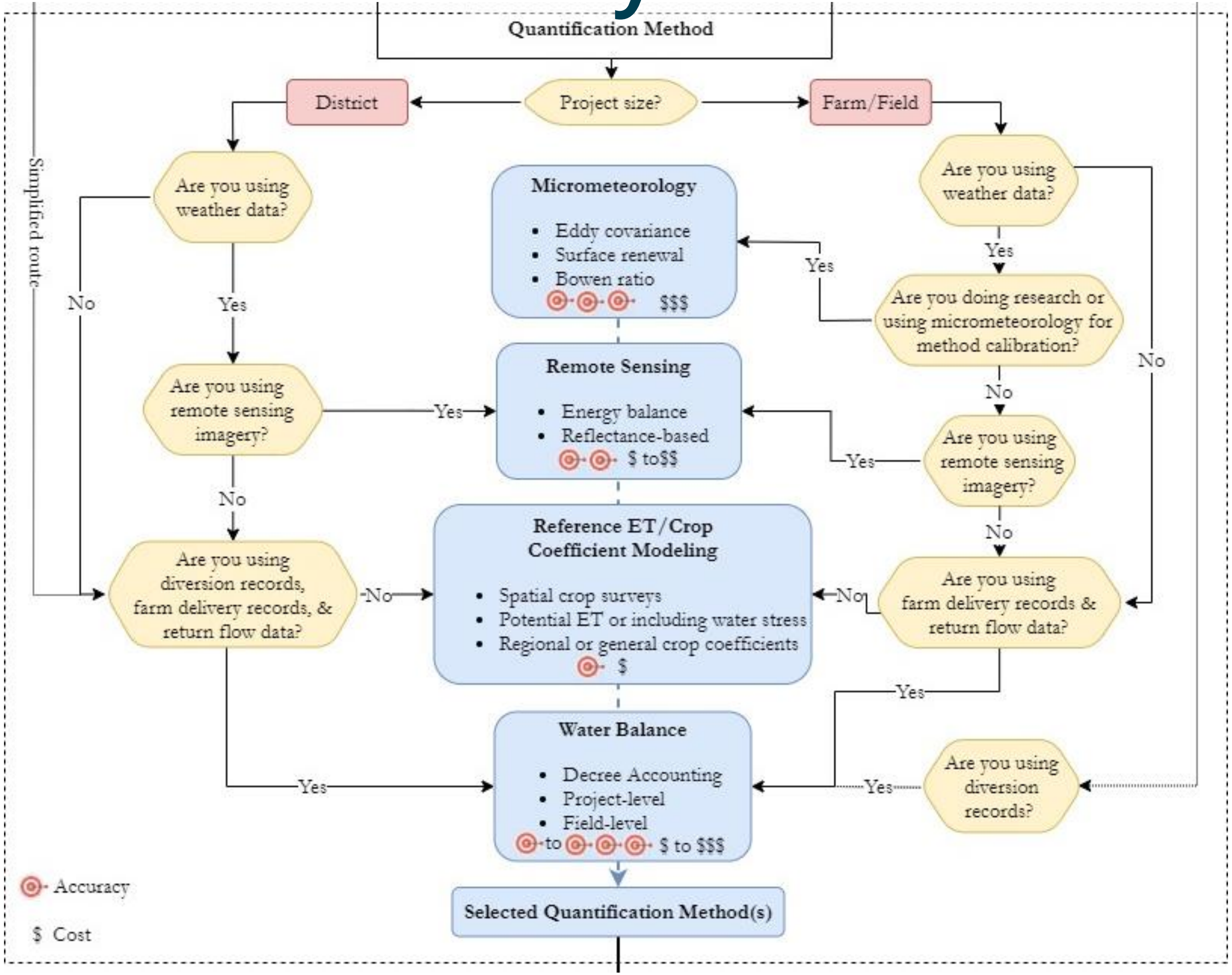
Decision Tree for Conservation Activities and Consumptive Use Quantification/ Comparison Methods



Decision Tree Summary



Decision Tree Summary



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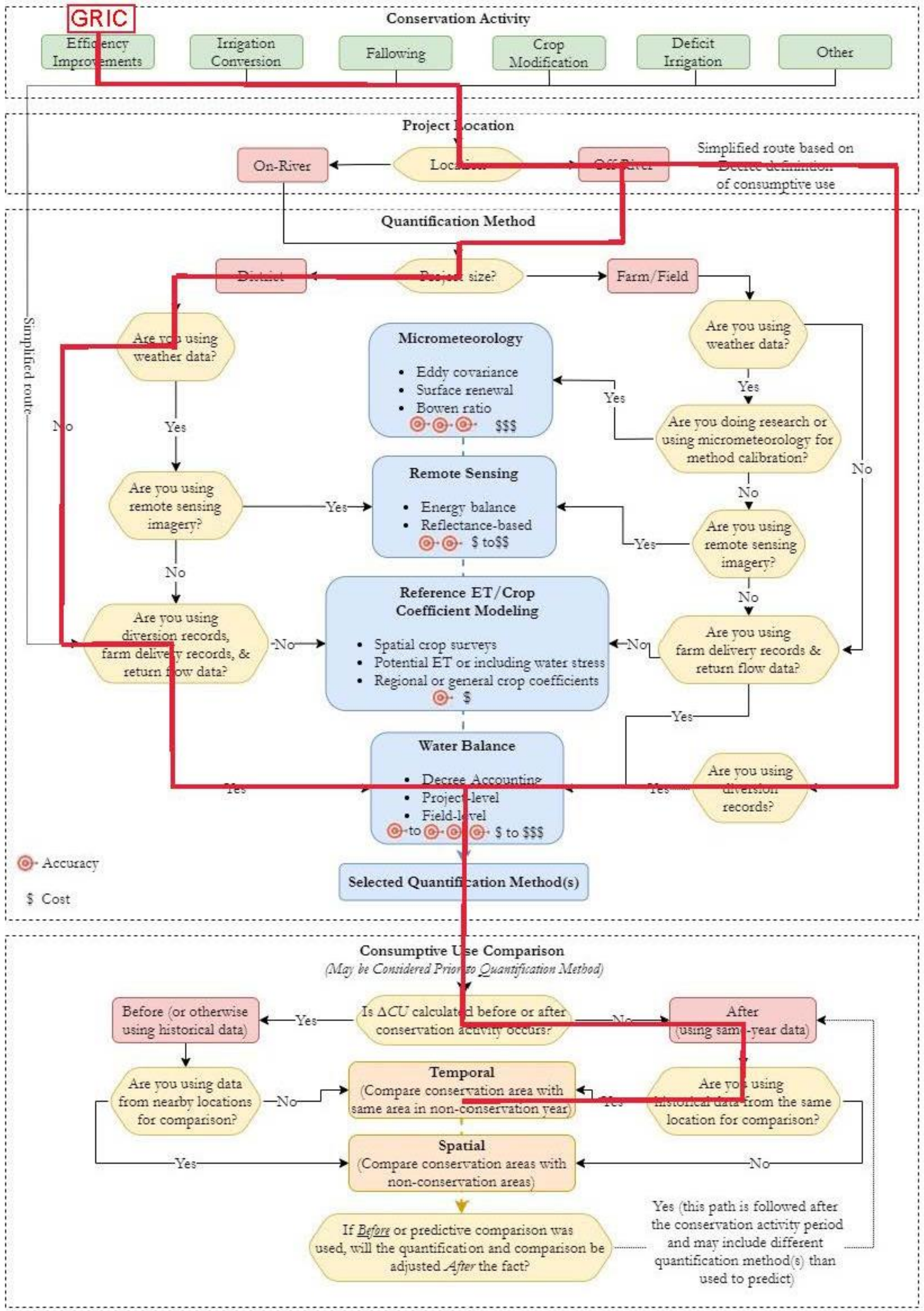
GRIC
Conservation Activity
Efficiency Improvements
Irrigation Conversion
Fallowing
Crop Modification
Deficit Irrigation
Other
Project Location
On-River
Location
Off-River
Simplified route based on Decree definition of consumptive use
Simplified route
Quantification Method
District
Project size?
Farm/Field
Are you using weather data?
Yes
No
Are you using remote sensing imagery?
Are you using diversion records, farm delivery records, & return flow data?
Micrometeorology
Eddy covariance
Surface renewal
Bowen ratio
$$$
Remote Sensing
Energy balance
Reflectance-based
$ to$$
Reference ET/Crop Coefficient Modeling
Spatial crop surveys
Potential ET or including water stress
Regional or general crop coefficients
$
Water Balance
Decree Accounting
Project-level
Field-level
to
$ to $$$
Are you doing research or using micrometeorology for method calibration?
Are you using farm delivery records & return flow data?
Are you using diversion records?
Accuracy
Cost
Selected Quantification Method(s)
Consumptive Use Comparison
(May be Considered Prior to Quantification Method)
Is ΔCU calculated before or after conservation activity occurs?
Before (or otherwise using historical data)
After (using same-year data)
Are you using data from nearby locations for comparison?
Temporal (Compare conservation area with same area in non-conservation year)
Are you using historical data from the same location for comparison?
Spatial (Compare conservation areas with non-conservation areas)
If Before or predictive comparison was used, will the quantification and comparison be adjusted After the fact?
Yes (this path is followed after the conservation activity period and may include different quantification method(s) than used to predict)

Quantification Synopsis

- Balance between cost and accuracy
- More than one method may be equally valid
- Availability of data
- Need for continual quantification improvement
- Quantification/comparison time period(s)
- Baseline considerations
- Similarity of comparisons (in time, in space, in data)
- Upfront certainty versus true-up accounting
- Relationship to Decree Accounting

Wrap-up and Next Steps

Pilot Study Schedule

- **Nov 2020**
  - **Workshop 1**
  - **Milestone 1**: Technical Memorandum 1 – Summary of Refined Scope & Case Study Definition
- **Feb 2021**
  - **Milestone 2:** Technical Memorandum 2 – Summary of Significant Findings from Literature Review & Recent/Current Activities in the Lower Basin
- **Mar 2021**
  - **Workshop 2**
- **Apr 2021**
  - **Milestone 3:** Technical Memorandum 3 – Summary of Case Study Definition, Site Selection & Evaluation Process
- **May 2021**
  - **Site Visits/Interviews**
- **Aug 2021**
  - **Milestone 4:** Technical Memorandum 4 – Case Study Evaluations
- **Sep 2021**
  - **Workshop 3**
- **Oct 2021**
  - **Milestone 5:** Pilot Study Executive Summary
- **Nov 2021**
  - **Pilot Study Final Report**
- **Dec 2021**
  - **Presentation at CRWUA**

BUREAU OF RECLAMATION