BUREAU OF RECLAMATION

Technical Memorandum 3 – Summary of Case Study Definitions, Site Selection, and Evaluation Process

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

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.

Technical Memorandum 3 – Summary of Case Study Definitions, Site Selection, and Evaluation Process

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 is to work collaboratively with a diversity of stakeholders to explore the current methods used to quantify certain agricultural water conservation activities in the Lower Basin, including the relationship of those quantification methods to the Lower Basin consumptive use 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 consumptive use (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 study 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 was made available for review and comment by participants prior to Workshop #2. Workshop #2 was held remotely on March 2, 2021. A copy of the presentation slides is included in the Appendix. The primary purposes of Workshop #2 were to:

- Provide a summary of the literature review documented in TM2,
- Present a review of some recent and on-going agricultural water conservation activities in the LCRB documented in TM2,
- Identify relevant case study opportunities in the LCRB in which specific conservation activities and/or methods of quantifying CU reductions could be reviewed in depth,
- Present a framework for categorizing case study opportunities considering location, type of conservation activity, and quantification methodology, and

- Seek input from workshop participants on any constraints or limitations regarding case studies and the site selection evaluation process

The purpose of this technical memorandum (TM3) is to document the results of Workshop #2 and the case study selection process.

Workshop #2 Participants

Over 50 people participated in Workshop #2. *Table 1* is a list of the workshop attendees.

Table 1 Workshop #2 Participants

Funding Partners			
Reclamation Dan Bunk Jeremy Dodds John Shields Amber Cunningham Nancy DiDonato Nohemi Olbert	**Central Arizona Water Conservation District** Chuck Cullom Deanna Ikeya	**Metropolitan Water District of Southern California** Bill Hasencamp Aaron Mead Larry Lai Noosha Razavian Jessica Arm Kira Alonzo Laura Lamdin David Bradshaw Ed Smith	**Southern Nevada Water Authority** Seth Shanahan Casey Collins

Agricultural Districts/Cities				
Imperial Irrigation District Dylan Mohamed Ben Brock	**Palo Verde Irrigation District** Ned Hyduke Andrew Slagan Bert Bell	**Mohave Valley Irrigation and Drainage District** Kerri Hatz Michael Pearce Vince Vasquez	**Coachella Valley Water District** Robert Cheng Ivory Reyburn	**Bard Water District** Nicholas Bahr

Tribal Representatives			
Bureau of Indian Affairs Jonathan Cody Denni Shields Cherry Bustos Gary Colvin	**Fort McDowell Yavapai Nation** Gerry Walker	**Colorado River Indian Tribes** Devin Heaps Angie Ingram Margaret Vick	**Gila River Indian Community** Jason Hauter
Navajo Nation Jason John	**Cocopah Tribe** Michael Smith	**Quechan Tribe** Jay Weiner	**Tohono O'odham Nation** Selso Villegas

State Agencies				
Arizona Department of Water Resources Bret Esslin	**Colorado River Board of California** Rich Juricich	**University of California Cooperative Extension** Ali Montazar	**San Juan Water Commission** Aaron Chavez	**Colorado River Commission of Nevada** Warren Turkett

Consultants/Attorneys/Other			
NRCE Tom Ley Ryan McBride Burdette Barker	**Jacobs** Lela Perkins Chris Kurtz Jason Smesrud	**Noble Law** Wade Noble Meghan Scott	Marissa Johnson

Agricultural Conservation Measures

This study focuses on agricultural water conservation measures that include both crop water use reductions and efficiency improvements. The distinction between these two categories of conservation measures was fully discussed in TM1 and TM2, and while there can be overlap, the distinction generally is dependent upon the where the conservation measure is implemented. CU reductions in which there is some type of change in crop water use (e.g. fallowing, deficit irrigation, crop mix changes, etc.) applies to both on-mainstream (of the Colorado River) diversions and uses, and to off-mainstream (i.e., transbasin or out of basin) diversions and uses. CU reductions due to efficiency improvements (e.g., conversion of on-farm irrigation systems to more efficient methods, canal lining, operational spill reduction, system automation, etc.), however, do not result in a CU reduction for on-mainstream diversions and uses. In contrast, efficiency improvements made under off-mainstream diversions and uses do result in CU reductions for the off-mainstream diversion.

CU reductions due to reductions in crop water use occur predominantly at the farm field level. Accurate measurement or estimation of CU savings can, among other approaches, require comparing CU from a field with a conservation measure to CU from neighboring fields that were not part of that conservation measure, or comparing CU from a field with a conservation measure to CU from the same field in previous years.

Efficiency improvements may be made at the conveyance/delivery system level and at the farm level. Often a water balance at the project level or sub-system level where improvements are implemented is necessary. The water balance must be performed prior to any efficiency improvement (to establish the baseline condition) and post-improvement (to quantify changes). Each component of the water balance (inflows, outflows, uses that remove water from the system, and changes in storage) is identified, characterized, measured, or estimated. As discussed above, efficiency improvements may or may not result in a CU reduction.

Information from TM2 was presented during Workshop #2 regarding the following agricultural water conservation measures:

- Deficit irrigation,
- On-farm irrigation system conversion,
- Seasonal fallowing,
- Crop rotation/alternative cropping,
- District/distribution system (efficiency) improvements,
- On-farm conveyance system (efficiency) improvements, and
- Advanced irrigation scheduling.

Methods to Quantify Consumptive Use

The primary focus of this Pilot Study is methods used to quantify CU reductions associated with different water conservation measures. The following methods to quantify CU were discussed in TM2 and highlighted during Workshop #2:

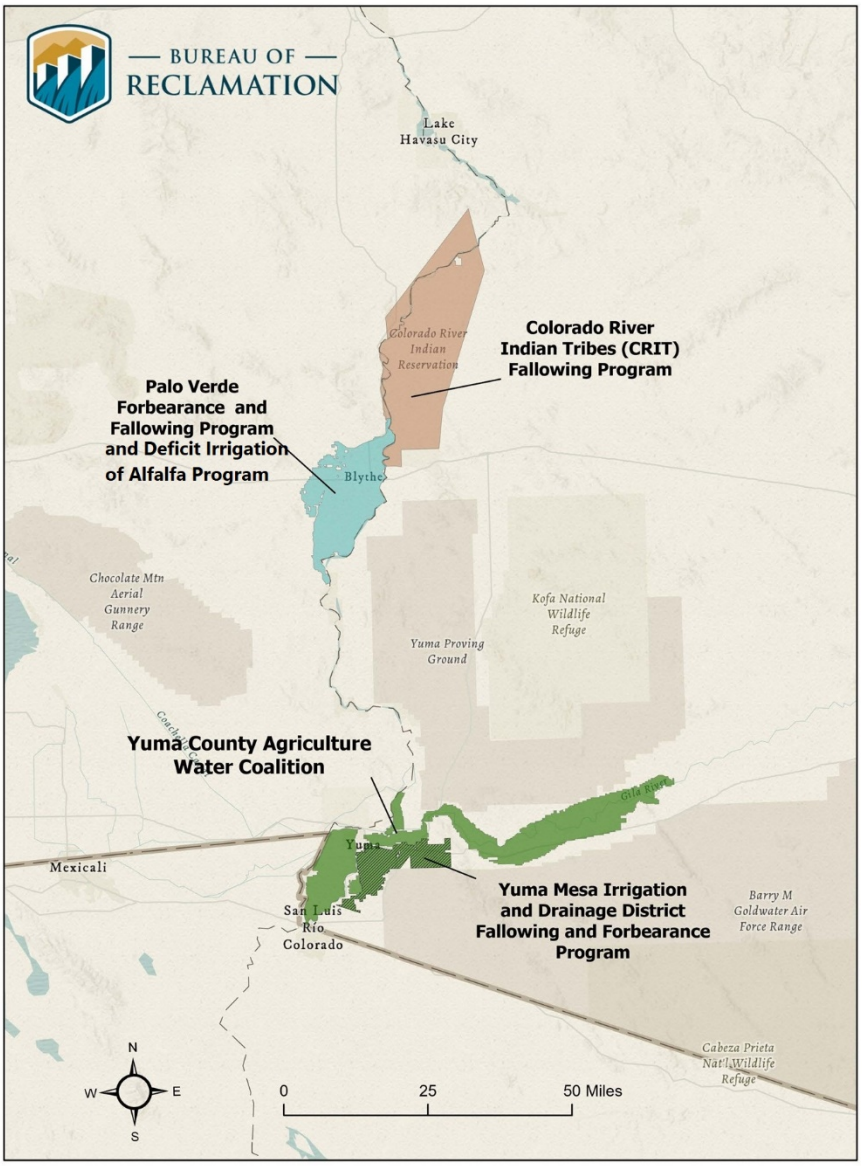
- Water balance,
- Lysimetry,
- Micrometeorology,
- Reference evapotranspiration, and
- Remote sensing.

Selected Current/Ongoing Conservation Activities

In addition to general conservation measures and CU quantification methods, the following current/ongoing conservation activities that were highlighted in TM2 and shown in *Figure 1* were reviewed during Workshop #2:

- Colorado River Indian Tribes (CRIT) Fallowing Program,
- Yuma County Agriculture Water Coalition Study,
- Yuma Mesa Irrigation Drainage District (YMIDD) Fallowing and Forbearance Program,
- Palo Verde Irrigation District (PVID) Forbearance and Fallowing Program, and
- PVID Deficit Irrigation Program.

Figure 1 Selected Current/Ongoing Conservation Activity Locations



Case Study Identification and Selection

The purpose of the case study analysis in this Pilot Study is:

- To gain knowledge from actual implemented (recent, current, or on-going) agricultural water conservation efforts in the LCRB regarding methods and approaches used to quantify water conserved; and
- To relate the results of conservation activities to quantification of CU under Reclamation's Decree Accounting.

Case Study Framework

A framework was developed to assist the identification of case study opportunities and final case study site selection. Considerations (to the extent possible) included representing:

- The geographical diversity within the LCRB,
- A diversity of agricultural conservation activities, and
- A diversity of water savings quantification methods.

Ideally, this framework would allow for selection of a set of case studies that are representative of agricultural water conservation activities in the LCRB.

Locations

Preferably, case study opportunities would represent both geographic diversity across the Lower Basin—all three lower basin States—Arizona, California, and Nevada; as well as projects that include both on-mainstream and off-mainstream water users. Quantification of CU in the latter situation depends on the fate of return flows. For on-mainstream projects, Reclamation has defined CU as diversions minus return flows, while for off-mainstream diversions, CU is equal to the diversion less any losses (or returns) that occur prior to water leaving the Colorado River drainage.

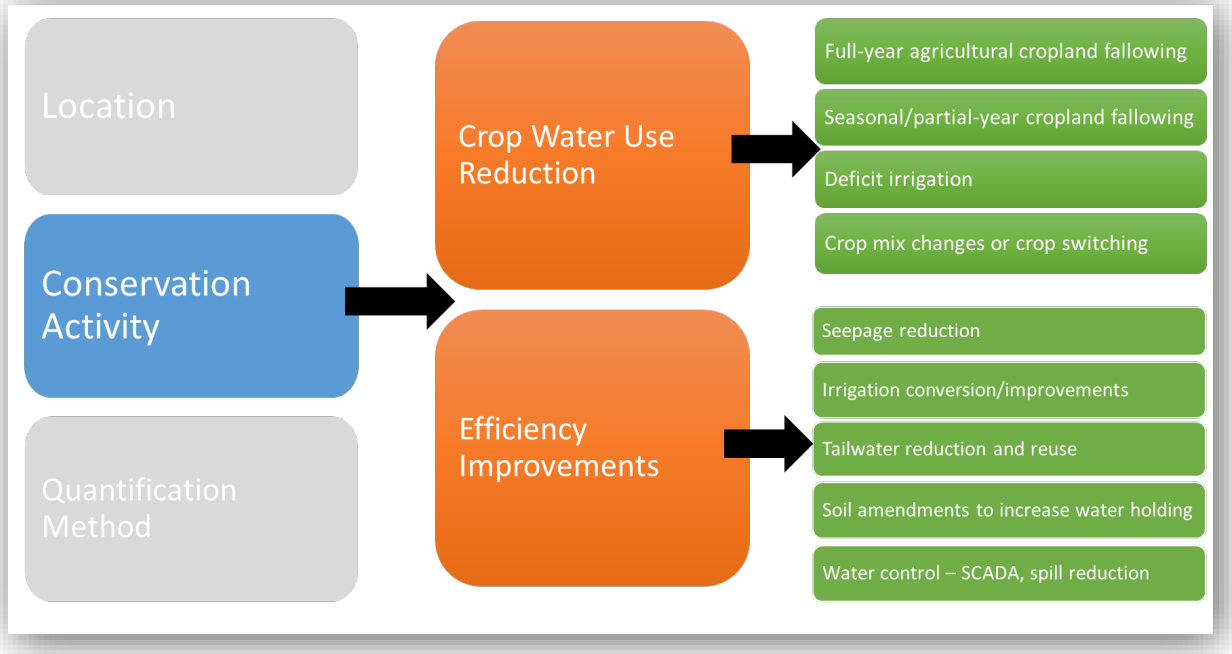
Conservation Activities

As discussed previously, there are two general categories of conservation activities under consideration: crop water use reductions and efficiency improvements. Both of these categories can be divided into sub-categories of irrigated agriculture water conservation activities, as shown in *Figure 2*.

As mentioned previously, whether or not a water conservation activity results in a CU reduction for the mainstream of Colorado River can be location dependent. For example, conservation activities that reduce crop water use generally may result in Colorado River CU reductions regardless of where the project is located. However, efficiency improvements, whereby the losses that occur during conveyance and application of water are reduced, as discussed above, may or may not result in CU reduction of Colorado River water.

- In the case of off-mainstream diversions, water savings from efficiency improvements (e.g., water savings from converting from flood irrigation to drip irrigation) do result in CU savings of mainstream Colorado River water. The entity or agency diverting and using the water can use the saved water for their purposes without increasing their Colorado River diversions.
- In the case of on-mainstream diversion and use, however, while the efficiency improvements still do reduce losses, most on-mainstream water users cannot use such savings because the water saved is system water and there is no net change in the available Colorado River water.

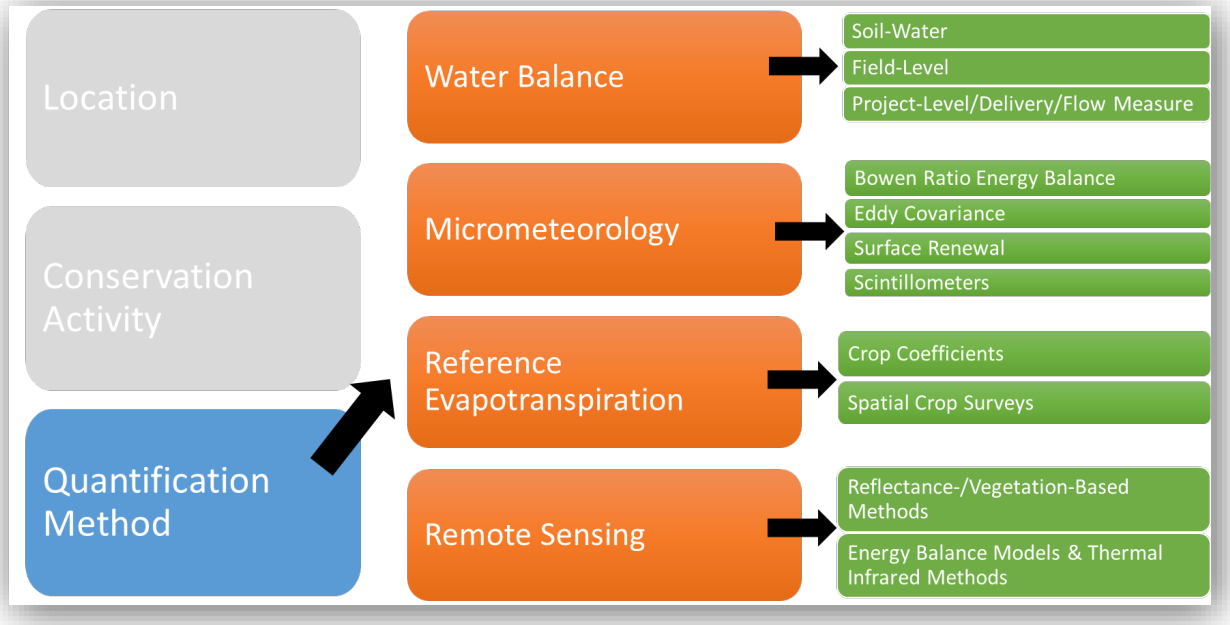
Figure 2 *Case Study Framework – Types of Conservation Activities*



Quantification Methods

As discussed previously, CU quantification methods were reviewed in detail and presented in TM2. The general categories of methods reviewed included water balance, micrometeorology, reference evapotranspiration, and remotes-sensing-based models. As shown in *Figure 3*, these categories can be divided into sub-categories as well.

Figure 3 *Case Study Framework – Quantification Methods*



Application of the Case Study Framework and Discussion of Recent Activities

During Workshop #2, Mr. Ned Hyduke of PVID introduced Dr. Ali Montazar of University of California Agriculture and Natural Resources (UCANR). Dr. Montazar delivered a presentation of a current and on-going study of "moderate" deficit irrigation of alfalfa within PVID in California (Montazar et al., 2020). The case study framework discussed above was applied to this particular conservation activity as an example.

Deficit irrigated alfalfa. Photo credit: A. Montazar, used with permission.

Other Workshop #2 participants were invited to provide short descriptions regarding conservation activities of the entities they represent:

- Mr. Michael Pearce spoke on behalf of the Mohave Valley Irrigation and Drainage District's (MVIDD's) fallowing program.
- Mr. Nick Bahr of Bard Water District (Bard) and Ms. Noosha Razavian of the Metropolitan Water District of California (MWD), spoke on behalf of the MWD/Bard Water District seasonal fallowing project.
- Mr. Devin Heaps of CRIT spoke briefly on behalf of CRIT regarding participation in the study.

Potential Case Studies

Table 2 is a matrix of the potential case studies that were identified along with the case study framework conditions they would satisfy. As shown, these potential case studies cover a range of the framework-defined conditions. Ideally, selected case studies would represent a cross-section of the different quantification methodologies. Case studies from sites where the same conservation activity has been implemented, but with different quantification methods, were also considered appropriate. It is important to note that *Table 2* is a list of identified current/recent programs and does not imply agreement by the organization to participate as a case study. Each of these potential case studies is described briefly below.

Table 2 Matrix of Potential Case Studies

Potential Case Study	Location		Conservation Activity					Quantification Method			
	On-/Off Mainstream	State	Deficit Irrigation	Irrigation Conversion	Fallowing	Crop Modification	Efficiency Improvements	Water Balance	Micrometeorology	Reference ET	Remote Sensing
PVID Forbearance and Fallowing Program	On-Mainstream	CA			X			X			
PVID Moderate Deficit Irrigation of Alfalfa Program	On-Mainstream	CA	X					X	X	X	
CRIT Fallowing Program	On-Mainstream	AZ			X			X		X	
MVIDD Fallowing Program	On-Mainstream	AZ			X			X		X	
Bard Water District Seasonal Fallowing Program	On-Mainstream	CA			X			X			
MSIDD Efficiency Improvements	Off-Mainstream	AZ					X				
CAIDD Efficiency Improvements	Off-Mainstream	AZ					X				
GRIC System Modernization	Off-Mainstream	AZ					X	X			
California Agriculture Extension On-farm Irrigation Studies	Off-Mainstream	CA		X			X		X	X	

Palo Verde Irrigation District Forbearance and Fallowing Program

In 2004, MWD and PVID landowners entered into a 35-year agreement wherein MWD pays for land to be fallowed in PVID's service area (MWD, 2019a). 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 nine and 35 percent, as determined by MWD. Any participating land is not fallowed for more than five years at a time. Maximum limits have been placed on the amount of land fallowed. The methods used to quantify CU reductions from the PVID forbearance and fallowing program include three basic components: 1) verifying of fallowing practice, 2) estimating average CU for fields under cultivation in PVID, and 3) determining CU reduction for fallowed lands. CU is quantified over various historical periods using measured diversions and 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 the assumption that fallowed lands would have had similar CU as the rest of PVID during the various analysis periods. See TM2 for more information.

Palo Verde Irrigation District Moderate Deficit Irrigation of Alfalfa Program

In 2019 and 2020, a deficit irrigation experiment in four fields in PVID was conducted by researchers at the UCANR, the University of California, Davis (UC Davis), and the U.S. Department of Agriculture Agricultural Research Service (Montazar et al., 2020). The project was conducted in four surface irrigated alfalfa fields in PVID planted in late 2018. The fields were paired by irrigation method (two were border irrigated and two were furrow irrigated) and by irrigation treatment. Each field included a section (or multiple sections) irrigated per the grower's convention. For the two furrow irrigated fields, deficit irrigation treatments were implemented by avoiding irrigation for three and two events in the summer in what the researchers call "moderate" deficit irrigation (Montazar et al., 2020). For the two border irrigated fields, two deficit irrigation treatments were implemented by avoiding irrigation for two events and one event in the summer. To quantify CU, the research team quantified applied irrigation water and ET. They quantified ET using eddy covariance and surface renewal methods in the grower irrigation treatments and used surface renewal systems from Tule Technologies for the deficit irrigation treatments. See TM2 for more information.

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. Starting in 2016 and continuing to present, CRIT has participated in system conservation programs to create conserved water for storage in Lake Mead. These programs 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 (Reclamation, 2019); and CRIT's three-year system conservation agreement with Reclamation, the Arizona Department of Water Resources (ADWR) and CAWCD 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 tracts in the temporary fallowing program are required to have been in irrigated cropping four of the previous five years, and no fields will be fallowed for periods longer than five years. CRIT has been compensated for its CU reductions under the various system conservation programs in which it has participated. CRIT quantified CU reductions due to fallowing of irrigated cropland by computing the average crop ET using the reference ET/crop coefficient method for the previous five-year period on the farm unit to be fallowed. See TM2 for more information.

Mohave Valley Irrigation and Drainage District Fallowing Program

MVIDD is conserving Colorado River water by fallowing MVIDD agriculture land that has a recent history of irrigation. An enrollment process was created whereby participating farmers voluntarily agreed to limit or alter the planting of crops on land that had been verified as actively cultivated in three of the then most recent five years. To make participation equitably available, the minimum fallowed area was 10 acres. The cropping history for each participating farm for the five-year period 2015-2019 was evaluated using satellite (Landsat) and aerial (National Agricultural Imagery Program, NAIP) imagery (MVIDD, 2019; Land-IQ, 2019). Cropscape, a National Agriculture Statistics Service remote sensing program, was also used. Crop CU for each of the previous five years was determined by using reference evapotranspiration computed using operational weather data collected at Arizona Meteorological Network (AZMET) electronic weather stations located in the Mohave Valley area. Crop coefficients for computing crop ET were adapted from Allen et al. (1998) and consultation with University of California, Davis faculty (Land-IQ, 2019).

Bard Water District Seasonal Fallowing Program

The Bard Water District is currently in a seasonal fallowing program in cooperation with MWD for 2020 – 2026 (MWD, 2019). In this program, MWD pays growers to not grow crops from April – July (Businesswire, 2019). MWD pays for this conservation (Businesswire, 2019). The program allows growers to continue growing "higher-value" winter crops (MWD, 2019b). Quantification of CU savings during this seasonal fallowing has been estimated (post facto) using Reclamation's decree accounting monthly reported diversions, return flows, and consumptive use for the Bard Water District and for the Yuma Project Reservation Division (J. Shields, communication, May 2021). CU (acre-foot per acre basis) during each of the four months of seasonal fallowing was determined for the Bard's total irrigable acres less the acres in the fallowing program. These monthly unit CU values were then multiplied by the acres fallowed to estimate total water savings. MWD uses the conserved water for diversion or Lake Mead storage (Businesswire, 2019). The program is reported to provide 6,000 acre-feet per year of water to MWD (MWD, 2019b).

Maricopa Stanfield Irrigation and Drainage District and Central Arizona Irrigation and Drainage District Efficiency Improvements

Maricopa Stanfield Irrigation and Drainage District (MSIDD) and Central Arizona Irrigation and Drainage District (CAIDD) are located in central Arizona. Significant investments to improve the irrigation delivery system and service and to improve on-farm irrigation efficiency have been implemented by both MSIDD and CAIDD over the past 30 years (HDR, 2013). The districts have invested extensively in improvements to their irrigation conveyance and delivery systems (canal lining and extensive system automation and control via supervisory control and data acquisition (SCADA) implementation and monitoring. A study of agricultural water efficiency for the Central Arizona Project (CAP) service area reported that MSIDD and CAIDD have delivery system losses and spills "…of less than 3%..." annually as result of these improvements (HDR, 2013). This same study reports the districts have also adopted on-farm irrigation methods with minimum irrigation efficiency of 80% for most farms.

Gila River Indian Community Irrigation System Modernization

The concept of the Pima-Maricopa Irrigation Project (PMIP) was developed as part of the Gila River Indian Community's (GRIC's) *1985 Master Plan for Land and Water Use* (Franzoy Corey, 1985; GRIC and EcoPlan, 1997). P-MIP is a large irrigation water delivery and distribution system that was planned to serve about 146,000 acres of land on the Reservation. P-MIP includes "rehabilitat[ion]" of existing irrigation infrastructure of the San Carlos Irrigation Project, which serves about 50,500 acres on the Reservation; and also service to other areas of the Reservation (GRIC and EcoPlan, 1997). P-MIP was planned to convey about 173,000 acre-feet per year (AF/yr) of CAP water, plus Gila River water, groundwater, Salt River water, reclaimed wastewater, and other sources (GRIC and EcoPlan, 1997). Project construction began in 1998 and continues through present (P-MIP, communication, 2021). Significant investment has been made in lined canals, pipelines, check structures, turnouts, and state of the art SCADA for water regulation and control, monitoring and measurement (P-MIP, communication, 2021).

California Agriculture Extension On-farm Irrigation Studies

Dr. Aliasghar Montazar, University of California Cooperative Extension Adviser in Imperial, Riverside, and San Diego Counties, and his associates have been collecting crop CU data in commercial production fields under different on-farm irrigation methods in the Imperial Valley of California. These studies have included comparisons of various combinations of comparisons of surface irrigation (flood or furrow), sprinkler (including linear move sprinklers) and drip (including

subsurface drip irrigation). Studies have included several commonly grown crops in the area, e.g., sugarbeet, onion, alfalfa, carrot, spinach, and lettuce. Many of the studies have been multi-year efforts and include two to three years of data collection. The research has been conducted in the fields of cooperating growers and, thus, represents production-level scale. The data include crop evapotranspiration measurements and resulting crop coefficients, farm delivery records, crop yield, etc. (A. Montazar, communication, 2021).

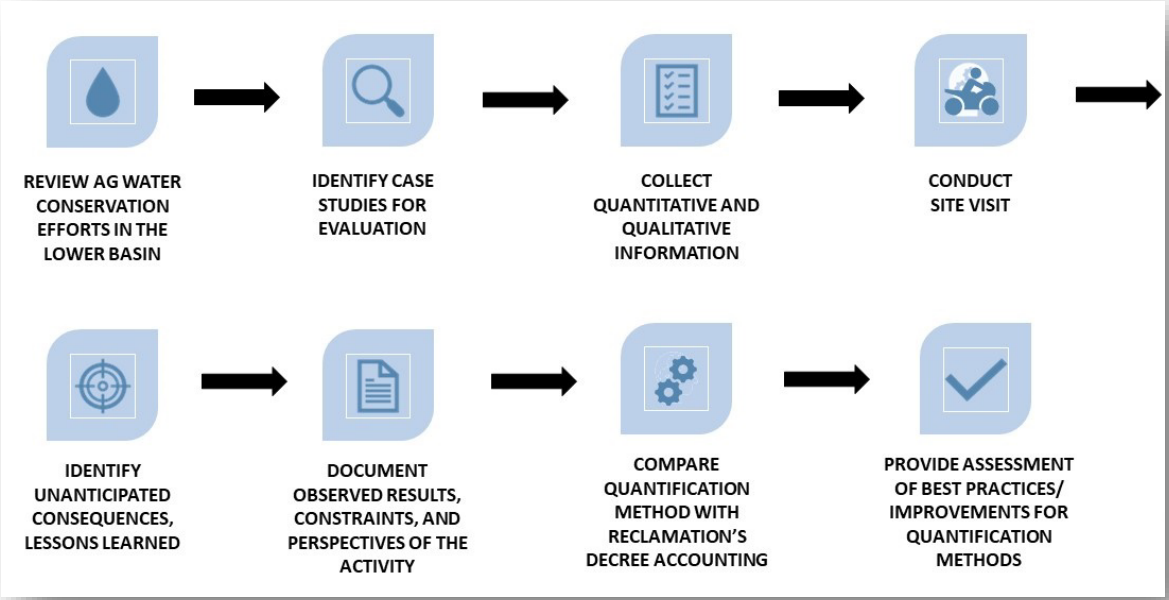
Case Study Evaluation Process

The case studies were evaluated with the goal of gaining knowledge on quantification methods and approaches. The envisioned process for carrying out each case study is shown in *Figure 4* and described below.

The case study process will include the following efforts:

- Site visits, in-person if possible, remote if necessary due to COVID-19,
- Interviews with case study participants,
- Reviews of documentation, reports, etc. relating to the conservation project and quantification methods,
- Identification of what did and did not yield desirable results with the project and quantification methods,
- Identification of what the participants would like to have done different and why,
- Determination of how the applied quantification approaches compare with the quantification approaches identified in TM2,
- Determination of whether a particular conservation activity and quantification approach could provide valuable information for application in other situations,
- Consideration of the accuracy of methods used in the project:
    - How well does the method quantify water savings/efficiency?
    - Characterization of the estimated water savings relative to the potential error limits of the quantification method,
- Consideration of costs of implementation (administrative, equipment, data collection, and analysis cost),
- Determination of whether or not the quantification method is conceptually complicated or difficult to implement,
- Determination of whether or not the conservation activity yielded expected conservation results,
- Determination of how widely the quantification method is currently used,
- Identification of the relationship of the conservation activity and quantification method to the Reclamation Decree Accounting—is there measurable reduction in mainstream Colorado River CU?
- Assessment of opportunities for improvement of the quantification method(s).

Figure 4 *Case Study Evaluation Steps*



The following constraints and limitations were specified or identified for the Pilot Study:

- This Pilot Study is not an exercise to promote or condemn any particular method or approach; rather the intent is to learn from what was done and to receive feedback from the implementing entities on what could be improved,
- The COVID-19 pandemic must be considered and participants may not want to host a large traveling group, and
- Use of the case study information and results will not negatively impact the case study participants.

Conclusions and Recommendations

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

- GRIC Irrigation System Modernization
- Bard Fallowing Program
- PVID Forbearance and Fallowing Program
- PVID Moderate Deficit Irrigation of Alfalfa Program
- CRIT Fallowing Program
- MVIDD Fallowing Program

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Appendix: Workshop 2 Presentation Slides

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

Workshop #2

March 2, 2021

BUREAU OF RECLAMATION

Welcome/Introductions

Workshop #2 Agenda

- Welcome and Introductions
- Pilot Study Overview
- Technical Memorandum 2 Results and Summary
- Presentation on PVID Deficit Irrigation Study
- Case Study Framework (with PVID Deficit Irrigation Study as an Application Example)
- Project Sharing Opportunities
- Wrap-up and Next Steps

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Pilot Study Overview

Pilot Study Objectives

- Participants' input and feedback is critical to the success of the Study
- Explore current methods to quantify agricultural water conservation
- Evaluate methods for consistency with Reclamation's Lower Colorado River water accounting methodology
- Evaluate case studies using both research and applied science
- Recommend approaches to improve methods of quantifying Lower Basin agricultural water conservation

Pilot Study Schedule

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Technical Memorandum 2 Results and Summary

www.lcrbpilotstudy.com

Technical Memorandum 2

1) A review of scientific literature and other sources to identify consumptive use (CU) quantification methods

2) A review of a several example conservation activities within the LCRB and the associated CU quantification methods which have readily accessible information

Literature Review

- Academic and technical literature – studies, reports, journals
- Documentation and evaluation of CU quantification methods
- Focus on LCRB and adjacent regions, some literature from other areas
- Including literature since *Moving Forward* report
- Annotated bibliography

Conservation Measures

Primary

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

Other

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

What is CU?

- In Reclamation's Decree Accounting, CU is defined as diverted water less return flows to the Colorado River
- Focuses on quantification of evapotranspiration
- Portion of ET derived from applied irrigation water
- CU of water for transbasin diversions is the total portion of the diversion that leaves the basin

Methods to Quantify CU

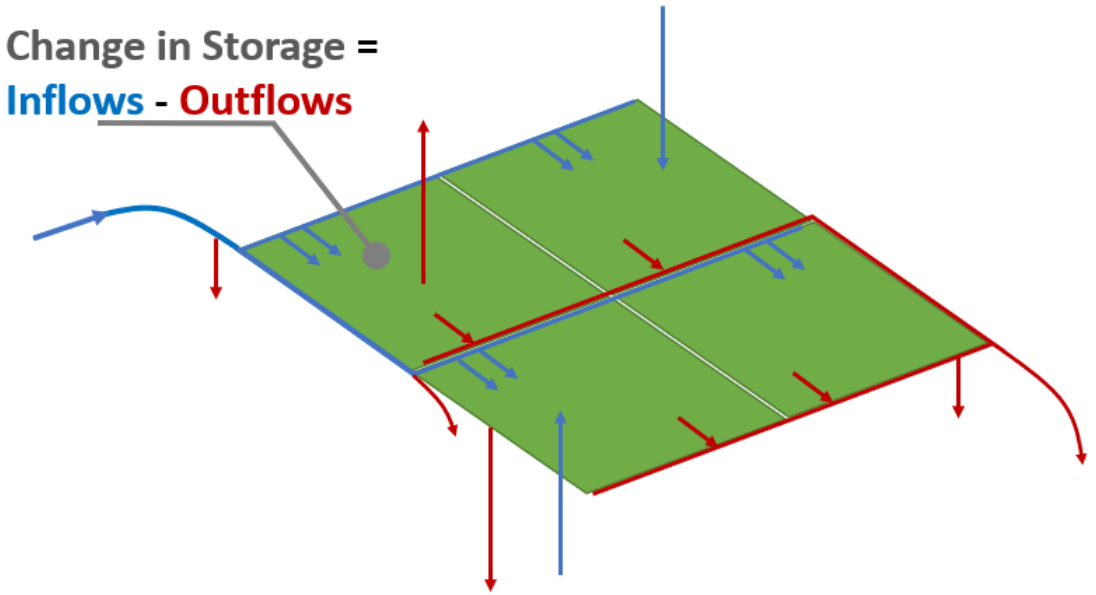
- Water Balance
- Lysimetry
- Micrometeorology
- Reference Evapotranspiration
- Remote Sensing

USDA-FSA NAIP Imagery, 2019, Yuma Co., AZ

Eddy Covariance Station, USDA ARS Conservation and Production Research Laboratory, Bushland TX. Photo courtesy of Tom Ley.

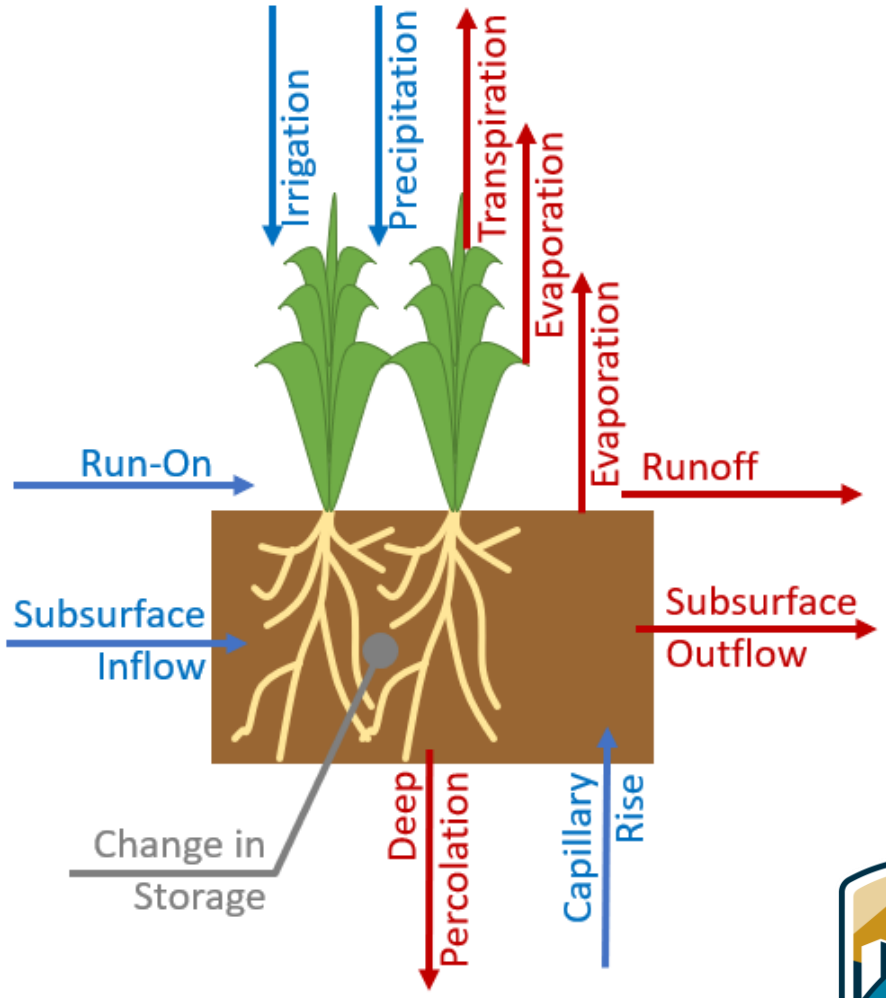
Water Balance

- Soil water balances and field-level water balances
- Project-level water balances
- Delivery and other flow measurements



Soil Water Balances and Field-Level Water Balances

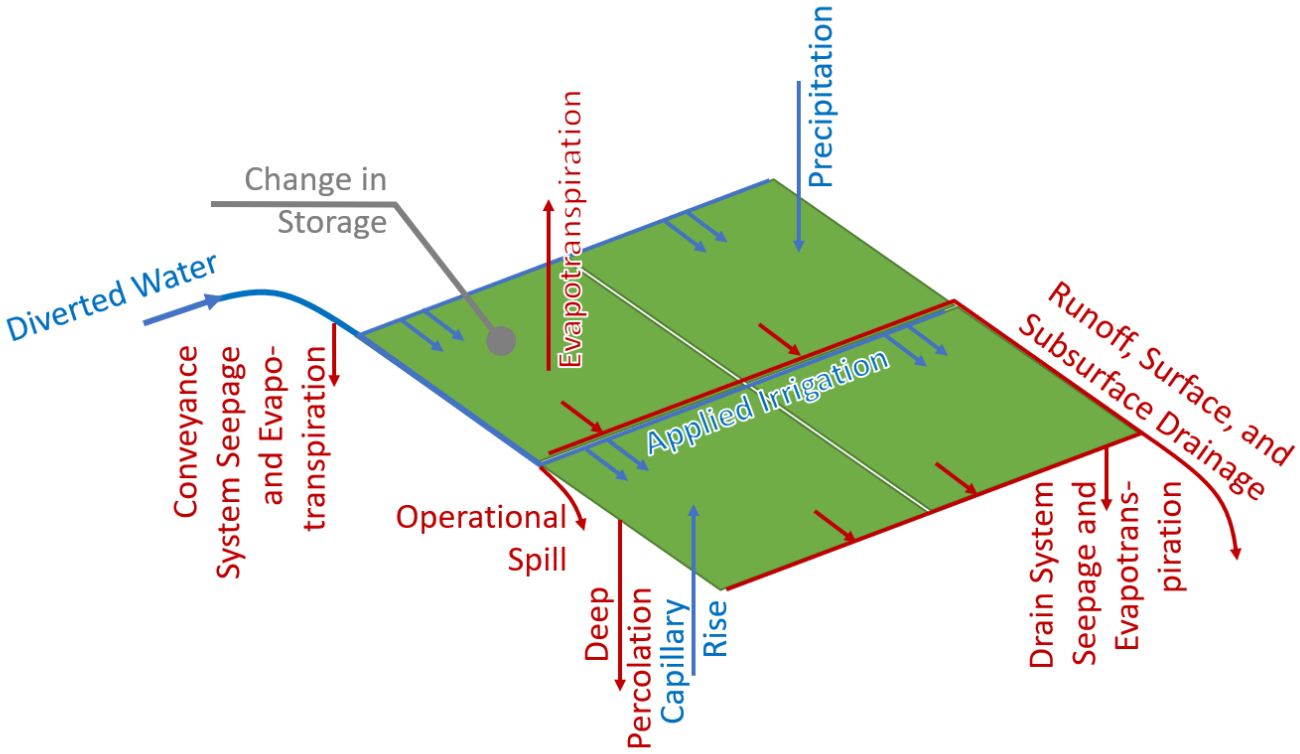
- Must simplify water balance (site conditions/management must fit assumptions)
- Soil water (soil moisture) sensing



Project-Level Water Balances, Delivery and other Flow Measurements

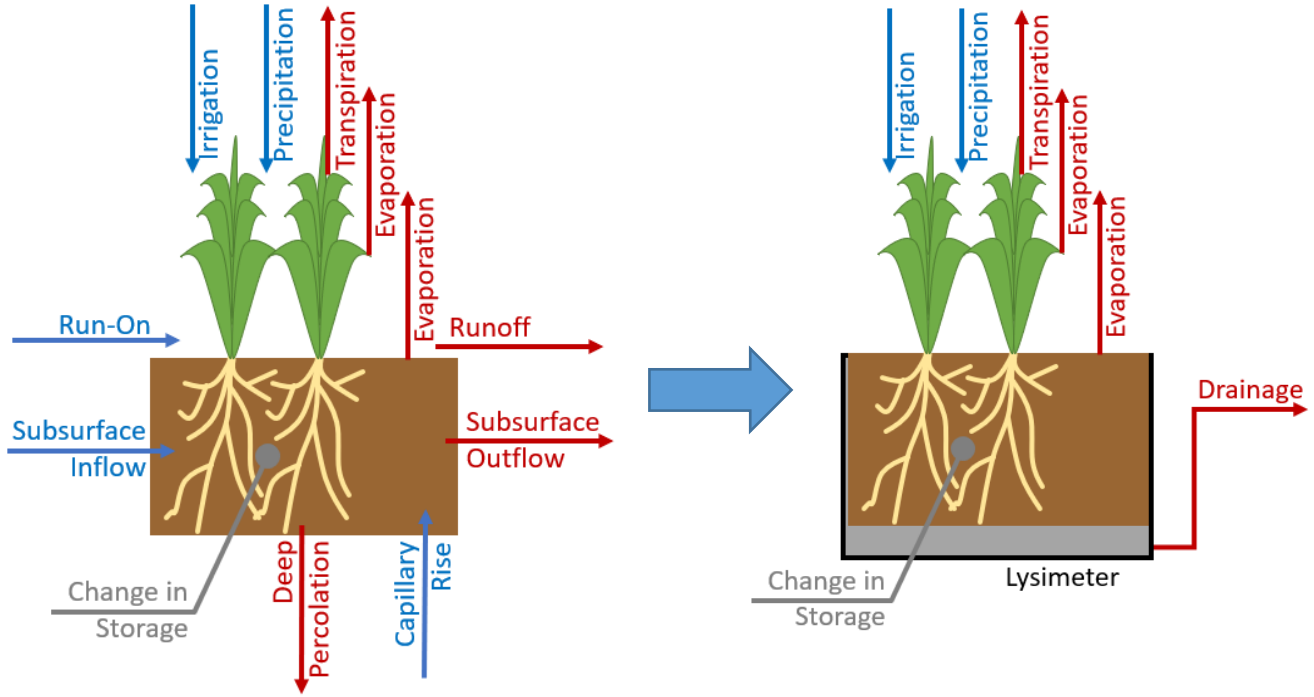
Must simplify water balance

Site conditions/management must fit assumptions



Lysimetry

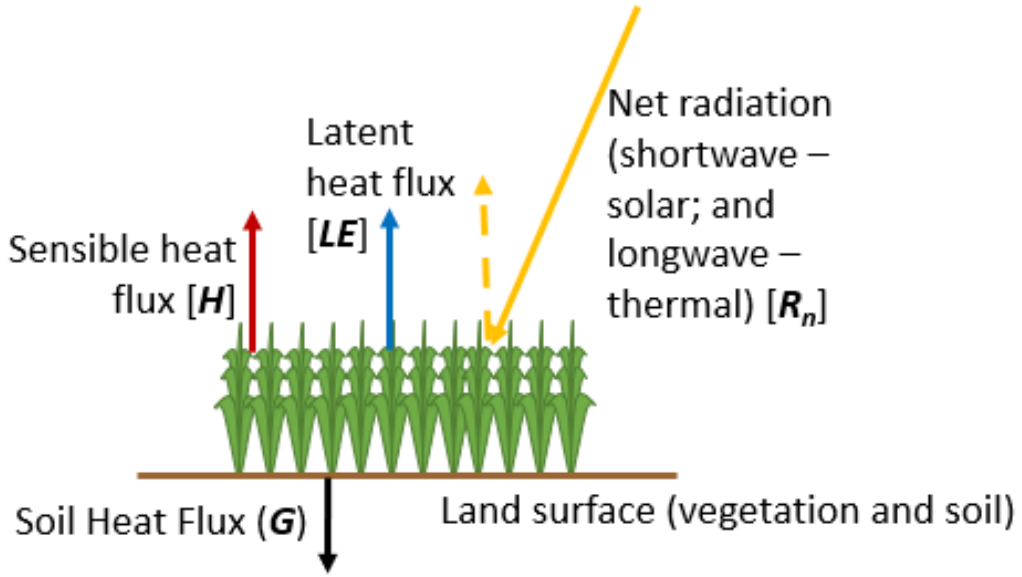
- Weighing lysimeters
- Drainage and other lysimeters
- Can be a highly accurate method
- Resource intensive
- Limited to research studies



3m x 3m weighing lysimeter with monolithic core at USDA ARS Conservation and Production Research Laboratory, Bushland TX. Photo courtesy of Tom Ley.

Micrometeorology

- Eddy covariance
- Bowen ratio energy balance method
- Surface renewal method
- Scintillometers



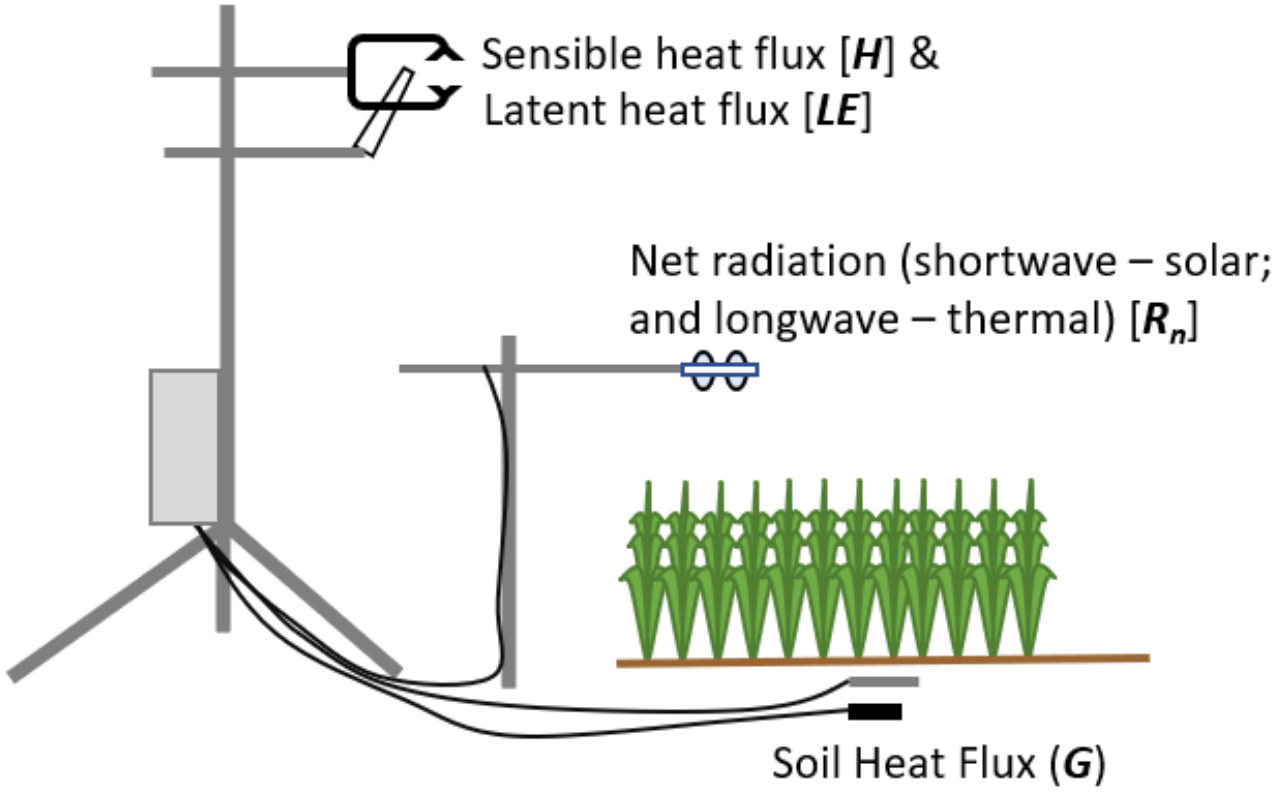
$$LE = R_n - G - H$$

$$ET = \frac{LE}{\lambda \rho_w}$$

Eddy Covariance

- Field-scale
- Widely used
- High operation requirements

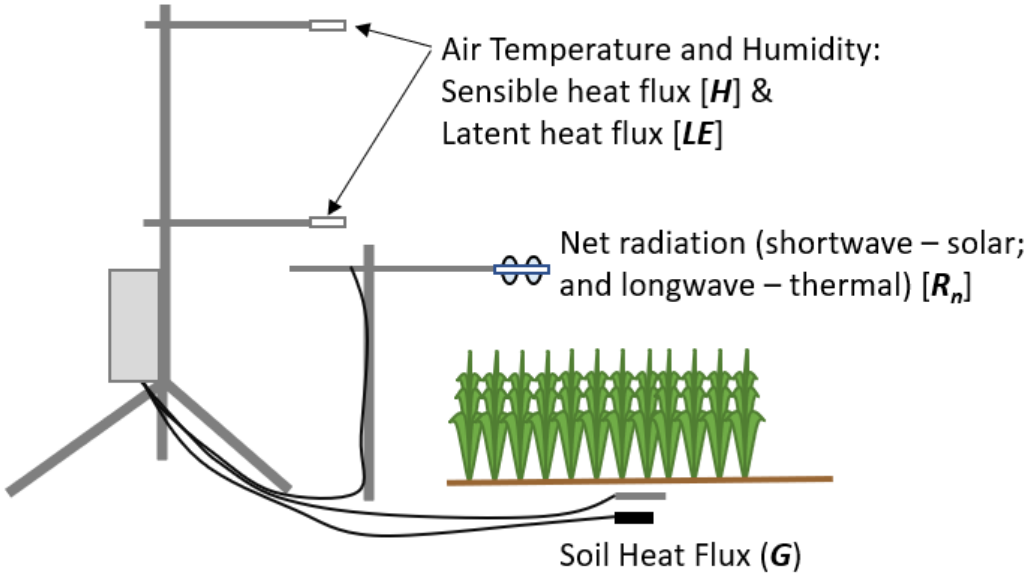
Eddy Covariance Station, USDA ARS Conservation and Production Research Laboratory, Bushland TX. Photo courtesy of Tom Ley.



Bowen Ratio Energy Balance

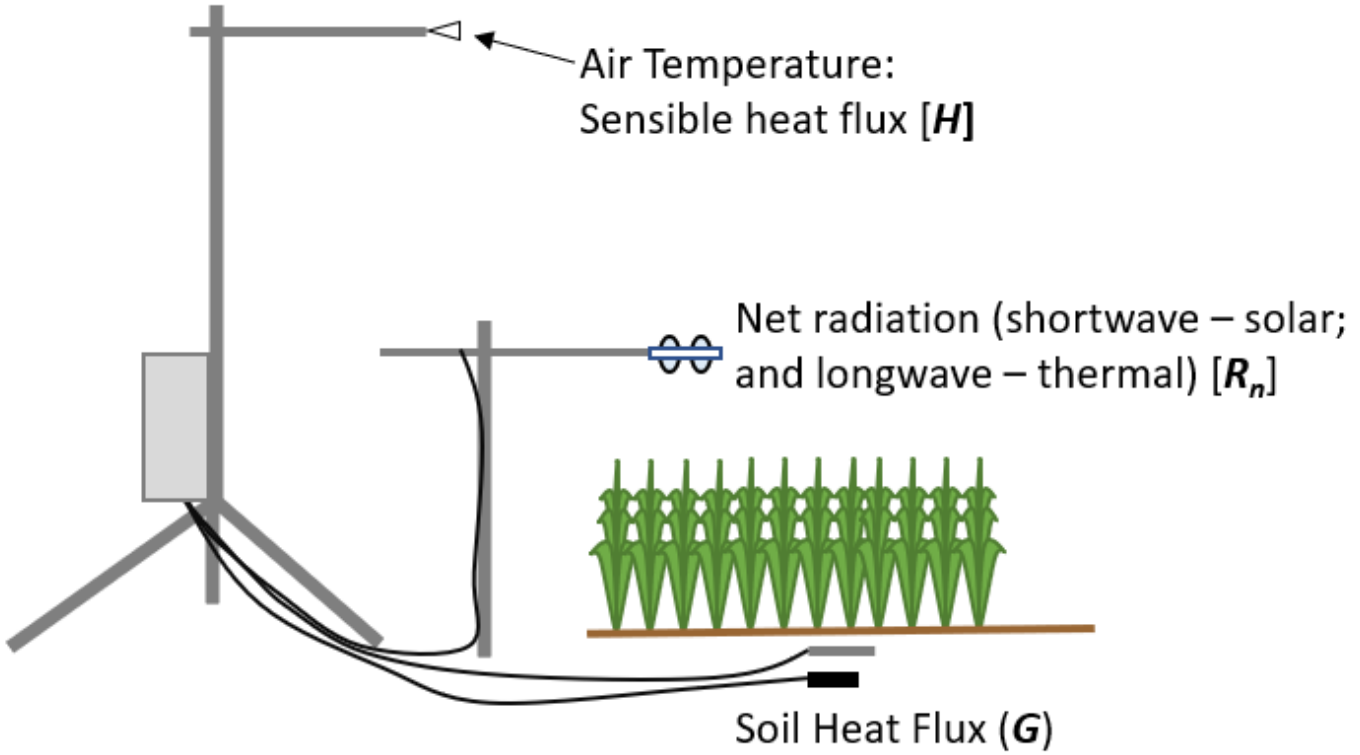
- Field-scale
- Moderately-high operational requirements

Bowen Ratio Station, USDA ARS Conservation and Production Research Laboratory, Bushland TX. Photo courtesy of Tom Ley.



Surface Renewal Energy Balance Method

- Field-scale and smaller
- Latent heat flux through energy balance
- Moderately-high operational requirements

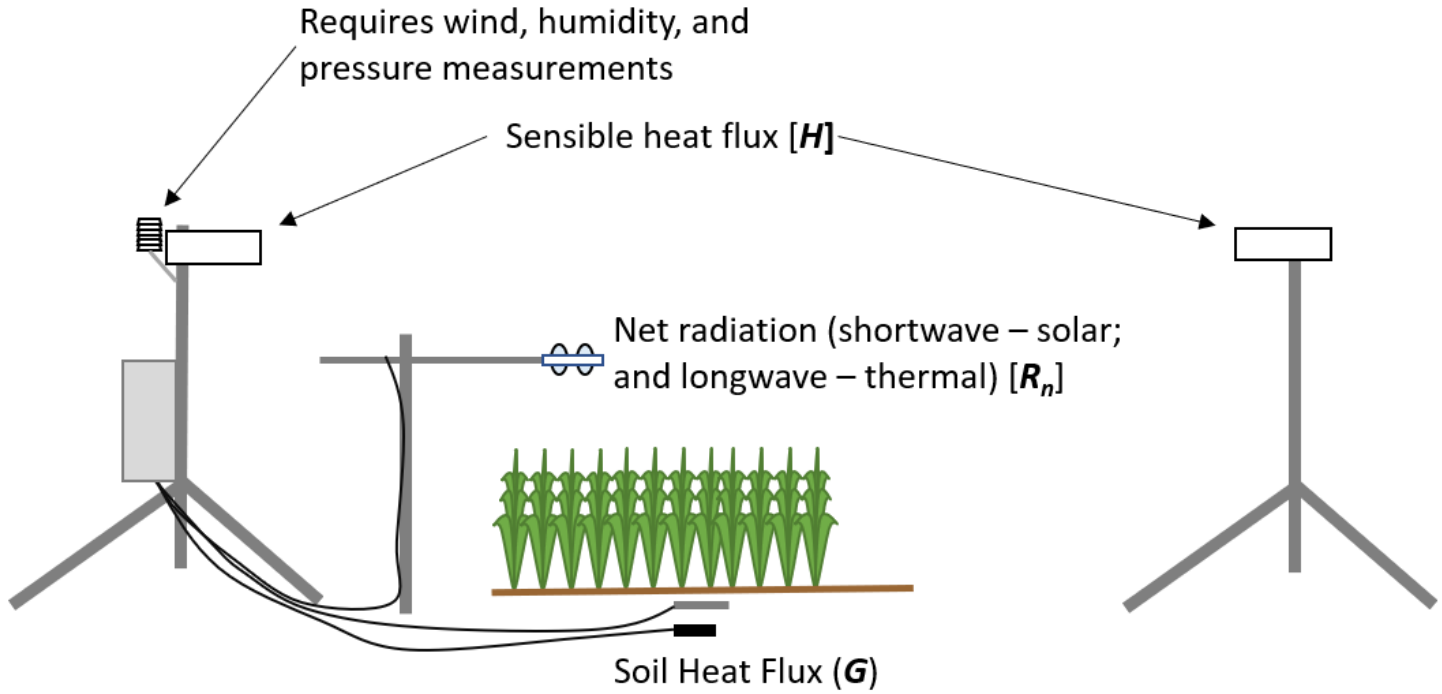


$$LE = R_n - G - H$$

Scintillometry

- Multiple-field-scale
- LE through energy balance
- Expensive and limited to research

https://en.wikipedia.org/wiki/Scintillometer

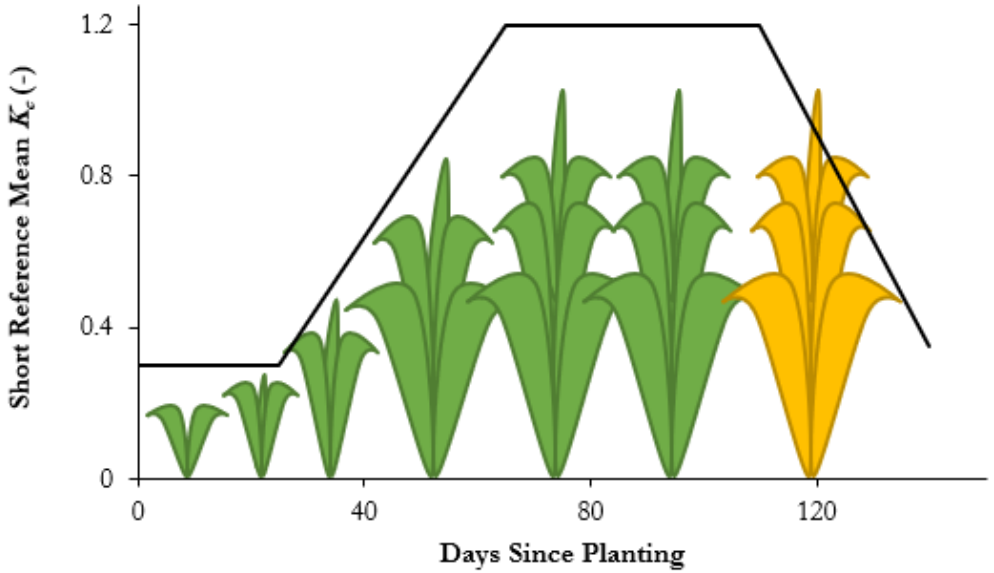


Based on: https://www.kippzonen.com/Product/193/LAS-MkII-Scintillometer#.YBmMSXJlCUk;
https://www.kippzonen.com/Product/193/LAS-MkII-Scintillometer#.YCQY83JlCUk;
https://www.kippzonen.com/Product/194/LAS-MkII-ET-System

$$LE = R_n - G - H$$

Reference Evapotranspiration

- Crop Coefficient
- Spatial Crop Surveys



Based on Allen et al. (1998) and Jensen and Allen (2016).

Automated agricultural weather station, Bushland, TX. Photo courtesy of Tom Ley.

$$ET_c = K_c ET_{ref}$$

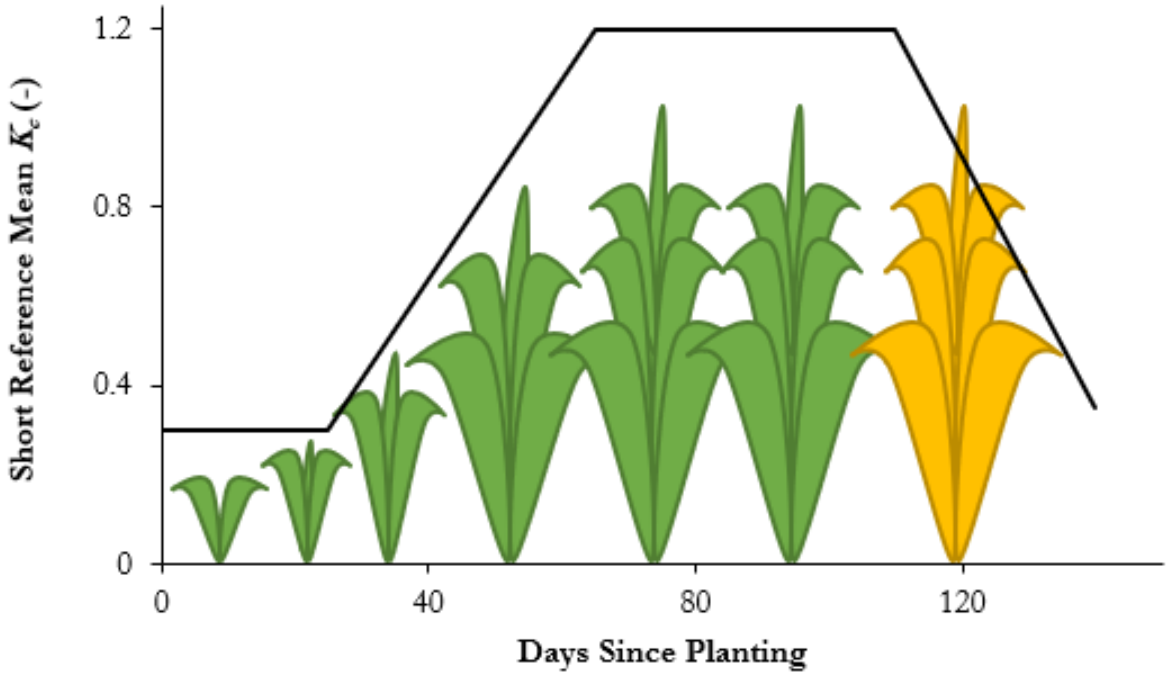
Reference Evapotranspiration

Reference methods (ASCE Standardized Reference Evapotranspiration Equation, ASCE, 2005)

"Potential" vs. actual ET or standard vs. non-standard conditions

Dual vs. single crop coefficient

Based on Allen et al. (1998) and Jensen and Allen (2016).



$$ET_c = K_c ET_{ref}$$

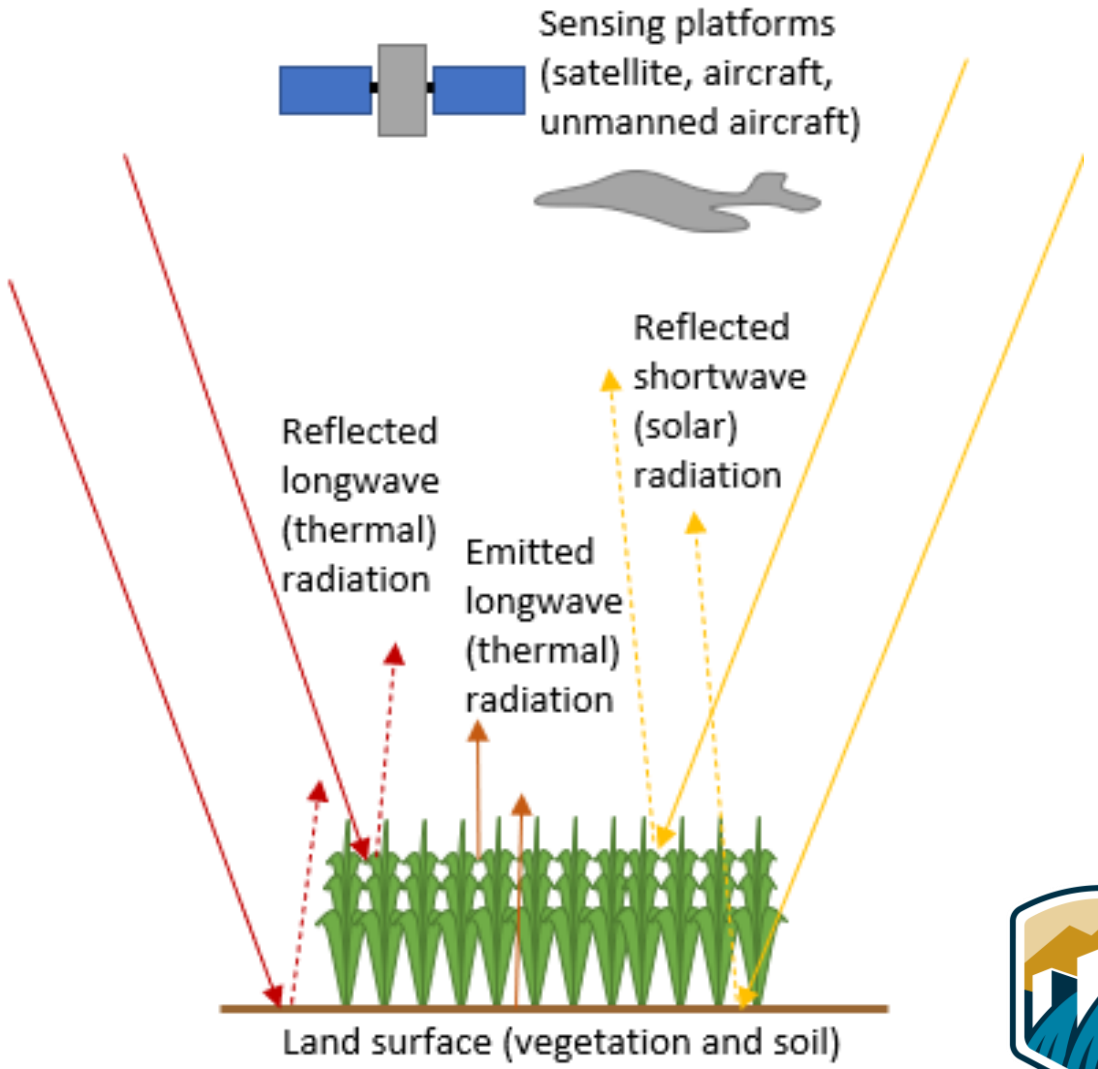
$$K_c = K_{cb} K_s + K_e$$

Based on Allen et al. (1998) and Jensen and Allen (2016).

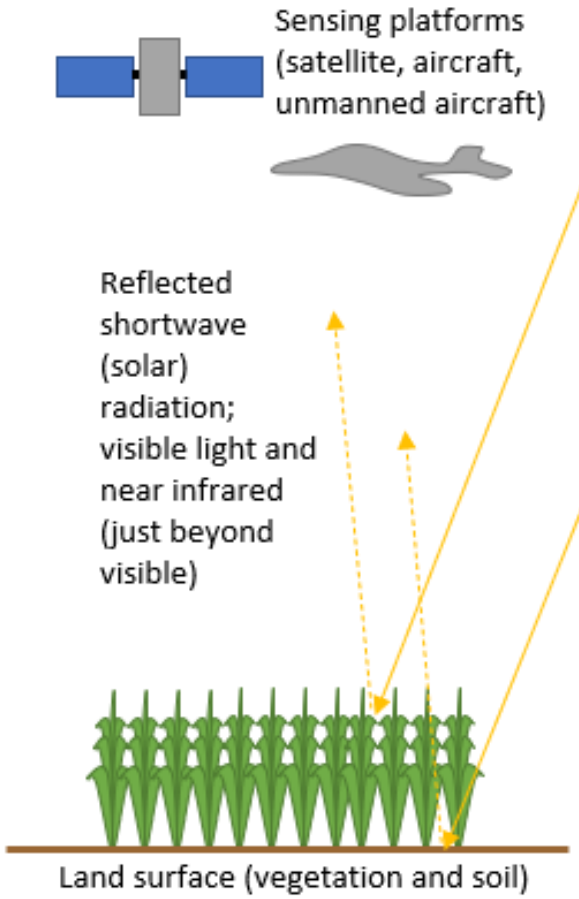
Remote Sensing Evapotranspiration Modeling

Reflectance-/Vegetation-Based Methods

Energy Balance Models and Thermal Infrared Methods

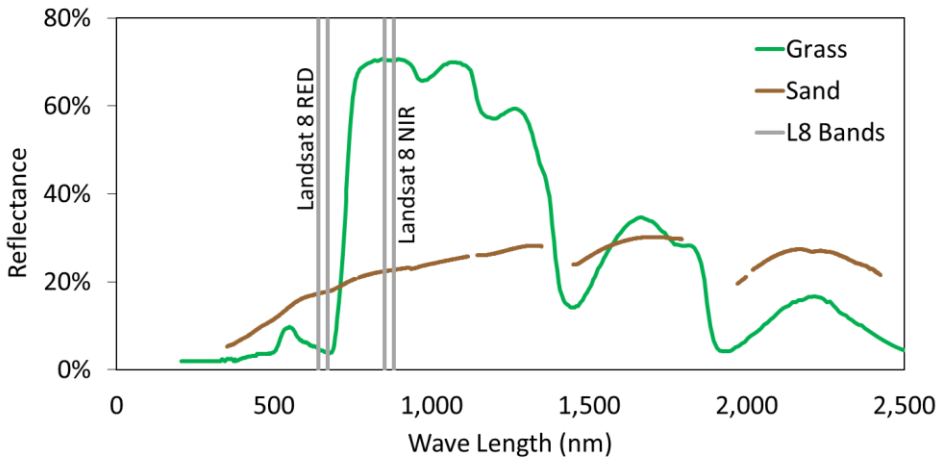


Remote Sensing Reflectance-/Vegetation-Based Methods

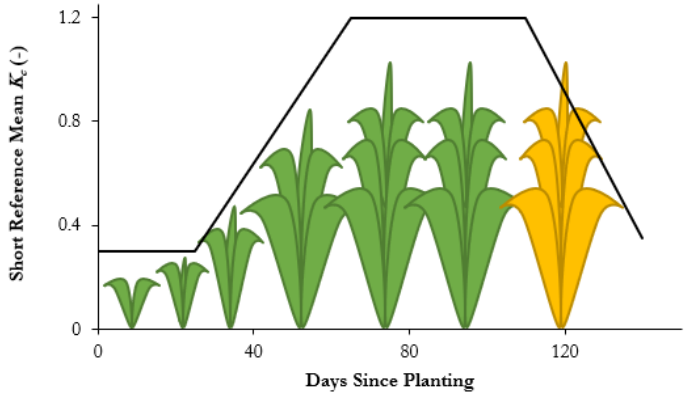


USDA-FSA NAIP Imagery, 2019, Yuma Co., AZ

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

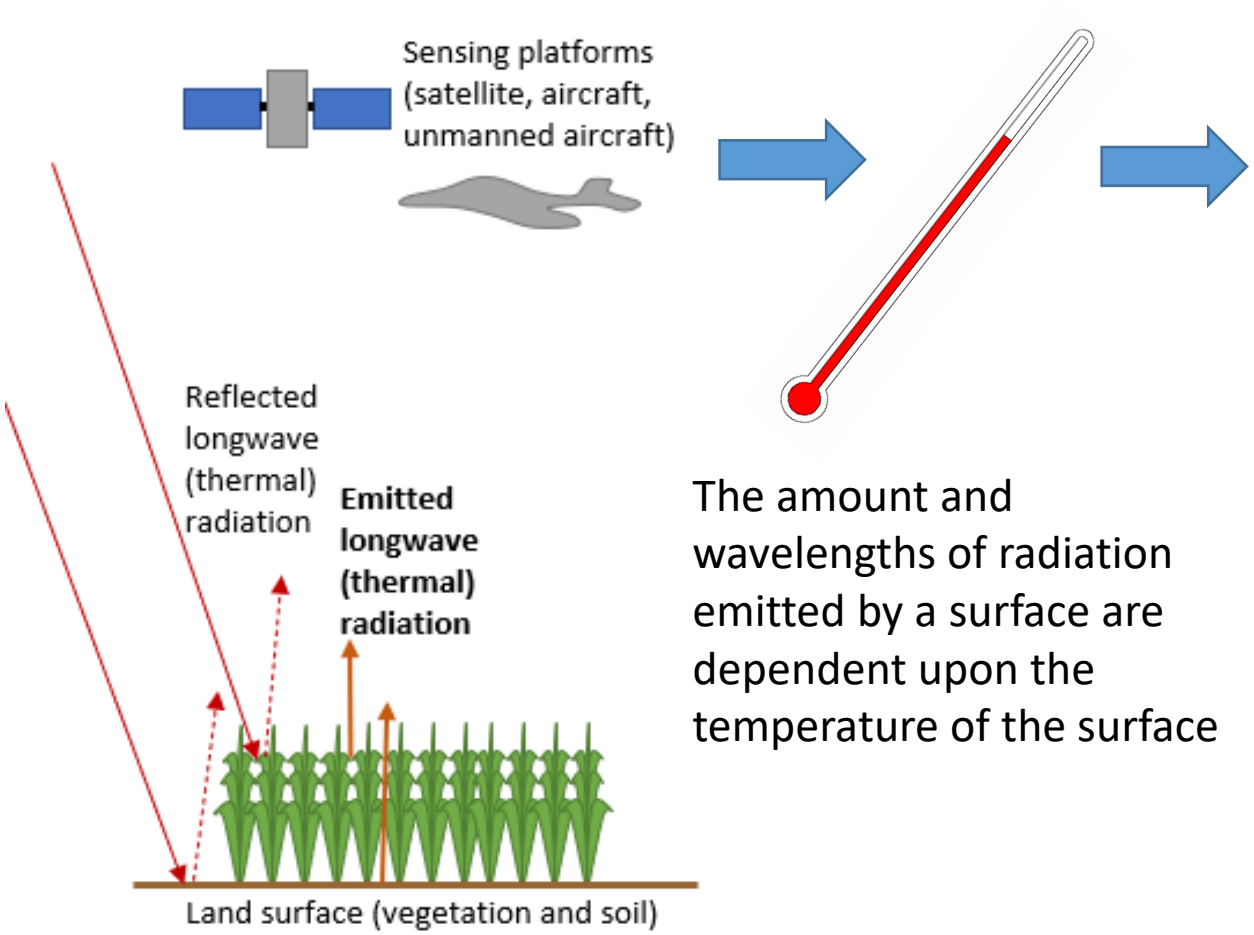


Data are presented for illustrative purposes and may not be comparable. Reflectance data from: Kokaly, R.F., Clark, R.N., Swayze, G.A., Livo, K.E., Hoefen, T.M., Pearson, N.C., Wise, R.A., Benzel, W.M., Lowers, H.A., Driscoll, R.L., and Klein, A.J., 2017, USGS Spectral Library Version 7: U.S. Geological Survey Data Series 1035, 61 p., https://doi.org/10.3133/ds1035. Landsat 8 bands from: https://www.usgs.gov/core-science-systems/nli/landsat/landsat-8?qt-science_support_page_related_con=0#qt-science_support_page_related_con



Based on Allen et al. (1998) and Jensen and Allen (2016).

Remote Sensing Energy Balance Modeling and Thermal Infrared Methods



The amount and wavelengths of radiation emitted by a surface are dependent upon the temperature of the surface

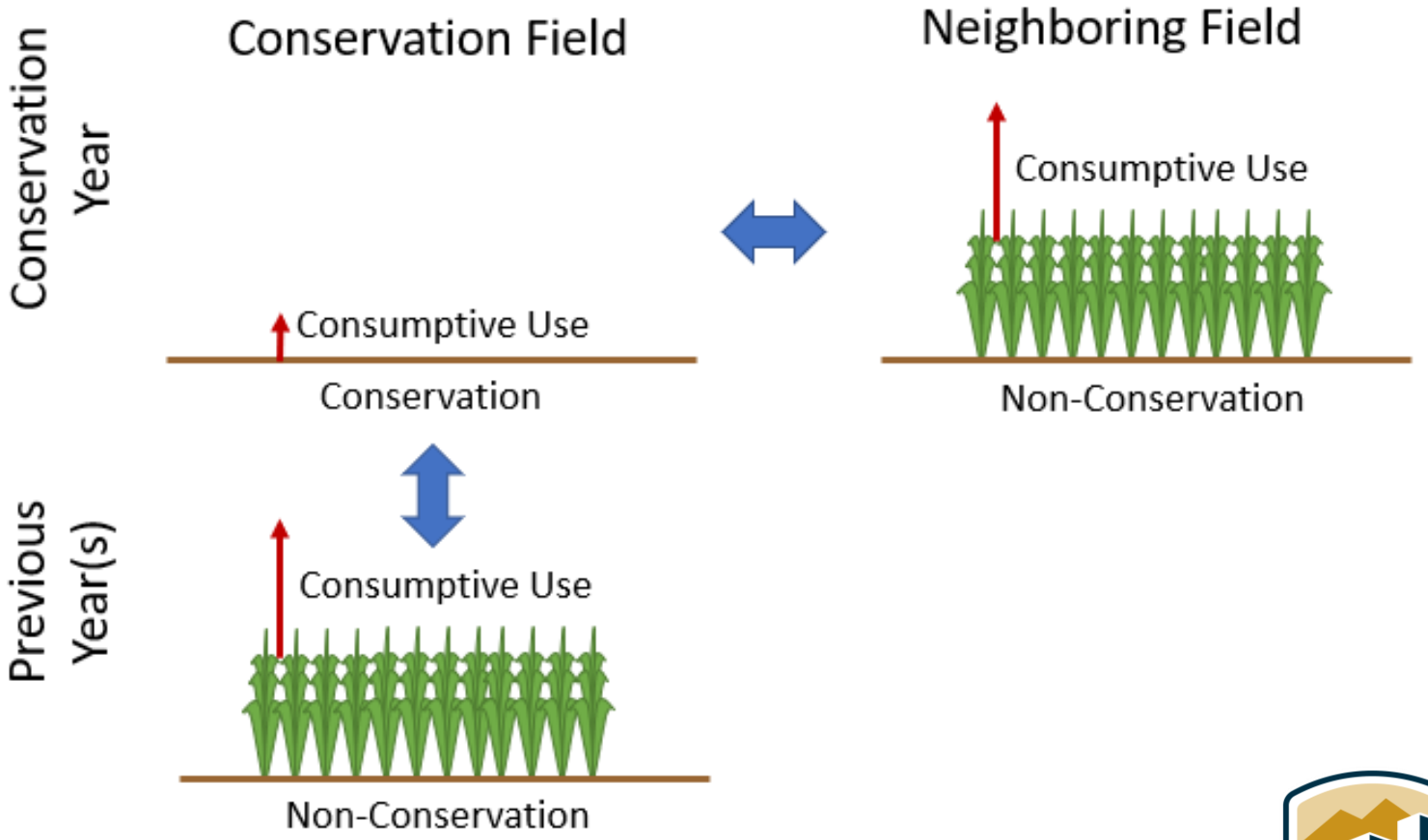
$$LE = R_n - G - H$$

- Land surface temperature is used to model sensible heat flux (H); latent heat flux (LE) is solved using the energy balance or concurrently with H
- Models differ largely in the methods of making use of the land surface temperature to compute energy fluxes
- Temporal scaling

Quantifying Differences in Consumptive Use

Methods for estimating consumptive use differences for conservation practices

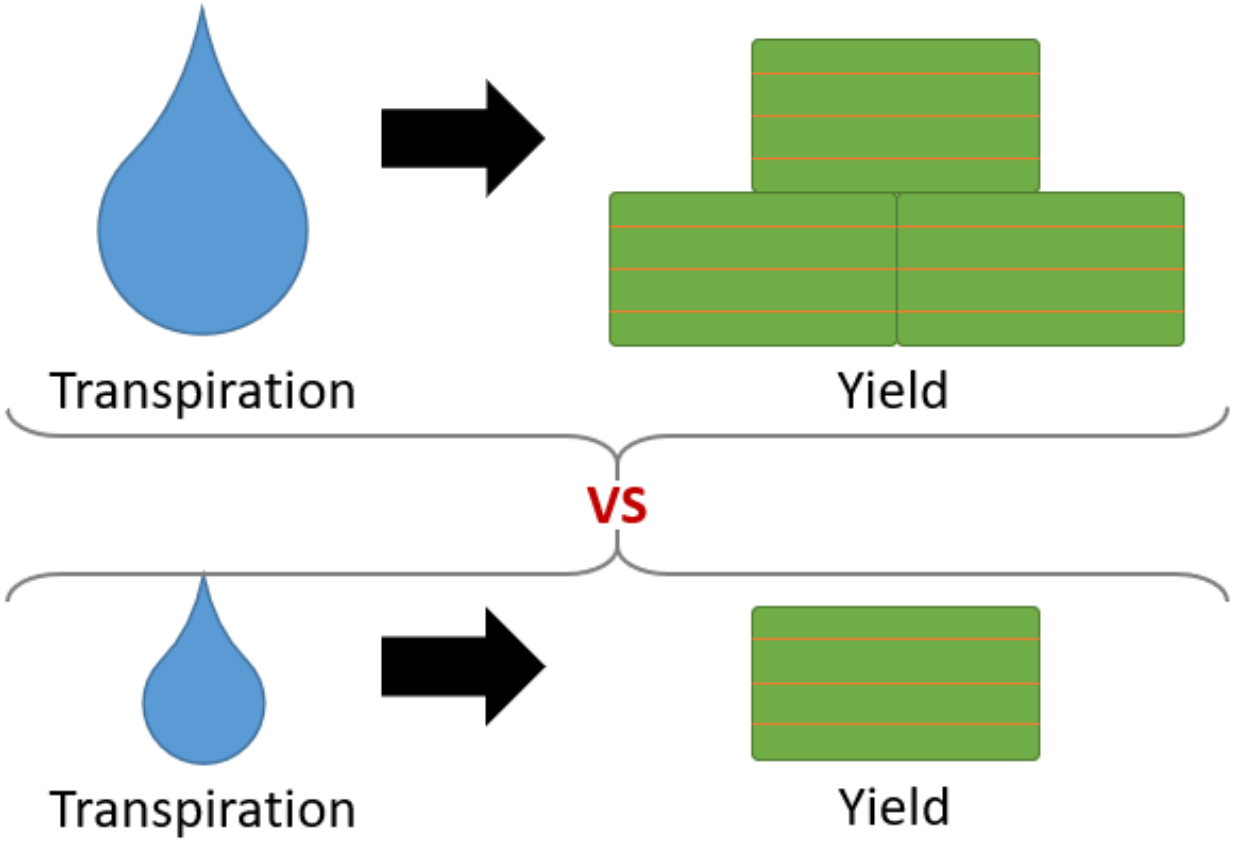
Comparisons of conservation vs. non-conservation



Yield Considerations

Impact of conservation on yield

Yield is related to consumptive use



BUREAU OF RECLAMATION

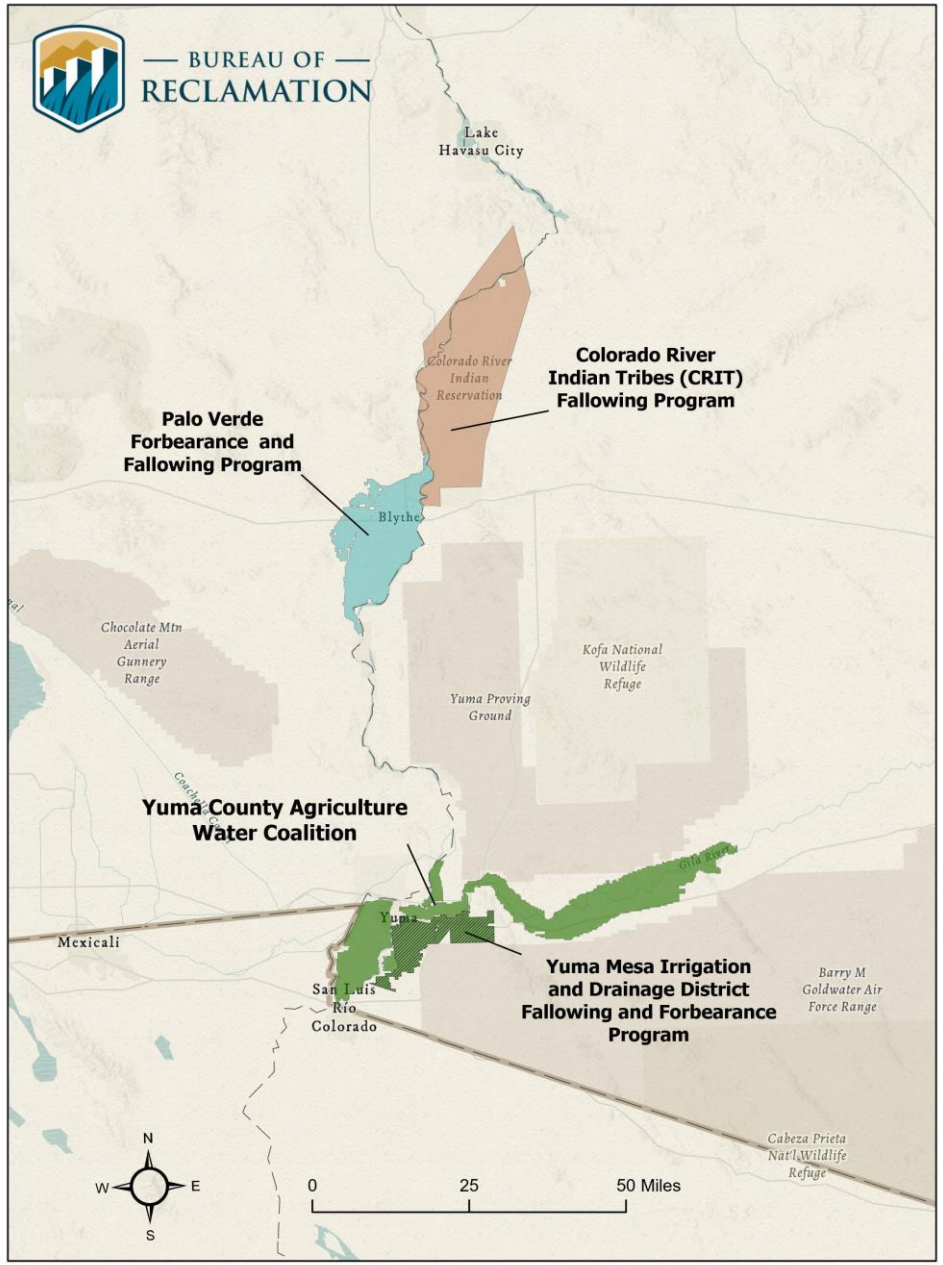
Findings from Current/Recent Conservation Activities

Ag Water Conservation in the LCRB

- Significant activity and experience across the LCRB over the past 20+ years
- Extensive investment in irrigation system improvements at the conveyance/delivery system and on-farm irrigation system levels
- Several recent conservation efforts with readily accessible information were selected as examples for review

Reviewed Conservation Activities

- Colorado River Indian Tribes (CRIT) Fallowing Program
- Yuma County Agriculture Water Coalition Study
- Yuma Mesa Irrigation Drainage District Fallowing and Forbearance Program
- Palo Verde Forbearance and Fallowing Program
- Palo Verde Deficit Irrigation Program



CRIT Fallowing Program

Program Summary

- 2016 – present
- CU reduction due to fallowing computed as average ET of crops produced on the parcel during at least 4 of previous 5 years
- Fallowing verification checks
- Satellite imagery analyses—NDVI and false color infrared

Quantification Method

- Crop coefficient/reference ET/spatial crop surveys
- ASCE Standardized Reference ET Equation
- AZMET electronic weather stations
- Crop coefficients from Reclamation LCRAS Program

CRIT Water Conservation by Fallowing

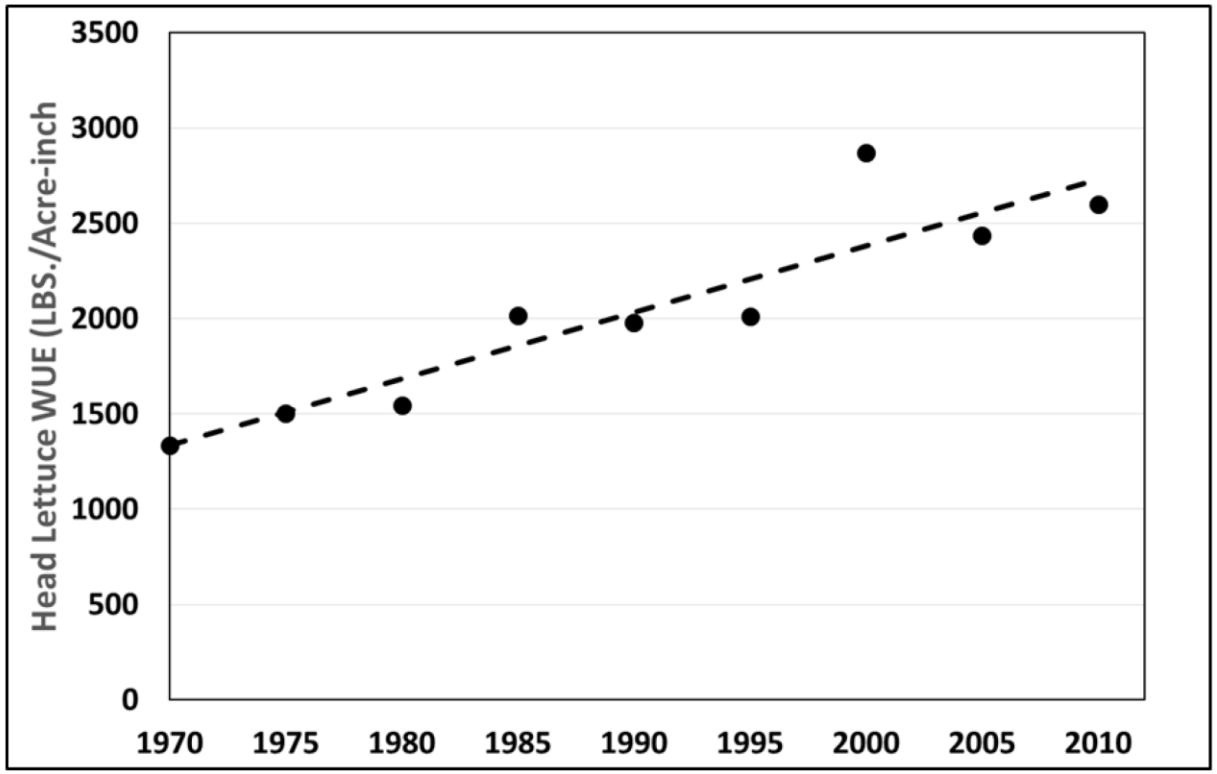
Program	Farm	Dates	Fallowed Acreage (ac)	Net Consumptive Use Reduction		Diversion Reduction
				AFY/ac	AF	AF
Pilot SCP-Phase 2	Kudu Farm	Oct 1, 2016 - Sep 30, 2018	1,591	5.39	17,144	30,772
Pilot SCP-Phase 3	MTA Farm	Oct 1, 2018 - Sep 30, 2019	1,884	5.70	10,697	19,932
Pilot SCP- Phase 3	Quail Mesa	Jan 1, 2019 - Dec 31, 2019	3,705	4.72	17,488	32,996
AZ DCP System Conservation	Multiple	Jan 1, 2020 - Dec 31, 2020	10,786	4.98	53,736	100,623
AZ DCP System Conservation	Multiple	Jan 1, 2021 - Dec 31, 2021	10,826	5.05	54,685	103,078
AZ DCP System Conservation	Multiple	Jan 1, 2022 - Dec 31, 2022	TBD			

Note: CRIT ICS Creation through fallowing during CY 2019 totaled 6,274 AF, but is not included here.
Under CRIT's DCP System Conservation Agreement during 2020-2022, any net consumptive use reduction in excess of 50,000 acre-feet (AF) is not compensated but is credited to CRIT's intentionally created surplus (ICS) account.

Yuma County Agriculture Water Coalition

Program Summary

- 2015 study
- Reviewed history/water management
- Crops changed from perennial crops to vegetable production
- Growers adopted alternative irrigation practices
- Increased crop yield



YMIDD Pilot Fallowing and Forbearance Program

Program Summary

- 2014 – 2016
- Agreement with CAGRD
- Spatial crop surveys
- Reference evapotranspiration
- Crop coefficients

Summary of Pilot Fallow Program (2014 – 2016)			
Year	**Enrolled Acres**	**Unit Consumptive Use (AF/ac)**	**Conserved Water (AF)[1]**
2014	1,406	4.86	6,827
2015	1,411	5.09	7,180
2016	1,401	5.36	7,509

[1]Includes removal of special water use such as dust control and tree removal

http://www.cap-az.com/documents/meetings/2018-09-20/1716-2.0_WEB FINAL_Information Brief_Fallowing Programs Report.pdf

Palo Verde Forbearance & Fallowing Program

Program Summary

- Started in 2005, 35-year agreement between MWD and PVID & contracts w/ individual farmers
- Average farmland in production = 91,400 acres
- 7% - 28% fallowed annually
- Temporary fallowing (no acre fallowed >5 years w/out rotation back into production)
- Reclamation's LCRB accounting consumptive use
- Comparison of fallow fields to other fields in PVID

From: https://www.usbr.gov/lc/region/g4000/4200Rpts/DecreeRpt/2019/27.pdf

http://www.mwdh2o.com/PDF_NewsRoom/6.4.2_Water_Reliability_Palo_Verde.pdf;
https://www.usbr.gov/lc/region/g4000/4200Rpts/DecreeRpts/DecreeRpt/2019/27.pdf

BUREAU OF RECLAMATION

PVID Deficit Irrigation Project Overview

BUREAU OF RECLAMATION

Case Study Framework

Case Study Considerations

- Location
- Conservation Activity
- Quantification Method

Case Study Considerations

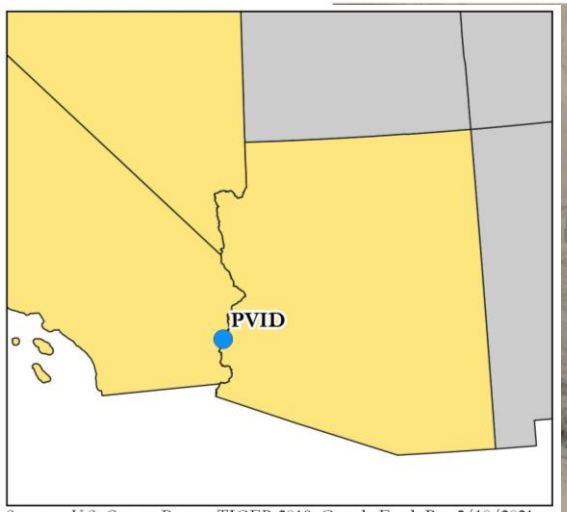
Location

Conservation Activity

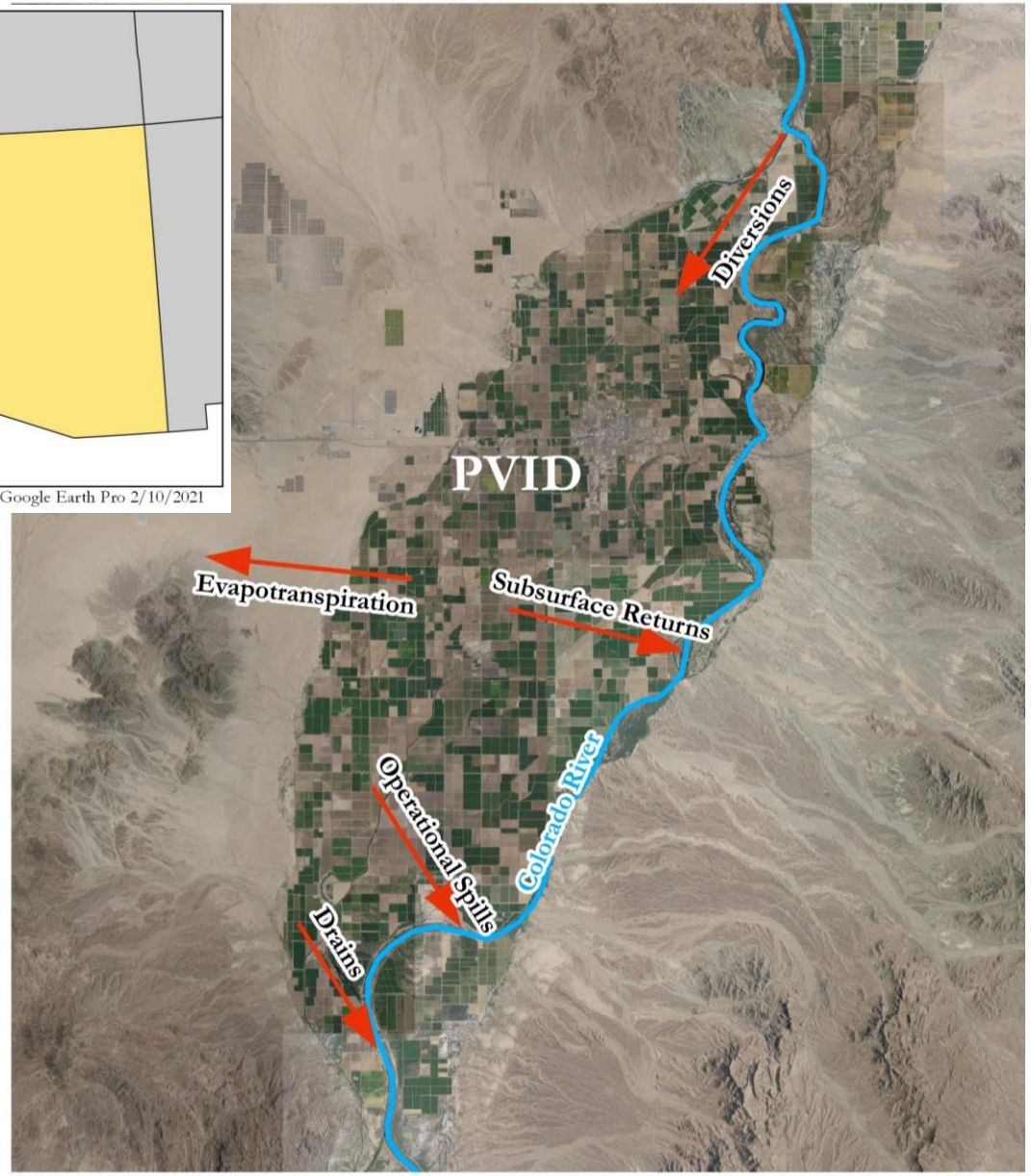
Quantification Method

- Geographical
- On-river/Transbasin

PVID Location: Palo Verde Valley, On-River



Sources: U.S. Census Bureau TIGER 2018; Google Earth Pro 2/10/2021



Source: USGS (2017) Basemap Imagery

Case Study Considerations

Location

Conservation Activity

Quantification Method

Consumptive Use (CU) Reduction

- Full-year agricultural cropland fallowing
- Seasonal/partial-year cropland fallowing
- Deficit irrigation
- Crop mix changes or crop switching

Efficiency Improvements

- Seepage reduction
- Irrigation conversion/improvements
- Tailwater reduction and reuse
- Soil amendments to increase water holding
- Water control – SCADA, spill reduction

PVID Conservation Activity: CU Reduction, Deficit Irrigation

- Deficit irrigation 1 (D1): Eliminate three irrigation events in summer harvest cycles (Jul – Sept)
- Deficit irrigation 2 (D2): Eliminate two irrigation events in summer harvest cycles (Aug – Sept)
- Deficit irrigation 3 (D3): Eliminate one irrigation event in summer harvest cycles (Aug – Sept)

Case Study Considerations

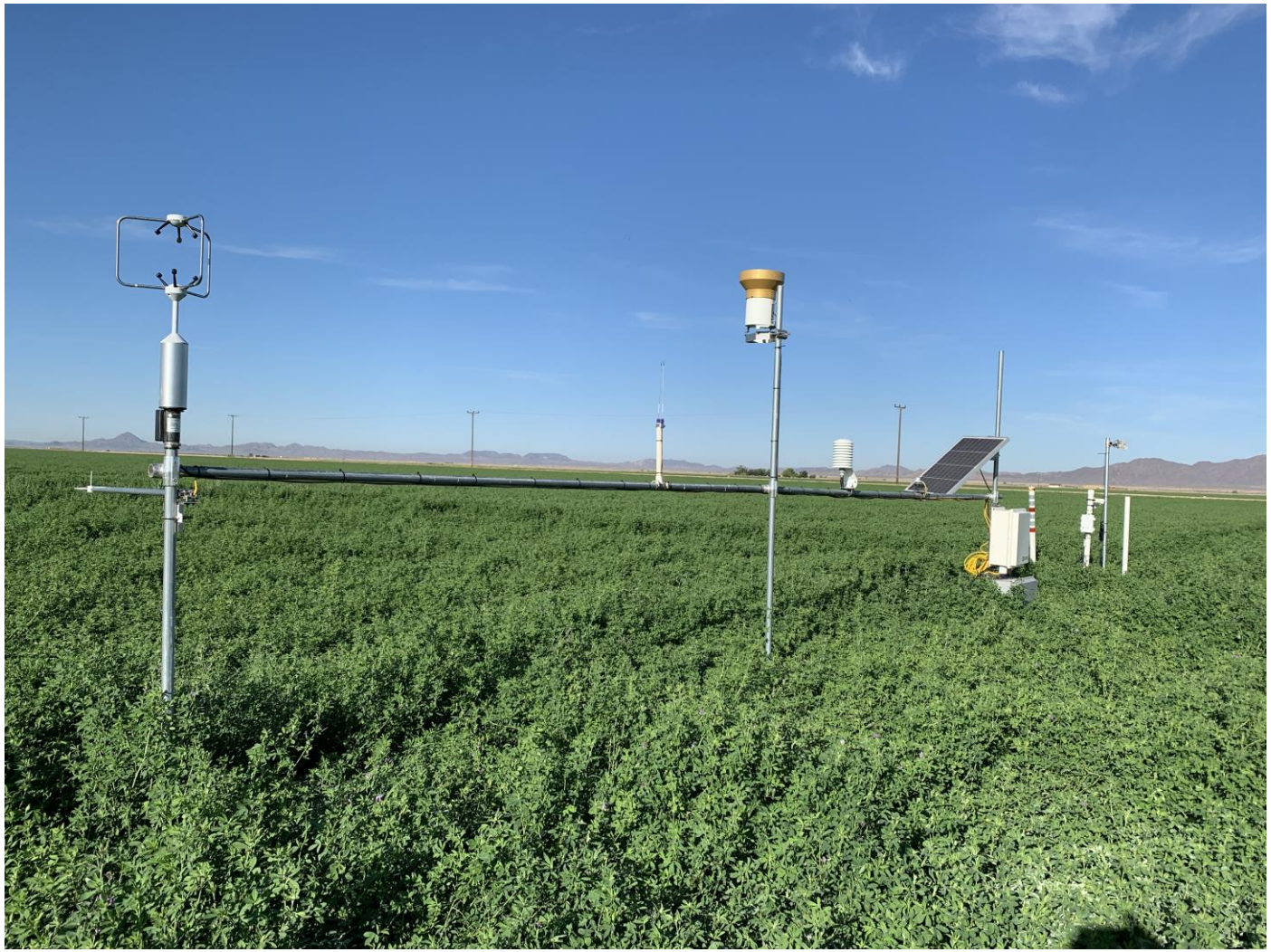
Location

Conservation Activity

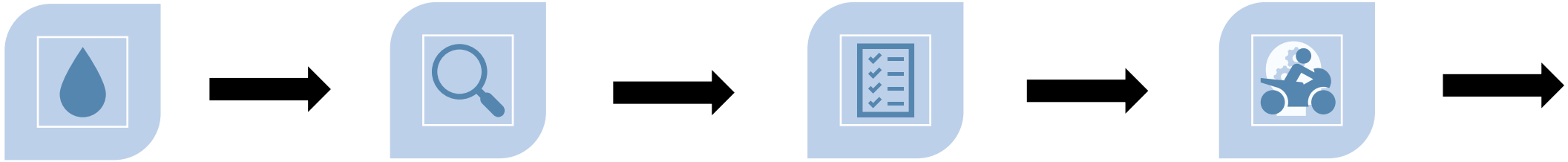
Quantification Method

- Water Balance
  - Soil-Water
  - Field-Level
  - Project-Level/Delivery/Flow Measure
- Micrometeorology
  - Bowen Ratio Energy Balance
  - Eddy Covariance
  - Surface Renewal
  - Scintillometers
- Reference Evapotranspiration
  - Crop Coefficients
  - Spatial Crop Surveys
- Remote Sensing
  - Reflectance-/Vegetation-Based Methods
  - Energy Balance Models & Thermal Infrared Methods

PVID Quantification Method: Micrometeorology (Surface Renewal & Eddy Covariance)



Case Study Evaluation Steps

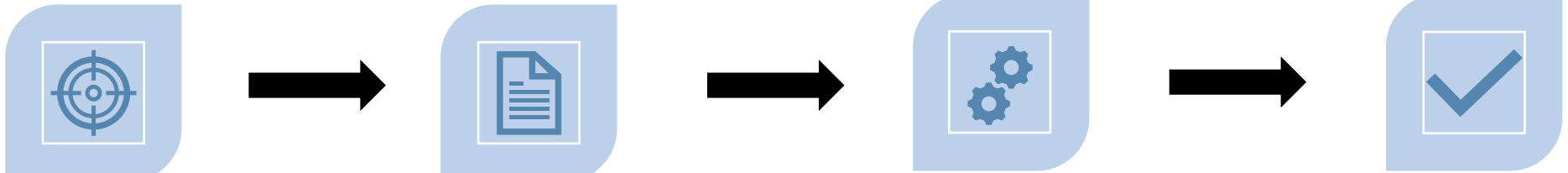


REVIEW AG WATER CONSERVATION EFFORTS IN THE LOWER BASIN

IDENTIFY CASE STUDIES FOR EVALUATION

COLLECT QUANTITATIVE AND QUALITATIVE INFORMATION

CONDUCT SITE VISIT



IDENTIFY UNANTICIPATED CONSEQUENCES, LESSONS LEARNED

DOCUMENT OBSERVED RESULTS, CONSTRAINTS, AND PERSPECTIVES OF THE ACTIVITY

COMPARE QUANTIFICATION METHOD WITH RECLAMATION'S DECREE ACCOUNTING

PROVIDE ASSESSMENT OF BEST PRACTICES/ IMPROVEMENTS FOR QUANTIFICATION METHODS

Matrix of Potential Case Studies

Potential Case Studies	Location		Conservation Activity					Quantification Method			
	State	On-river/ Transbasin	Deficit Irrigation	Irrigation Conversion	Fallowing	Crop Modification	Efficiency Improvements	Water Balance	Micrometeorology	Reference ET	Remote Sensing
PVID/MWD Forbearance and Fallowing Program	CA	On-river			X			X			
PVID Partial Year Deficit Irrigation of Alfalfa Program	CA	On-river	X					X	X	X	
CRIT Fallowing Program	AZ	On-river			X			X		X	
Mohave Valley IDD Fallowing Program	AZ	On-river			X			X		X	
Bard Water District Seasonal Fallowing Program	CA	On-river			X			X			
Central Arizona IDD	AZ	Transbasin					X				
Maricopa-Stanfield IDD	AZ	Transbasin					X				

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Project Sharing Opportunities

BUREAU OF RECLAMATION

Wrap-up and Next Steps

Pilot Study Schedule