BUREAU OF RECLAMATION

# Executive Summary

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

**U.S. Department of the Interior**

November 2021

# Mission Statements

The Department of the Interior (DOI) conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

# Executive Summary

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

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# Project Definition and Background

Following on the Colorado River Basin Supply and Demand Study (Basin Study)[1] and the Moving Forward[2] efforts, the U.S. Bureau of Reclamation's (USBR) WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program selected and provided funding for this Exploration of Quantification Methods for Agricultural Water Savings in the Lower Colorado River Basin Pilot Study (Pilot Study), which was financially matched by three non-Federal partners to explore methods of quantifying agricultural water savings through the knowledge shared by participants and an evaluation of existing case studies. Through a voluntary and collaborative process, the general objectives of the Pilot Study were to:

- Identify and describe methods currently in use to quantify agricultural water conservation.
- Evaluate those methods for consistency and accuracy with Reclamation's Lower Colorado River water accounting methods.
- Evaluate existing case studies using a combination of research and applied science.
- Recommend approaches to improve methods of quantifying agricultural water conservation in the Lower Colorado River Basin (LCRB).

The project team acknowledges the assistance and information provided by many individuals and organizations during this Pilot Study.

# Review of Literature and Recent Conservation Activities

A review of the technical literature and of recent conservation activities was undertaken to identify consumptive use (CU) quantification methods. The literature reviewed included documentation of specific CU quantification methods, application of such methods, and comparisons between methods. Some of the literature reviewed focused on certain conservation activities rather than CU quantification. As part of the literature review, an annotated bibliography was prepared documenting over 150 references that were reviewed in greater detail.

## Quantification Methods

The reviewed literature covered several CU quantification methods, or method classes. Ultimately, the reviewed CU quantification methods were summarized in the following categories, focused largely on ET quantification methods:

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[1] 2012. *Colorado River Basin Water Supply and Demand Study. U.S. Bureau of Reclamation.* U.S. Department of the Interior Bureau of Reclamation. Available at: https://www.usbr.gov/lc/region/programs/crbstudy.html

[2] U.S. Bureau of Reclamation (Reclamation). 2015. *Colorado River Basin Stakeholders Moving Forward to Address Challenges Identified in the Colorado River Basin Water Supply and Demand Study: Phase 1 Report.* U.S. Bureau of Reclamation. Available at: https://www.usbr.gov/lc/region/programs/crbstudy/MovingForward/index.html

- Water balances
    - Soil water balances and field-level water balances
    - Project-level water balances
    - Delivery and other flow measurements
- Micrometeorology
    - Eddy covariance
    - Bowen ratio energy balance
    - Surface renewal energy balance
    - Scintillometry
- Lysimetry
- Reference evapotranspiration/crop coefficient modeling and spatial crop surveys
- Remote sensing evapotranspiration modeling
    - Reflectance-/Vegetation Index-based methods
    - Energy balance models/thermal methods
- Other (micro-lysimeters, sap flow, etc.)
- Combined methods

## Conservation Activities

The literature review was focused primarily on the following four conservation methods:

- Deficit irrigation
- On-farm irrigation system conversion
- Seasonal fallowing
- Crop rotations/alternative cropping

Other conservation methods that were considered include (but are not limited to):

- District/distribution system conveyance system improvements
- On-farm conveyance system improvements
- Advanced irrigation scheduling

# Case Study Selection

A framework was developed to assist the identification of case study opportunities and final case study site selection with the following considerations:

- Geographical diversity within the LCRB
- Diversity of agricultural conservation activities
- Diversity of water savings quantification methods

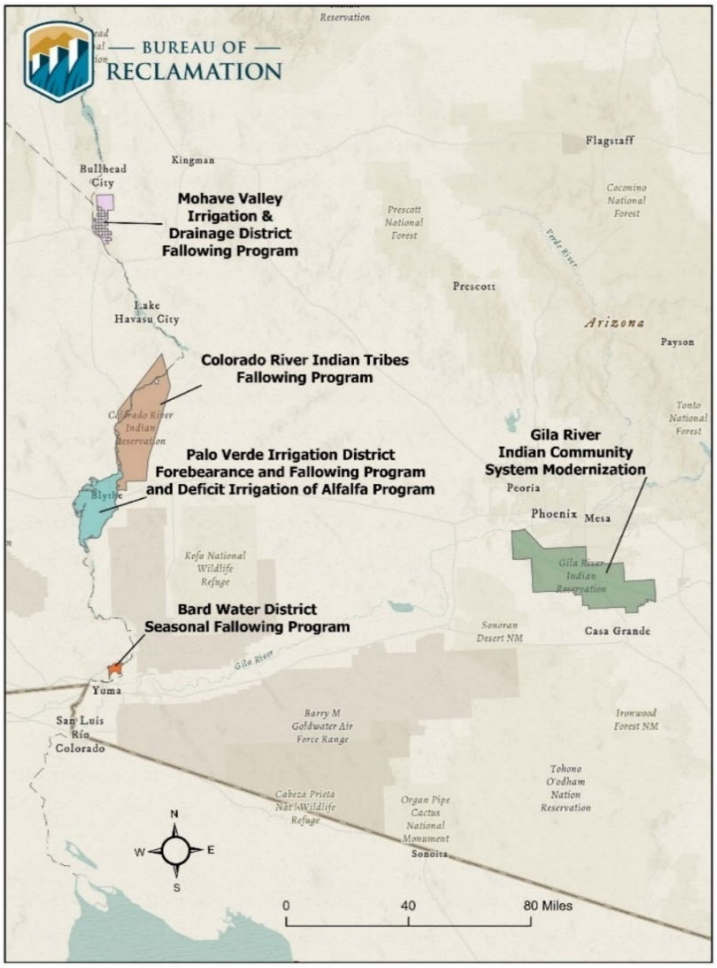
Nine candidate case study projects were identified throughout the LCRB. The final six case studies were selected from among the available choices to represent a variety of conservation activities, quantification methods, and project locations (*Figure 1*).

- 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 Moderate Deficit Irrigation Program
- Colorado River Indian Tribes (CRIT) Fallowing Program
- Mohave Valley Irrigation and Drainage District (MVIDD) Fallowing Program

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, 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)

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




# Summary of Case Studies

A full analysis for each case study was completed. A brief description of each of the case studies is provided below and summarized in *Table 1*.

*Table 1 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.

## Gila River Indian Community System Modernization

GRIC is located just south of Phoenix in Central Arizona. GRIC has been undertaking an extensive rehabilitation, rebuild, and expansion of existing irrigation infrastructure on and/or serving the Gila River Indian Reservation. This effort is referred to as the Pima-Maricopa Irrigation Project (P-MIP). The P-MIP irrigation water delivery and distribution system is planned to serve up to 146,300 acres of land on the Reservation and includes the rehabilitation and reconstruction of existing irrigation infrastructure within BIA's San Carlos Irrigation Project (SCIP) service area and other areas on the Reservation. Project construction began in 1998 and will continue through 2030. The project includes rehabilitation, modernization, and construction of canals, pipelines, turnouts, and measurement and control structures. The overall efforts by GRIC also include consolidation of operation and maintenance of the P-MIP system by the formation of an operating entity the Gila River Indian Irrigation and Drainage District (GRIIDD). The CU quantification for these improvements was based on diversion measurements, represented by supply measurements at the Reservation boundary. Other flow measurements and farm deliveries were also used.

## Bard Water District Seasonal Fallowing Program

Bard is located in southeastern California. For the present study, Bard will refer specifically to the Bard Unit of the Yuma Project Reservation Division. The Bard seasonal fallowing program has been going, in different forms, since 2016. The present program is funded by the Metropolitan Water District of Southern California (MWD). Under the agreement with MWD, participating growers do not grow or harvest crops or irrigate fields from fallowed land from 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 in contrast with other fallowing programs analyzed in this study. Conserved water is made available to MWD for diversion or storage in Lake Mead for future use. CU is quantified using a district-wide water balance based on the Decree Accounting reports. The reduction in CU is assumed to be equal to the CU for the Bard Unit divided by the area irrigated during fallowing multiplied by the fallowed area. CU is quantified for an average of multiple years, including the year of conservation.

## Palo Verde Irrigation District Forbearance and Fallowing Program

PVID is located in southeastern California. PVID serves over 131,000 acres of land, most of which is in the Colorado River floodplain, but roughly 27,000 acres are on the Palo Verde Mesa. 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. 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. Maximum limits have been placed on the amount of land fallowed. The CU quantification is based on a district-wide water balance based on the Decree Accounting reports. The PVID quantification includes both historical inter-annual averages and conservation year CU, though, the conservation year is not included in a multi-year mean. The fallow field reduction in CU is computed using water-toll area (used for water assessment). As with other fallowing programs, it is important to note that the quantification method includes verification of the fallowed land.

## Palo Verde Irrigation District Moderate Deficit Irrigation 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. The purpose of the study is to measure the impacts of "moderate" deficit irrigation during the summer on applied irrigation water, CU, yield, yield quality, soil salinity, and alfalfa plant stand[3]. The deficit irrigation strategy in the study is to eliminate one to three irrigation events during the summer (July – September). The study is being conducted in two border irrigated fields and two furrow irrigated fields. Each field included a section (or multiple sections) irrigated per the grower's convention and two deficit irrigation treatments. To quantify CU, the research team used farm turnout records for applied irrigation water

[3] Montazar, A., O. Bachie, D. Corwin, and D. Putnam. 2020. "Feasibility of Moderate Deficit Irrigation as a Water Conservation Tool." Agronomy. 10(11): 1640. https://doi.org/10.3390/agronomy10111640

and micrometeorological methods for ET. The micrometeorological methods were eddy covariance and surface renewal.

## Colorado River Indian Tribes Fallowing Program

The Colorado River Indian Reservation is located on both sides of the Colorado River in western Arizona and eastern California, with most of the land in Arizona. The Reservation is home to the CRIT. Starting in 2016 and continuing to present, CRIT has participated in system conservation programs to create conserved water for storage in Lake Mead. Currently, CRIT's program is part of a three-year system conservation agreement with Reclamation, the Arizona Department of Water Resources, and Central Arizona Water Conservation District under the State of Arizona's Drought Contingency Plan. Conserved water in each case has consisted of CU reductions due to temporary fallowing of irrigated cropland on CRIT's Arizona lands. Field parcels being fallowed were required to have been in active irrigated crop production for at least four of the previous five years. The CU reduction was quantified using the reference ET/crop coefficient approach, which was adjusted based on regional remote sensing studies. A five-year average modeled crop ET for each fallowed field was used to estimate the CU reduction. A diversion reduction was estimated by applying a system-wide irrigation efficiency.

## Mohave Valley Irrigation and Drainage District Fallowing Program

MVIDD is in western Arizona. MVIDD's irrigation water is from wells in the Colorado River alluvial aquifer. In 2020, MVIDD began a fallowing program for system conservation. 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. The CU reduction was quantified using the reference ET/crop coefficient approach paired with remote-sensing-based crop surveys. A five-year mean modeled crop ET for each fallowed field was used to estimate the CU reduction. A diversion reduction was estimated by using the district's per-acre diversion cap.

# Synopsis and Recommendations

A summary decision tree was developed to condense the results and observations from the case studies into a single summary (*Figure 2*). 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 decision tree, it is important to review the associated commentary in TM4.

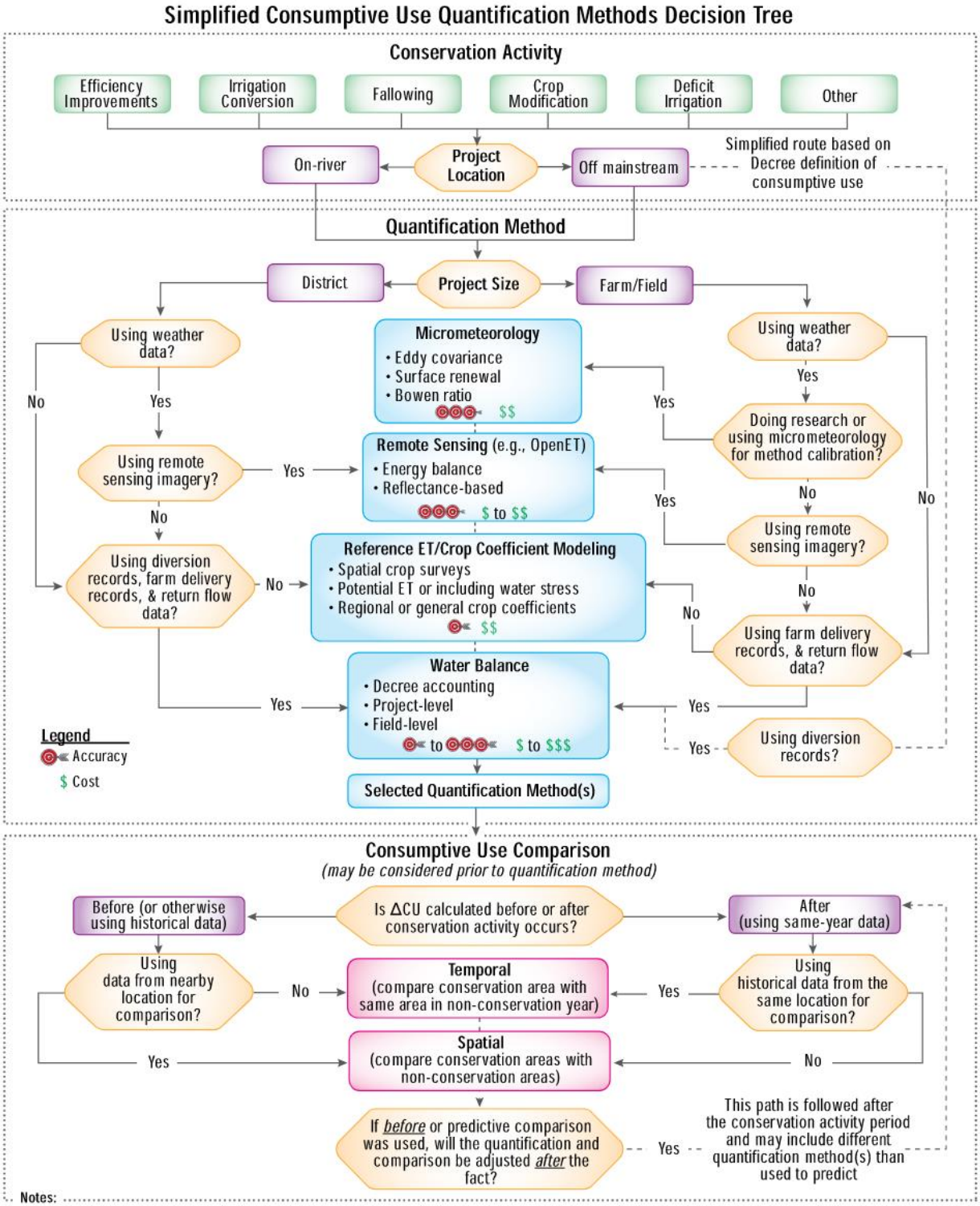
One thing not fully captured in the decision tree is the full set of assumptions associated with each quantification method, which are discussed at length in TM4. Such assumptions are very situation-dependent, as demonstrated in the case study discussions. The tradeoffs between different assumptions can be observed by reviewing the different quantification methods selected in each case study project. Associated with the various method assumptions, there is often a tradeoff between cost and accuracy. The assumptions are also specific to site and conservation method. Data availability can also limit the available CU methods.

In addition to accuracy, assumptions, and cost, it is important to consider the similarity of the areas or times being used in CU comparisons and the amount of time used in making comparisons. Increasing availability of remote sensing ET products and the use of statistical analyses were presented as options to address some of these challenges.

Decisions regarding CU quantification methods should be agreed upon collectively by all parties involved in a conservation program. 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 that CU methods should be reviewed and changed as necessary.

Each of the studied cases have employed CU quantification methods that are in some way different than those applied by the others. None of the quantification 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 case. 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 could also benefit from refinement. For all cases, the ever-improving CU quantification methods, technology, and data products should be evaluated and incorporated in a continuous process. No CU 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.

*Figure 2 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).