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A California Crop Coefficient (3C) Database to Enhance Agricultural Water Demand Estimations and Irrigation Scheduling in the Water-limited Context of California

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1.1 EXECUTIVE SUMMARY

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Summary

In the water-limited context of California, improving the accuracy of water demand estimations has become of critical relevance for climate-adaptive water resource planning, securing reliable water supply, water allocations and deliveries, and irrigation management. However, over the past several years it has also become evident that the information on crop coefficients (Kc), originally developed in California during the 1950s and 1960s and still utilized for estimating water demand and manage irrigation, are not accurate or applicable anymore and need to be updated. In the last decades, improvements in the equation for estimating reference evapotranspiration (ETo) and to make this data available throughout California have been made by the scientific community, while significant changes of crop varieties, planting densities, farming practices, irrigation methods and strategies have been implemented by the agricultural production community, thanks to research advancements and technological innovations. To fill the existing knowledge gaps on crop water needs, in 2018 the California Department of Water Resources (DWR) and the University of California Agriculture and Natural Resources (UC ANR) established the California Crop Coefficient (3C) Science Collaborative with the aim of developing, organizing and disseminating science-based Kc information with broad industry-wide participation and consensus. In this project, the 3C Collaborative plans to conduct applied-science work for: 1) updating Kc information for major water-demanding crops in California through research activities, as well as through analysis, interpretation, and review of datasets and information collected from on-going and previous studies; 2) compiling the Kc information in peer-reviewed documents and materials, with the consensus of industry leaders and representatives from the agricultural production and regulatory communities; 3) making the updated Kc information available and usable with existing tools to enhance the capability for modeling/forecasting water demand and irrigation scheduling; 4) developing a web repository of the updated Kc information and materials that will allow access and retrieval by water managers and various other end-users, while promoting their broad dissemination; 5) organizing trainings and workshops, and developing educational materials to encourage the broad adoption of updated and new Kc information for water planning and management purposes in California.

This cross-disciplinary work will start on June 1, 2020 and will be completed over the course of three years. The work proposed for this project will focus on agricultural production areas of the Intermountain region, the Sacramento and San Joaquin valleys, the Central and South coast, and the Low Desert region of California. All the project activities will be conducted at non-

federal facilities made available by University of California, Davis (UC Davis), UC ANR, DWR, Commodity Boards, and commercial production farms.

Leveraging a scientific and programmatic presence in all California counties through the internationally recognized community of research and extension professionals from the University of California Cooperative Extension (UCCE), the project will involve the following commodities: nut crops (almond, pistachio, walnut); fruit crops (peaches, nectarines, plums); subtropical crops (citrus, avocado, olive); vine crops (wine grapes, table grapes, raisins, strawberries); vegetables (celery, artichokes, broccoli, etc.); field and agronomic crops: (alfalfa, corn, rice, wheat cotton, processing tomatoes). The project team will focus mostly on major water-demanding crops, but will also update Kc information for urban and natural landscapes.

1.2 TECHNICAL PROJECT DESCRIPTION AND MILESTONES

1.2.1 Background and Motivation

1.2.1.a Estimating Water Demand in the Western Region

Accurate estimation of agricultural water demand is a crucial component for water budgets, water allocation, storage, conveyance and deliveries, as well as for scheduling irrigation and managing water application at farm and field levels. Enhancing the capacity to model and forecast agricultural water needs and to schedule deliveries and final water applications to cropped fields has become of high relevance for water planners, managers, consultants and growers in the water-limited context of California. These water actors operate along the water supply chain, from the source to conveyance, storage, distribution, delivery and final water use, under increasing pressure to achieve higher resource-efficiency, economic productivity and ecological sustainability, but at the same time with increasing weather variability.

In California, crop evapotranspiration (ETc) under well-watered conditions is often estimated as the product of reference evapotranspiration (ETo) and a crop coefficient (Kc) using the well-known formula ETc = ETo x Kc. In the last 20 years, significant advancements have been made to make accurate ETo data timely and publicly available throughout California with different time-steps that are suitable for water resource planning and management at various scales. Increased accuracy has been achieved by state and federal agencies in both modeling ETo at point and spatial scales (AgriMET, CIMIS, Spatial CIMIS, PRISM) and forecasting ETo (FRET). Efforts by state agencies and academia to model and forecast evapotranspiration of applied water (ET_{AW}) are underway for resource planning, allocation and management purposes, and for evaluating the compliance of water management schemes and procedures with more stringent environmental regulations.

In order to effectively use ETo data for water planning and management, accurate Kc values by growth stages are needed for the different crops. However, many of the Kc values currently in use in California were developed from studies conducted during the 1950s and 1960s for crops, farming and nutrient management practices, and infrequent irrigation methods (surface and sprinkler irrigation) that were typical of that time, which generated significantly lower yields relative to the current cropping systems and practices. Over the recent years, it has become evident that the information on Kc originally developed in California may not be applicable anymore due to remarkable changes that occurred in farming systems and practices, and other factors. Specifically, improvements in the equation for estimation of ETo were made by the scientific

community, and substantial changes have been implemented by the farming industry in crop cultivars, rootstocks, planting densities and canopy management, soil and nutrient management practices, all resulting from embracement of research advances and technological innovations. In addition, wide adoption of micro-irrigation systems and improved water management practices by growers of annual and perennial crops have occurred, thanks to research outcomes, technological improvements, and financial subsidies provided by state and federal agencies. These changes have brought agronomic advancements and enabled farmers to attain significantly higher yields and better quality of productions, along with substantial gains in resource-efficiency and economic water productivity relative to the past.

This project will develop and make available updated information on water use of major California crops that will enhance the capability to estimate and forecast water demand and manage water supplies with higher accuracy. The adoption of updated Kc information will address water supplies shortfalls and uncertainties imposed by more stringent environmental regulations, recurring droughts, and climate variability. The project will also improve Kc information for urban and natural landscapes, thus contributing to enhance resource management to meet competing demands by the agricultural, urban and environmental sectors.

1.2.1.b Enhancing Modeling and Forecasting Capabilities

Research efforts to update Kc values for the major water-demanding crops and landscapes continue in California, partly in response to water supply limitations imposed by recurring droughts, increased inter-annual weather variability, progressive expansion and intensification of high market value crop productions, as well as by the compliance with current and upcoming environmental regulations. There is, however, no coordinated effort in California for developing, reviewing, evaluating, analyzing, consolidating, unifying and distributing science-based and quality-assured Kc information to various users, including water managers, irrigation practitioners and consultants, farm managers, individual growers, various other stakeholders and the broad public. In addition, no active repository has been established and maintained within the State for updated Kc information with broad statewide and industry-wide consensus that water resource planners, managers and various other users can access and use for accurately estimating water needs to improve water resource planning, allocation, supply management and deliveries. The information is also critically important for water marketing and transfers, especially during drought years.

To fill these knowledge gaps and overcome limitations in information-sharing, in October 2018, the California Department of Water Resources (DWR) and the University of California Agriculture and Natural Resources (UC ANR) established the California Crop Coefficient (3C) Science Collaborative with the aim of developing, organizing and disseminating science-based Kc information with broad industry-wide participation and consensus. The 3C Science Collaborative is now pursuing the acquisition of funding to conduct a set of planned activities for updating and disseminating science-based Kc information for the major water-demanding crops grown within the State, as well as for urban and natural landscapes, and enhancing water demand modeling/forecasting and irrigation scheduling tools.

Accessing updated and quality-assured Kc information will enable more accurate estimation of water demand, which in turn will lead to more realistic and dependable water budgets, water allocation, storage, conveyance and deliveries, as well as improved irrigation scheduling and applications. Better information on crop water use will help to improve decision

on conjunctive use of ground and surface water and it will contribute to conservation efforts and improved on-farm application efficiency by better defining the appropriate application depths.

We estimate that relying on better Kc information will enable water managers to improve the accuracy of demand estimations, allocations and irrigation delivery and scheduling decisions by 15-30%, with the lower figures resulting for cropping systems where only minor changes have occurred, and the upper figure for crops and systems that experienced major changes and large agronomic improvements in the last decades.

Table 1 describes how the proposed project will contribute to meet the water management objectives listed as Funding Opportunity Announcement (FOA) goals.

Table 1. Contributions of the proposed project to accomplishment of FOA goals

FOA Goals	Contribution of the proposed project to FOA Goals
Develop updated/new hydrologic information	The availability of quality-assured crop coefficients with industry-wide consensus for water-demanding California crops and landscapes is a crucial factor for accurate estimations of water needs and irrigation scheduling to pursue economically profitable and resource-efficient crop production in the State. This project will develop and make available updated Kc information, which can be then adopted by water planners, managers and other stakeholders to devise water planning (allocations, storage, transfers) and management (distribution and delivery) decisions for agricultural production and urban areas commanded by water systems and/or supplied by aquifers.
Enhance water management tools	The project will make available, and facilitate the integration of updated and quality-assured Kc information into existing models and tools that water managers can access, use and build upon to support water resource planning, allocation, transfers, and management, as well as irrigation scheduling with improved accuracy and industry-wide consensus.
Improve modeling/forecasting capability	The use of updated Kc information, along with enhanced tools (validated by the project team) will improve the capability to model and forecast water demand and use at various levels along the water supply chain by water managers and other end-users for different production regions of California.
Drought management activities	Accurate estimates of crop water demand under well-water conditions represent the reference baseline to devise and implement partial allocations and deliveries of water, as well as deficit irrigation strategies under various levels of water supply limitations that may occur during droughts and as a result of compliance to current and upcoming environmental regulations. The updated Kc information can also inform water marketing and transfer strategies among different hydrologic units and individual users during drought years.
Conjunctive use of ground and surface water	Comparing improved estimations of water demand with available ground and surface water supply will allow evaluating opportunities for conjunctive use, water transfers, and water marketing with better accuracy, both in the spatial and temporal domains.
Water conservation and efficiency	The enhanced capability to model and forecast water demand resulting from information developed through this project could eventually be extended in the domain of crop yield prediction, and thus enable

	evaluations of water use efficiency, water productivity, and water conservation scenarios under various levels of partial (sub-optimal) water supply availability. All these aspects could also inform land use changes to match water demand and supply, and thus pursue resource conservation goals, as well as resource-efficient and sustainable water management.

The main purpose of this project is to use results from more advanced research methods, such as the surface energy balance (through eddy covariance and surface renewal techniques) to refine and improve the current crop coefficient information in California. The overall goal is estimating crop water use more accurately, which is one of foundations of water demand forecast and water budget analysis. This project will provide the best possible information on agricultural water demand for use in the California Water Plan, which is updated every five years to present the status and trends of California's water-dependent natural resources; water supplies; and agricultural, urban, and environmental water demands for a range of plausible future scenarios. California agriculture is a multi-billion-dollar industry, the number one agri-food producer in the nation, and among the largest consumers of water. The agricultural water demand is high and increasing because water supplies are limited and competition for those supplies is growing. The DWR is aware of the need for good planning, and the 3C Collaborative was developed to address the planning needs. The DWR requires accurate estimates of consumptive use to more effectively manage California's water resources. The increased emphasis on water conservation and the last four-year California drought further underscore the need for accurate information on crop water use. Because of its crucial importance, a network of evapotranspiration measurement stations (combining eddy covariance and surface renewal equipment) was established in California through a joint effort between UC Davis and DWR over the last 15 years. The network continuously updates crop coefficients to provide water resources policymakers, planners, water suppliers, and growers with improved evapotranspiration estimates.

This project will provide growers, water managers, and planners with part of the information needed to optimize irrigation application efficiency with reliable, accurate water use data between irrigation events. The cumulative ETc between irrigation events provides an estimate of the root zone, soil water depletion below field capacity, and the optimal application efficiency and crop productivity are typically achieved by infiltrating a mean depth of water into the low quarter (LQ) of a field that is equal to the cumulative ETc. The distribution uniformity (DU) is a measure of how evenly water infiltrates into the soil of a field that is calculated as the ratio of the mean depth of water infiltrating into the LQ to the mean depth of water infiltrating the entire field. The mean depth of water that infiltrates into the entire field is computed as the ratio of the LQ soil water depletion (SWD) to the DU. For example, if the SWD of the LQ is 40 mm and the DU=0.80, then the applied water is AW=40/0.80=50 mm, which is the depth of water that should be infiltrated. With this application, the application efficiency would be approximately AE=100×DU, and the AE could be improved by optimizing the system to achieve a higher DU or by applying less water. Applying less water, however, can lead to reduced production depending on the extent of the deficit irrigation, so it is only recommended for drought tolerant crops. Therefore, for most crops, the best method to improve application efficiency is refill the LQ at each irrigation and improve the DU. This project is critically important because accurate Kc and ETc data are necessary to know the SWD between irrigation events, which is needed to know how much to apply to the LQ. The improved AE comes from an improve DU and infiltrating an accurate depth

of water to the LQ. Providing accurate ETc information will greatly help with our efforts to improve irrigation systems to reduce diversions for on-field irrigation, and match water deliveries with actual water needs.

1.2.1.c Previous and Ongoing Efforts to Address Water Demand

Multiple efforts to provide information and tools for accurate estimations of water demand and use have been made by the academia, water agencies and regulatory entities in California, and further endeavors will continue in the near future in response to increasing water supply limitations and uncertainties due to stringent environmental regulations, recurrence of droughts, competing water demands, and increased inter-annual weather variability. There is, however, no coordinated effort in California for updating, unifying and distributing science-based and quality-assured crop water use information to various users. Establishing the 3C Science Collaborative, which is co-convened by DWR and UC ANR, was the first step to agree upon the need to develop and maintain an active, easy-access repository of updated Kc information with broad statewide and industry-wide consensus that will add value to other efforts in the domain of water resource planning and management within the State of California. Below we provide brief descriptions of past and ongoing efforts in the area of agricultural water resource management, and explain how the proposed project will complement and add value to related endeavors, services and products.

While the development of the California Irrigation Management Information System (CIMIS), Spatial CIMIS, and the National Weather Service (NWS) forecast ETo product (FRET) have greatly improved the dissemination of reference evapotranspiration information to water users and water delivery agencies, both spatially and temporally, the development and dissemination of accurate Kc information needs improvement. CIMIS is a network of automated weather stations providing accurate near-real-time ETo information from about 150 station locations throughout agricultural and urban regions of California to aid growers, landscape professionals, and homeowners with irrigation scheduling information. Although the 150 CIMIS stations cover a large portion of California, the number and placement are inadequate to cover the entire State, so Spatial CIMIS was developed by UC Davis and DWR on satellite-based solar insolation estimates and GIS estimates of weather data to provide near-real-time estimates of ETo with a spatial resolution of 2 km x 2 km grid over the entire State.

The use of CIMIS and Spatial CIMIS greatly enhanced the ability to obtain accurate ETo information and agricultural water demand estimation, which is relevant especially for water users irrigating with infrequent surface and sprinkler irrigation. However, recent studies at UC Davis have shown a dramatic decrease in surface irrigation systems and a sharp increase in low volume (drip and micro-sprinkler) irrigation systems during recent decades within California. Because the CIMIS and Spatial CIMIS ETo data are near-real-time and are available only up through the previous day, the CIMIS and Spatial CIMIS data are somewhat inadequate for planning upcoming irrigation events for low-volume irrigation systems, which are now the predominant method used in the State. To help resolve this issue, researchers at UC Davis and DWR worked with the NWS to develop an ETo forecast product called FRET, which stands for Forecast ET. FRET is now available nationwide and it provides a seven-day ETo forecast for any point within the continental USA from the current date through six days in the future. This product has greatly enhanced the ability to schedule water applications with low volume (high frequency) irrigation systems (drip and micro-sprinkler), as well as high frequency urban irrigation, as long as accurate Kc information are also available.

Historically, Kc values are used with ETo to estimate the evapotranspiration of well-watered (energy-limited) crops (ETc). This was generally adequate for infrequent surface and sprinkler irrigated crops, but more recent research has shown that full irrigation is unnecessary for some crops during some periods or years when deficit irrigation will reduce water consumption without negative impacts on production, or eventually benefitting crop quality. In some deciduous permanent crops, the yield potential in a given year is based on early fruit or nut set, and applying less water during seasons with low fruit or nut load could save water without negative impacts on current or following seasons. In other crops, deficit irrigation can improve the crop quality (e.g. wine grapes, almond, pistachio), while in others well-watered irrigation is desirable. While the symbol ETc is still reserved for full irrigation to meet energy limited crop evapotranspiration, there is a need to develop stress coefficient (Ks) values to estimate the actual evapotranspiration (ETa) from the ETc as: $ETa=ETc\times Ks=ETo\times Kc\times Ks$, with $0\leq Ks\leq 1.0$ and $Ks=0$ when the $ETa=0$ and $Ks=1.0$ when the $ETa=ETc$. While Ks values are difficult to generalize due to differences in soils, rooting depths, crop characteristics, and management practices, it is possible to provide some guidelines on Ks values to growers based on local information, soil water monitoring, and plant-based measurements. In the proposed project, we plan to improve the dissemination of information to help growers define and use Ks estimates for appropriate crops.

While CIMIS and Spatial CIMIS provide relatively good ETo estimates for California water users, there are some problems that make it difficult to provide fully accurate ETc and ETa estimates. CIMIS weather stations are mostly located over a standardized, well-watered grass surface with minimal obstructions and adequate grass fetch (distance of grass around the station) to obtain accurate ETo data. California's topography and proximity to the ocean leads to a plethora of micro-climates. While it would be good to have CIMIS stations for every microclimate, it is financially infeasible. Past research has shown that it is possible to measure some weather variables in one microclimate and use data from CIMIS station in a different microclimate to give a more accurate ETo value. For example, solar radiation measurements do not require a large grass fetch around a station, whereas wind speed and air temperature are affected by fetch. In California, the dew point temperature (humidity) is dominated by air moving from the Pacific Ocean across the State, and the dew point is a conservative value, i.e. it does not vary much within a regional scale. Therefore, one could measure solar radiation at a grower's field and use temperature, humidity and wind speed from a CIMIS station to estimate ETo at the grower's field. This could potential improve the availability of accurate ETo information in microclimates where ETo currently do not exist.

Water table contributions to crop water uptake, interception of fog and light rainfall, and dew deposition can contribute water to evapotranspiration and irrigation water needs are commonly over-estimated in locations with water tables, fog, light rainfall, and dew contributions. For example, near the coast it is common for fog interceptions to wet plant surfaces and for fog to drip off the plants onto the soil. Fog drip is one of the main contributors to survival of coastal forests, which clearly demonstrates that it is also a factor in crop water requirements in a similar environment. Some ideas on how to account for contributions from fog, light rainfall, and dew are available, and this project will attempt to help growers include adjust for those contributions where needed. Contributions from non-saline water tables can also provide water for crop production, and the proposed project will attempt to provide information on how growers can determine those contributions and reduce irrigation applications.

When the CIMIS development project was initiated in 1982, there was a joint agreement between all the main players including the University of California, DWR, the US Department of Agriculture – Agricultural Research Service, and the US Bureau of Reclamation that CIMIS would improve the dissemination of ETo information to California growers, which was considered a big first step in improving water management by providing a library of ETo information to cover the State. It was also agreed that the second most important goal was to improve ETc estimates by providing a repository where that latest and best information on Kc data is available. The proposed project is designed to achieve that goal. In addition, it is desirable to provide information on how to estimate Ks values for crops that are deficit irrigated including estimates based on soil, crop and ET information as well as using soil and plant-based measurements. Since the ultimate goal is to improve irrigation management, the project will also address improving local ETo information, and enhancing estimates of water table, fog, dew, and light rainfall contributions to ET that will affect irrigation applications. The aim is to establish and maintain a central web database for all interested parties to access information for improving water balance estimates for the main California crops and landscapes. Once the 3C database is established, further work to provide information on all crops, urban and natural landscapes will continue. Once the improved water balance information is made available, a future project to help growers improve system design and management to optimize on-farm irrigation efficiency and water productivity is forthcoming.

UC Davis and the DWR are currently developing an updated ETo Zone Map for the state of California based on weather data from the 150 existing automated weather stations of the CIMIS network. The preliminary versions of the new ETo Zone Map show a larger number of ETo zones relative to the original map developed for California by DWR and UC Davis during the late ‘80s on the basis of the 52 weather stations existing at that time within the CIMIS network. In addition, the new ETo Zone Map will be available in electronic format, and could be used in conjunction with the GIS-based land use maps recently developed by Land IQ for the entire state of California, and with the updated Kc information. In other terms, the updated Kc information resulting from the proposed project will complement the maps of land use and ETo Zone, and forecasted ETo from FRET, thus enabling resource planners and managers to better estimate/predict water demand and use for different areas of the State based on historical and forecast ETo information.

Finally, it is worth indicating that multiple efforts are being deployed by several research groups to estimate agricultural water demand and consumptive use with remote sensing methodologies and techniques for large areas using imagery acquired by satellite/airborne platforms and un-manned vehicles at various spatial and temporal resolutions. The availability of updated Kc information will help these research groups to validate remotely-sensed water demand estimations, and will also help developing and testing new hybrid methodologies to obtain more accurate water use information from the combined used of ground data and bio-physical parameters estimated with remote sensing.

Efficient management of water systems relies on accurate data on water deliveries, efficiency of water use, and water losses. This project will improve information on plant water uptake that will allow water managers to accurately calculate water budgets and optimize water flows within their boundaries. Accurate water budgets are necessary for all areas of water management. Optimization of water deliveries requires information on water uptake and water use. Knowing ET is necessary to create water budgets that are necessary to operate water systems and regulate water markets. Allocating water for non-farm purposes such as environmental flows

and endangered species preservation also requires accurate water budgets. This project will play a crucial role in ensuring accurate water use and budget information.

1.2.2 Rationale and Significance

Multiple water purveyors and stakeholders along the water supply chain make regular use of Kc information for their normal estimation procedures with model and tools at different time-steps and spatial scales. Despite the importance of using accurate and current Kc information that reflect typical farming management and irrigation practices, for simplicity water managers often use Kc values obtained from international publications (i.e. the UN-FAO Irrigation and Drainage Handbook No. 56 of 1998) or professional society manuals (i.e. ASCE Manual of Practice No. 70 of 2001). These publications report generalized Kc from research studies conducted in past decades in various regions of the world on crops grown with farming practices and average yields that are significantly different from those of California. As such, these generalized crop water use information may not be accurate or applicable to various production areas of the State, and thus often lead to inaccurate water demand estimations.

Recent research in California has shown that Kc values are sometimes different for the same crop within the same ETo zone. For example, crop coefficients in FAO 56 and ASCE manual of Practice No. 70 only provide Kc values for crops on flat ground and do not account for differences in Kc on sloped grounds. In addition, those manuals do not refer Kc values to plant/tree density, canopy covers, row orientations, and crop yields. We have observed differences in ET of wine grapes on hillsides that are not well-known, and that information needs to be disseminated to growers. We have also observed that east-west rows have higher Kc values than north-south rows in citrus orchards. The Kc information should account for row orientation. Differences in Kc value were observed in several years of data collected over almond orchards in various ETo regions, and work is need to adjust Kc values for micro-climate differences. While FAO 56 does have a climate correction for Kc values, that correction is fundamentally incorrect and a new climate correction model for Kc values was proposed (Guerra et al., 2014). This climate correction is based on midseason ETo rates, so it is easy to apply in California where we have good information on ETo zones. The above-mentioned factors are not well known and there is a need to disseminate the information and to help people optimize their Kc values.

The project results are information of practical and direct use by water purveyors and actors that operate along the water supply chain, as well as enhanced tools that could simplify water demand modeling/forecasting and irrigation scheduling decisions by integrating the updated Kc information with ETo data and land use maps.

1.2.2.a Stakeholder Participation

This project is mainly designed to augment our earlier work to develop CIMIS, Spatial CIMIS, and FRET, which were meant to improve the information available to California growers and to water managers. In the original CIMIS project, one of the long-term goals was to evaluate and improve crop coefficients for application with the new CIMIS ETo estimates, and to develop and test for Kc values appropriate for improved crop varieties and irrigation systems. Since the end of CIMIS, we have made tremendous advances in Kc information through field research studies using eddy covariance and surface renewal on a range of crops including irrigated pasture, alfalfa, cotton, maize, tomatoes, grapevines, almonds, walnuts, pistachios, citrus, and urban landscapes. We have learned that the older Kc values were often not appropriate for the new ETo

equation values, and that cultural practices and irrigation methods can significantly impact on Kc values. The next step in our quest to complete the original plan from the 1980s CIMIS project and Kc development during the 1990s to the present is to build an electronic library of information to enhance the process and help growers improve their application efficiency and production and to help water managers obtain better water demand information. We were able to develop the well-defined and well operated CMIS network, Spatial CIMIS, and FRET, but the next step is to outreach the new and better information on Kc values. This will greatly help growers to improve their on-farm application efficiency and it will dramatically improve water demand information for managing water deliveries to agriculture.

The Almond Board, Pistachio Board, Walnut Board, Citrus Research Board, Avocado Commission, Cherry Research Board have all supported the development of Kc values in the past and they provided support letters for this project because they recognize the need for outreach of the information (Appendix B). We have provided information to the Delta Modelling Group at the DWR and they need additional information to optimize their models. New and better information on Kc and ETc data was requested by DWR hydrologists working on the Sustainable Groundwater Management Act (SGMA) because they want a source of information that is readily available and accurate. We also have improved information on urban landscapes that can help to conserve water usage in cities and urban areas, which is commonly requested by urban water managers. New and updated Kc information are also sought by private farming corporations (The Wine Groups) for crops that have largely expanded on hillside and marginal areas (wine grape), as well as by farmers' advocacy groups (Farm Bureau Federation; Napa Valley Wine Growers Association) to enable their associated growers improving estimates of water needs for water supply allocations, and enhancing on-farm irrigation water management practices.

1.2.2.b Expected Results and Impacts

The proposed project will leverage a multi-disciplinary, collaborative effort that greatly benefit multiple end-users, including water district managers and planners, individual growers, farm managers, farming corporations, crop and irrigation consultants, crop commodity boards, farmers' advocacy groups, and other stakeholders including regulators, water coalitions, and groundwater management agencies.

Expected outcomes of this project are accurate and updated water use and Kc information for major California crops and landscapes that reflect current practices of different areas across the State. All the information generated will be quality-assured through review by domain experts included in the crop-specific workgroups (UCCE Specialist and Advisors and UC Davis faculty), the Expert Review/Advisory Committee, and finally by experts appointed by the UC ANR Publication Service during the peer-review process. Such information is vital to growers in determining irrigation needs and for planners to predict water use at the statewide level and for various agricultural production regions within the State. The information generated through this project will help manage water resources for systems such as the Colorado River basin that provides water to seven states including California.

The project team plans to involve the potential end-users of updated information holding dedicated meetings with water planners and managers, and with representatives of commodity boards, private production corporations, and farmers' advocacy groups to tailor the formats of Kc information and educational materials to specific needs of different users. In addition, the team

will organize multiple dissemination and outreach events to further involve end-users over the course of the entire project.

The project team will also facilitate the adoption and integration of updated Kc values into existing agro-hydrological simulation models and calculation tools. Water managers will be given access to the 3C Web Platform and Database and enabled to use models and tools with updated Kc in conjunction with ETo information from sources providing retrospective data (AgriMET, CIMIS, Spatial CIMIS, PRISM, ETo Zone Map) as well as forecast data (FRET). In addition, the project team will make available in the 3C Web Platform the upcoming information on irrigation systems and methods that is being developed from a statewide survey conducted in 2016-2017 by DWR and UC Davis, which, along with application efficiency data from various sources (RCD Mobile Labs, and various reports and surveys, etc.) will allow the estimation of gross agricultural and irrigation water demand with increased accuracy.

These information and tools will significantly enhance the capability to model and forecast agricultural water demand and irrigation scheduling, and thus will be of direct and immediate use by water planners and managers, individual growers, commodity boards, farm managers, and consultants to pursue resource-efficient management of water supplies. Currently, application programs for water demand planning (i.e., Cal-SIMETAW, SIMETAW, DETAW, and CUP Plus) are available to help determine ETc and ET of applied water (ETaw), which is an estimate of the seasonal irrigation requirement assuming 100% application efficiency. Improvements to these applications are possible if the information on Kc values and growth dates are updated to better represent current farming conditions and irrigation management practices.

The expected project results will therefore provide unified and quality-ensured knowledge to inform agricultural water management decisions and enhance modeling/forecasting capabilities at various levels along the resource supply chain, from water allocation, to conveyance, storage, distribution, delivery and final on-farm water usage. Specifically, the project outcomes are information that can be readily used to enhance the capability for more accurate estimates of agriculture water demand under various weather scenarios and will present opportunities for conjunctive management of ground and surface water supplies, thus contributing to pursuit of water supply reliability within the framework of climate-adaptive resource management. In addition, new advances in adjusting Kc values for microclimate differences can lead to the dissemination of more accurate crop water use estimates for different production regions across the State. This in turn can lead to improvements in on-farm irrigation efficiency and better water resource management. Recent research at UC Davis has shown possible methods to develop climate corrections, and one goal of this project will be to enhance the outreach this new information.

1.2.3 Project Implementation Including Planned Activities and Approach

1.2.3.a Applicant and Project Specifications

This proposal is submitted by the University of California Agriculture and Natural Resources (UC ANR), an applicant of Category B (Universities, nonprofit research institutions, federally-funded research and development centers, and non-profit entities). For the proposed project, UC ANR will collaborate with the California Department of Water Resources (DWR), a partner of Category A (States, Indian tribes, irrigation districts, water districts, or other organization with water of power delivery authority).

We envision organizing a proposed set of activities in four work packages (WP) and multiple tasks (T). The DWR will provide in-kind support, as well as scientific and technical expertise contributing to Work Package 1 (Task 1.2), Work Package 2 (Tasks 2.3 and 2.4) and Work Package 3 (Tasks 3.1, 3.2, 3.3). A detailed description of work packages and tasks is provided in the section 1.2.3b below.

1.2.3.b Objectives, Methodology, and Approach

The proposed project aims to: 1) develop updated Kc information for ten major water-demanding crops in California through research activities, as well as through analysis, interpretation and review of datasets collected from on-going research and previous studies; 2) produce peer-reviewed short publications (fact sheets) with updated Kc information for the major water-demanding crops (annual and perennial), with the consensus of industry leaders and representatives from the agricultural production and regulatory communities; 3) make the updated Kc information available and usable with some selected existing tools to enhance the capability for modeling/forecasting agricultural water demand and irrigation scheduling; 4) develop the 3C Web Platform as online repository of the updated Kc information and materials that will enable water managers and other actors and end-users in the water arena to retrieve such information, while promoting their broad dissemination; 5) organize trainings and workshops for specific audience, and develop educational materials to encourage the broad adoption of updated and new Kc information for water planning and management purposes in California.

The set of planned activities will be organized in three work packages and nine tasks as described hereinafter, with indication of the responsible entity, the supervisory group, and the anticipated implementation periods.

WP 1 – Conducting research on crop water use and review and evaluation of Kc information.

Within this WP, funds and cost-share will be used to extend on-going research efforts that investigate ET and Kc for specific crops over additional crop growing seasons with the aim to obtain reliable and accurate results. In addition, the project team will use resources to establish and operate crop-specific workgroups and contract support personnel for analyzing and reviewing relevant Kc information obtained from studies conducted in California in the last 15 years and from the on-going research efforts.

T1.1: Collect information on evapotranspiration of specific crops (i.e. citrus, grapes, vegetables, etc.) under well-watered conditions within on-going studies that require additional research for developing reliable and dependable Kc information. Researchers from UC ANR will conduct research to determine crop ET in well-watered non-stressed and high-yielding production settings using the residual of energy balance method based on micro-meteorological measurements collected with a combination of eddy covariance and surface renewal equipment. Responsible entity: Executive Group (Research Investigators). Supervisor: Leadership Group. Period: June 2020 – December 2021 (two consecutive growing seasons).

T1.2: Conduct expert review and evaluation of Kc information on ten major water-demanding crops in California (both annual and perennial crops), and develop science-based, current and quality-assured sets of Kc values of these crops for various production regions of California. Six crop-specific workgroups (nut crops; fruit crops; subtropical crops; vine crops; vegetable crops; field crops), and one urban/natural landscape workgroup will be established that will include experts from UC ANR and UC Davis. Each workgroup will have a lead expert organizing and

coordinating the work necessary to review, analyze and interpret existing and upcoming Kc information from earlier studies and on-going research for the specific target crops. Priority will be given to high water-demanding crops, and urban/natural landscapes for which available Kc information are considered sufficient and current. Responsible entity: Executive Group (Crop-specific Workgroups). Supervisors: Leadership Group and Expert Advisory/Review Committee. Period: October 2020 – September 2022.

WP2 – Preparing publication materials, and making Kc information available to enhance capability for modeling/forecasting agricultural water demand and irrigation scheduling.

Funds and cost-share will be used in this WP package to support the activity of crop-specific workgroups, contract support personnel with adequate expertise to prepare and review materials, finalize publications, and facilitate integration of updated Kc information in selected existing models and tools.

T2.1: Develop peer-reviewed short publications (4-6 page fact sheets) with updated Kc information for ten major California water-demanding crops. The team will focus on crops where Kc information is considered current, adequate and applicable for water planning, allocation, and management purposes. Responsible entity: Executive Group (Crop-specific Workgroups). Supervisors: Expert Advisory/Review Committee and Leadership Group. Period: January 2021 – November 2022.

T2.2: Develop a database schema and associated Application Programming Interface (API) to manage and provide access to the collected and updated Kc information for various users. Responsible entity: Executive Group (UC Davis Library). Supervisor: Leadership Group Period: July 2021 – September 2022.

T2.3: Review existing tools (models and interactive maps) that water managers and other stakeholders can use to model/forecast agricultural water demand (ex. CUP Plus, SIMETAW, CALSIMETAW, ETo Zone Map, Spatial CIMIS, etc.), and devise irrigation scheduling decisions (ex. CropManage, Basic Irrigation Scheduling, Aquacrop, etc.). Develop and demonstrate compatibility of Kc information with these existing applications. Responsible entity: Executive Group (UC Davis Library). Supervisor: Leadership Group. Period: January 2021 – June 2022.

T2.4: Test and validate the selected tools with updated Kc information for accuracy, to ensure water demand estimations and irrigation scheduling can be reliably devised and informed. The UC Davis Library will work on this task in collaboration with the Project Leaders and with inputs and feedbacks from the Crop-specific Workgroups and the members of the Expert Advisory/Review Committee. Responsible entity: Executive Group (UC Davis Library) Supervisors: Leadership Group and Expert Advisory/Review Committee. Period: June 2021 – September 2022.

WP3 – Disseminating and promoting the broad adoption and use of updated Kc information and enhanced tools.

Funds and cost-share will be used in this WP to design, establish and maintain the knowledge-sharing 3C Web Platform during the entire duration of the project and beyond, prepare and make available educational materials, and organize multiple training and dissemination events for water resource planners, supply managers, and water users.

T3.1: Design, develop and maintain the 3C Web Platform, a user-friendly web repository of updated Kc information and tools (including models and interactive maps) that water planners, supply managers and other stakeholders can easily access, retrieve, and build upon, thus enhancing

the capability for agricultural water demand estimation, modeling, forecasting and irrigation management.

The 3C Platform will be a web application aimed to promote adoption of updated Kc information, and to provide simple user interfaces to Kc data, and its applications. Using the API developed in T2.2, the platform will provide a search and browse interface for the updated Kc data. In addition, it will offer interactive tools to exercise the Kc information in the context of California water data management. For example, we will provide a map interface that will combine crop Kc coefficients along with expected weather parameters from the Spatial CIMIS program or FRET, and land use maps from Land IQ to create estimated water demand for regions within the State, aggregated to DWR's water planning units (detailed analysis units, DAUs). In the process, we will develop and publish reference functions for combining Kc with weather data for various ET calculations. An example of such integrated product is provided in Figure 2. The 3C Web Platform will be designed, established and maintained by the UC Davis Library with inputs from the Project Leaders. Responsible entity: Executive Group (UC Davis Library). Supervisor: Leadership Group. Period: February 2021 – May 2023.

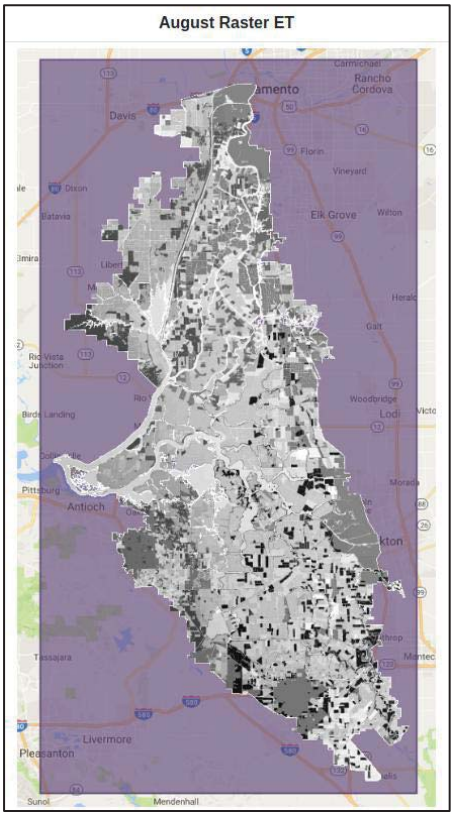

Figure 1. Map of ET calculated from Spatial CIMIS weather data combined with CUPS+ Kc values and Land IQ Crop maps.

T3.2: Organize multiple training events to encourage the broad adoption and proper use of updated Kc information and enhanced tools by water managers and various other end-users to model/forecast agricultural water demand and schedule irrigation. Responsible entity: Executive Group (Extension and Outreach Group). Supervisor: Leadership Group Period: November 2021 – March 2023.

T3.3: Prepare educational materials (videos, recorded talks, webinars, online training modules, users' guidelines, monographs, sample case studies, etc.) on how to make proper and accurate use of updated/new Kc information and enhanced tools. The Outreach group will collaborate with the Project Leaders to perform this task, with inputs and feedback from the Expert Advisory/Review Committee. Responsible entity: Executive Group (Extension and Outreach Group). Supervisors: Leadership Group and Expert Advisory/Review Committee. Period: January 2022 – February 2023.

1.2.3.c Project Implementation, Work Plan, and Timeline

Table 2 presents the timetable of the proposed tasks within the three work packages.

Table 2. Timeline of work packages and tasks

Work package & Task		Months					
		1-6	7-12	13-18	19-24	24-30	31-36
WP1	**Conduct research on crop water use; review and evaluation of Kc information**						

	T1.1 – Research to determine evapotranspiration of specific crops under well-watered conditions						
	T1.2 – Expert review and evaluation of Kc information on ten major crops						
WP2	**Preparation of publication materials; integration of Kc information in existing models and tools**						
	T2.1 – Develop peer-reviewed short publications of updated Kc information						
	T2.2 – Develop and test a user-friendly database and API for updated Kc information						
	T2.3 – Review existing modeling tools for agricultural water demand and irrigation scheduling						
	T2.4 - Test and validate for accuracy the modeling tools with updated Kc information						
WP3	**Disseminating updated Kc information promoting the use of enhanced tools**						
	T3.1 - Develop and maintain a user-friendly web repository of updated Kc information and tools						
	T3.2 - Organize multiple trainings for the proper use of updated Kc information and enhanced tools.						
	T3.3 - Prepare educational materials on updated Kc information and enhanced tools						

Interim performance reports will be prepared and submitted on at least a semi-annual basis. Upon conclusion of the project, a final performance report will be provided to US Bureau of Reclamation.

1.2.3.d Project Management

The project management will be articulated around three entities, which will operate to establish and maintain the necessary workflow to perform the set of planned activities, as described below.

The **Leadership Group** is composed by five members (R. Snyder; D. Zaccaria; K. Bali; M. Orang; D. Parker) from the partner institutions of UC ANR and DWR, and whose role is the general coordination and oversight of all planned activities to ensure that the project goals are achieved timely and with the expected level of scientific accuracy and reliability. The Leadership Group will coordinate with the Research Investigators, the Crop-specific Workgroups, the UC Davis Library, the Expert Advisory/Review Groups, and with the Outreach and Education Group for the execution of all the project activities within the scheduled timeline. All the materials produced within the project will be reviewed by the Leadership Group and by the Expert Review/Advisory Committee for ensuring scientific accuracy and quality.

a. **Daniele Zaccaria**, Ph.D. – Agricultural Water Management Specialist in Cooperative Extension at the Department of Land, Air and Water Resources of UC Davis

(http://lawr.ucdavis.edu/ people/faculty/zaccaria-daniele), will be the Project Leader and oversee all three work packages and nine tasks in collaboration with the other members of the Project Leadership group.

b. **Richard L. Snyder,** Ph.D. – Emeritus Bio-meteorologist Specialist in Cooperative Extension at the Department of Land, Air and Water Resources of UC Davis (http://lawr.ucdavis.edu/people/ faculty/snyder-richard), will work as Project Co-leader. He will coordinate with other project leaders and cooperators to collect, evaluate, archive, and disseminate crop coefficient information in a readily usable format through the 3C Web Platform.
c. **Morteza Orang**, Ph.D. - Land Use Unit Manager of the California Department of Water Resources, will work as Project Co-leader. Orang will be responsible for co-overseeing the three planned work packages and nine tasks.
d. **Khaled Bali**, Ph.D. – Irrigation Water Management Specialist in Cooperative Extension (https://ucanr.edu/?facultyid=95) at UC Kearney Agricultural Research and Extension Center. He will work as Project Co-leader, thus overseeing the entire set of planned work packages and tasks.
e. **Doug Parker**, Ph.D. – Director of the California Institute for Water Resources, CIWR (https://ucanr.edu/?facultyid=19563) will provide project coordination, and will be assisting the project team by facilitating the timely execution of all work packages and activities. CIWR will assist with communications of project outcomes to users of this information.

The **Executive Group**. It consists of four different entities that will conduct work in parallel directions under the supervision of the Leadership Group, as described below:

- ✓ the **Research Investigators**, will conduct research on crop ET under well-watered conditions over two consecutive growing seasons to collect water use and Kc information for specific annual and perennial crops, such as small vegetables, citrus, wine-grape and table-grape;
- ✓ the **Crop-specific Workgroups** will be established after the project onset and will review and evaluate existing and upcoming Kc information from earlier and on-going studies, and will prepare the fact-sheets for publication; a separate Workgroup will be also established to review and analyze data from urban and natural landscapes;
- ✓ the **UC Davis Library** will design, establish and maintain the 3C Web Platform that will function as online repository of Kc information and modeling/forecasting tools. Personnel from the Library will also work in coordination with the Leadership Group members to review and select existing tools for modeling/forecasting agricultural water demand and for scheduling irrigation. The UC Davis library will receive the quality-assured information from the Leadership Group after review and approval by the Expert Review/Advisory Committee, and will make this set of information suitable for fast integration and use with the selected modeling/forecasting tools;
- ✓ the **Extension and Outreach Group** will design, organize and execute training and outreach events for water planners, managers and irrigation water users. This group will also be responsible for development of educational materials such as videos, webinars and users' manuals, under the supervision of the Leadership Group and of the Expert Advisory/Review Committee.

The **Expert Advisory/Review Committee** will be composed by five members with high-level scientific competence and expertise in agricultural water resources planning and management: 1) Kyaw Tha Paw U, professor of atmospheric science and bio-meteorology at UC Davis; 2) Kenneth Shackel, professor of plant water relations at UC Davis; 3) Dr. James Ayars, retired senior research scientist from USDA-ARS Agricultural Water Management Unit; 4) Dr. Stephen Grattan, UCCE Specialist emeritus in soil-plant-water relations at UC Davis; 5) Mark Grismer, professor in hydrologic science at UC Davis. The Expert Committee will review the material prepared by the Crop-specific Workgroups, provide suggestions for revisions and improvements, and then finally recommend the submission of reviewed material to the UC ANR Publication Service for the peer-reviewed process. The Expert Committee will also review the educational materials prepared by the Extension and Outreach Group and provide feedback prior to its upload onto the 3C Web Platform.

1.2.3.f Institutional Capacity, Personnel, and Resources

The partners of the proposed project are the University of California Agricultural and Natural Resources (UC ANR), and the California Department of Water Resources (DWR). UC ANR works hand in hand with the agriculture industry in California to enhance markets, help the balance of trade, address environmental concerns, protect plant health, and provide growers with scientifically tested production techniques to improve productivity and enhance food safety. UC ANR has over 200 specialists on four campuses (Davis, Berkeley, Riverside, and Merced), nine Research and Extension Centers, and a statewide network of 200 locally based Farm Advisors and Specialists at 57 local Cooperative Extension county offices to leverage UC's research and outreach capacity.

Over the past years, scientists from UC ANR, UC Davis and DWR have worked together on multiple collaborative projects for making available to California water planners, managers, growers and irrigation practitioners data and tools for improving water management. Among others, CIMIS, Spatial CIMIS, FRET and ETo Zone Map were all developed through collaborative projects. In addition, UC ANR and DWR have worked collaboratively to develop multiple tools such as CUP Plus, SIMETAW, CALSIMETAW, and new information such as the results from Survey of Irrigation Methods and the electronic new ETo Zone Map that improved dramatically the availability of crucial data for water budgeting and allocation in the water-limited context of California. In 2014-2016, UC ANR and DWR have also collaborated on a Drought Management Technical Assistance project that developed crucial information to California growers and stakeholders for managing water under drought conditions and mitigating the adverse effects of surface water curtailments and groundwater supply limitations and impairment. The project produced 22 peer-reviewed Drought Tips Fact Sheets written by UC academics and reviewed by DWR scientists and by UC ANR Publications Service, 74 online webinars given by water experts on different aspects related to water planning and management under drought conditions, multiple training workshops and various educational videos for growers and other stakeholders.

Project results will complement the preceding efforts conducted by UC ANR and DWR, and further enhance the capability of water purveyors to effectively plan water resources allocation, and manage the available supplies.

1.2.3.g Project Outputs

This project will generate the set of outputs and deliverables indicated below, each of which will provide specific value to the US Bureau of Reclamation, to water planners and managers, water management agencies, and the agricultural production and regulatory communities:

A) **A set of 12 short peer-reviewed publications.** These are 4-6 page long fact-sheets with updated Kc information prepared by the crop-specific workgroups that will be reviewed by the Expert Advisory/Review Committee and then will go through the UC ANR Publication Service peer-review process. Ten of these fact-sheets will concern major water demanding crops (annual and perennial) selected from the six target commodities (nut crops; fruit crops; subtropical crops; vine crops; vegetable crops; agronomic crops) based on priority ranking and availability of current and reliable crop water use data. The remaining two fact-sheets will deal with Kc information for urban and natural landscapes.

B) **A digital library** of updated, science-based and quality-assured Kc information for major water-demanding California crops, as well as for common urban and natural landscapes. Water stakeholders and users will be granted access to the electronic library to query and retrieve the updated Kc information through the developed API for use with models and tools for water resource planning and management purposes.

C) **A web repository** (the 3C Web Platform) of the updated Kc information, designed, established and maintained to provide easy-access, query and retrieval, and use of stored information and tools for water purveyors, professionals, and agencies, and for irrigation practitioners. The UC Davis Library will maintain the 3C Web Platform active and enable access to information and tools for ten years, thus beyond the 3-year project duration.

D) **A set of educational materials**. The presentations given by experts during the training events will be recorded and posted on the 3C Web Platforms as permanent resource for various stakeholders and end-users of information. An online training module will be prepared and include users' guidelines for accessing the 3C Web Platform and retrieving the updated Kc information and enhanced models/tools made available through this project for water planners and managers. Three 20-min webinars will also be prepared and posted on line as permanent sources of information, one of which on Kc of permanent crops, one on Kc of annual crops, and the third on Kc of urban and natural landscapes.

E) **Four training and outreach events** will be organized, two of which will be held in Davis/Sacramento area and the other two at UC Kearney Agricultural Research and Extension Center in Parlier, CA. Two of these events will be designed for training and outreaching information to water purveyors, while the other two will be for irrigation practitioners.

F) **Four reports** on the training and outreach events. These documents will be prepared by the project team, indicating the training/outreach contents, the target audience, the number of participants, the types of information disseminated, and the technical aspects discussed. The reports will also describe the feedback received from participants.

G) **A technical memo**. This document will describe the methodologies used for collection of ET and Kc datasets within the research studies, the methods and tools used for data processing, analysis and interpretation to develop new or updated Kc information on the studied crops and landscapes. The technical memo will also highlight the possible limitations of various research studies and applicability of results.

H) **A Final project report and presentation**. The project team will prepare these two documents for the US Bureau of Reclamation to illustrate the project objectives, the methodological

approach followed, the results attained, and indicate the main outcomes stemming out of the project activities, and finally outline the practical implications for the agricultural, urban and environmental water arenas and their main actors.

1.2.4 Dissemination of Results

A strong extension and outreach program will be conducted within this project, with specific focus both on water resource planning and management aspects. In detail, the project team will organize two statewide training events for water resource planners and managers to illustrate how to access and use the information and tools made available in the 3C Web Platform. One training will be in the area of Davis/Sacramento during the year 2022, while the other will be at UC Kearney Agricultural Research and Extension Center (KARE) in Parlier, CA early in year 2023. In 2022 and 2023, the project team will organize four additional outreach and training events in Davis/Sacramento area and at KARE in Parlier, CA to target the agricultural production audience, i.e. growers, farm managers, crop and irrigation consultants and other farm personnel involved in aspects related to irrigation planning and management. These events will be designed to assist growers and irrigators employing adaptive and resource-efficient irrigation management practices that support crop production, optimize irrigation and energy use, and ensure environmental protection. The project team will make the updated Kc information broadly available on the 3C Web Platform in the form of peer-reviewed short publications (4-6 pages), but also as user-friendly electronic libraries that various users can access to retrieve data. The UC Davis Library will maintain the 3C Platform for at least 10 years, thus far beyond the duration of the proposed project.

Finally, the project findings will be disseminated through web platforms of various commodities and groups (UC Davis Fruit and Nut Research and Information Center, UC Davis Agronomy Research and Information Center, California Alfalfa Online Workgroup, UC Rice Online, etc.) and through dissemination events organized by UCCE and commodity boards (Almond Production Short Course and Almond Day; Citrus Research Conference; Pistachio Production Short Course and Pistachio Day; Walnut Production Short Course; Avocado Production Course; etc.) and professional society meetings (American Society of Agronomy, ASA; American Society of Horticultural Science, ASHS; Western Alfalfa and Forage Symposium; United States Commission of Irrigation and Drainage, USCID; American Society of Agricultural and Biological Engineering, ASABE; American Society of Civil Engineering, ASCE; American Society of Viticulture and Enology, ASEV; etc.) and will inform resource-efficient irrigation planning, design, operation and management practices for the ten major water-demanding California crops.

1.2.5 Department of the Interior Priority Alignment

Supporting Department of the Interior priorities related to *utilizing science to identify best practices to manage land and water resources and adapt to changes in the environment*, this applied science project will develop, organize, and disseminate science-based Kc information with broad industry-wide participation and consensus. The use of updated Kc information, along with enhanced tools will improve the capability to model and forecast water demand and use at various levels along the water supply chain by water managers and other end-users for different production regions of California. In doing so the project also aligns with priorities for *reducing administrative and regulatory burden imposed on U.S. industry and the public*.

1.3 PROJECT LOCATION

The work proposed for this project will focus on agricultural production areas of the Intermountain region, the Sacramento and San Joaquin valleys, the Central and South coast, and the Low Desert region of California (Figure 2).

Leveraging a scientific and programmatic presence in all California counties through the internationally recognized community of research and extension professionals from the University of California Cooperative Extension, the project will involve the following commodities: nut crops (almond, pistachio, walnut); fruit crops (peaches, nectarines, plums); subtropical crops (citrus, avocado, olive); vine crops (wine grapes, table grapes, raisins, strawberries); vegetables (celery, artichokes, broccoli, etc.); field and agronomic crops: (alfalfa, corn, rice, wheat cotton, processing tomatoes).

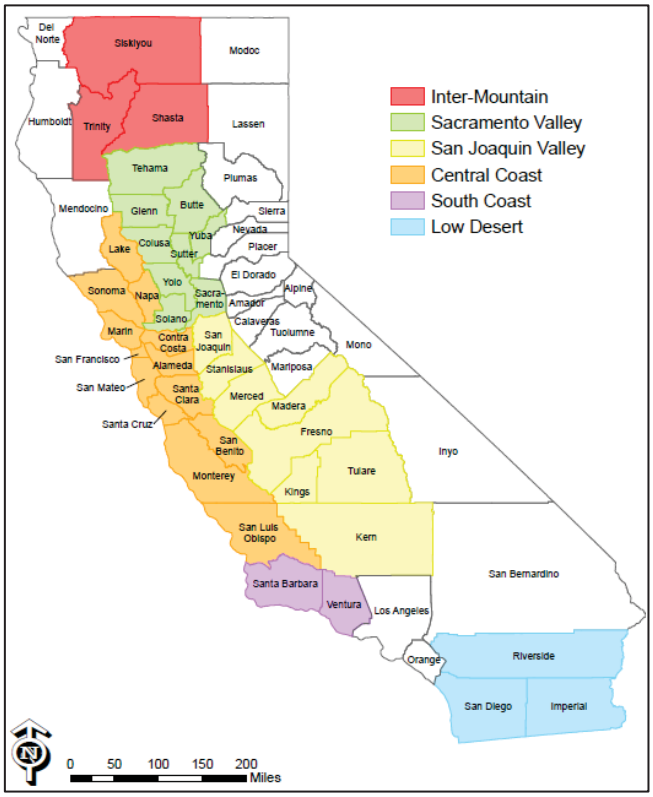

Figure 2. Focus areas for the proposed project

1.4 DATA MANAGEMENT

All data products and application will be developed with open rights statements; the database under the Open Data Commons license (https://opendatacommons.org/licenses/by/1.0/index.html). Both application development and the Kc data will be managed in a freely accessible software management system, eg. github. Kc and supporting data will be available via an API backed by an SQL database. The database will be version controlled, and individual versions will be maintained and documented as a set of CSV files in the same management system as any application. This will allow for complete access to the data without requiring uses to use necessarily the software API. Exchange data formats will typically be JSON, for broad compatibility. Supporting machine documentation will be via JSON schema. Vector based geographic information, eg ETo zone maps, will be based on the GeoJSON and TopoJSON formats. Any spatially explicit data or tools developed in the performance of an award made under this FOA must be developed in industry standard formats that are compatible with Geographic Information System (GIS) platforms.

1.5 ENVIRONMENTAL AND CULTURAL RESOURCES COMPLIANCE

This project will not result in any ground-disturbing activities. We anticipate no direct impact on environmental or cultural resources.

1.6 REQUIRED PERMITS OR APPROVALS

Permits or approvals will not be required for the proposed work.

2. PROJECT BUDGET

2.1 FUNDING PLAN AND LETTERS OF FUNDING COMMITMENT

The project budget covers a three-year project to be conducted at the University of California, Agriculture and Natural Resources (UC ANR), beginning June 1, 2020 and ending May 31, 2023.

This project will conduct applied-science work with the aim of developing, organizing and disseminating science-based Kc information with broad industry-wide participation and consensus. Direct project costs will include salary support, travel expenses, consultant services, and materials and supplies. Environmental and regulatory compliance costs are not applicable to the project. The costs indicated for each category are totals for the overall project duration.

The project will leverage a percentage of nine (9) UC Davis and UC ANR academics' time and effort dedicated to this project towards the required 1:1 match. The percent effort attributed to the three-year project is in-kind, and are non-federal costs that will be contributed by the applicant. The resulting cost-share amounts to $312,586. Please reference the authorized representative approved cost-share commitment letter (Appendix A).

2.2 BUDGET PROPOSAL

Table 3. Total Project Cost Table

SOURCE	AMOUNT
Costs to be reimbursed with the requested Federal funding	$299,627
Costs to be paid by the applicant	$312,586
Value of third-party contributions	$120,000
TOTAL PROJECT COST	**$ 732,213**

Table 4. Budget Proposal

Budget Item Description	Computation		Quantity Type	Total Costs ($)
	Unit/ Rate ($)	Quantity		
Salaries and Wages				
Programmer 3	26.1538	3211	Hours	84,009
Fringe Benefits Staff Exempt rates: 54.8% (Y1) 56.4% (Y2) 58.1% (Y3)				
Programmer 3	See above	84,009	Salary	49,005
Travel				
Workgroup Meeting Travel	0.58	54,310	Miles	33,285
Supplies and Materials				
Workgroup leader honoraria	3,400	7	Leaders	23,800
Outreach events	7,175	4	Events	28,700
Contractual				
Land IQ Services	9,500	2	Years	19,000
Third Party In-kind				

Land IQ – ETa services	6,666.66	3	Years	20,000
Pistachio Board – training sessions	50,000	2	Years	100,000
Other In-kind – Project collaborator time and effort				
In-kind Salaries and Wages				
A. Biscaro at 5%	104	111.01	Hours	11,545
B. Faber at 10%	208	238.92	Hours	49,695
B. Sanden at 10%	208	91.25	Hours	18,981
D. Zaccaria at 5%	104	179.84	Hours	18,703
G. Torres Londono at 5%	104	93.20	Hours	9,693
G. Zhang at 3%	62.4	99.41	Hours	6,203
K. Arnold at 5%	104	93.20	Hours	9,693
K. Suvocarev at 10%	208	142.99	Hours	29,741
M. Battany at 5%	104	157.46	Hours	16,376
In-kind Fringe Benefits Academic rates: 43.4% (Y1) 44.7% (Y2) 46.0% (Y3)				
A. Biscaro at 5%	See above	11,545	Salary	5,241
B. Faber at 10%	See above	49,695	Salary	22,558
B. Sanden at 10%	See above	18,981	Salary	8,616
D. Zaccaria at 5%	See above	18,703	Salary	8,490
G. Torres Londono at 5%	See above	9,693	Salary	4,400
G. Zhang at 3%	See above	6,203	Salary	2,815
K. Arnold at 5%	See above	9,693	Salary	4,400
K. Suvocarev at 10%	See above	29,741	Salary	13,500
M. Battany at 5%	See above	16,376	Salary	7,434
In-kind Indirect Costs				
A. Biscaro at 5%	26%	16,786	Base	4,364.36
B. Faber at 10%	26%	72,253	Base	18,785.78
B. Sanden at 10%	26%	27,597	Base	7,175.22
D. Zaccaria at 5%	26%	27,193	Base	7,070.18
G. Torres Londono at 5%	26%	14,093	Base	3,664.18
G. Zhang at 3%	26%	9,018	Base	2,344.68
K. Arnold at 5%	26%	9,693	Base	3,664.18
K. Suvocarev at 10%	26%	43,241	Base	11,242.66
M. Battany at 5%	26%	23,810	Base	6,190.60
Indirect Costs				
Base	237,799	Rate	26	61,828
TOTAL ESTIMATED PROJECT COSTS				**732,213**

2.3 BUDGET NARRATIVE

Salaries and Wages:

Daniele Zaccaria, Project Manager

Dr. Zaccaria is an Associate Agricultural Water Management Specialist in Cooperative Extension with the University of California, Agriculture and Natural Resources. He is based within the

Department of Land, Air and Water Resources on the University of California, Davis campus. Zaccaria will be responsible for the overall planning, design, coordination, and supervision of all aspects of the project, including project coordination with the partner institution, California Department of Water Resources (DWR) for successful completion of the project. For this effort, he will also oversee the hiring, training, and supervision of project staff supporting the project. He will collaborate with the Project Technical Coordinator to ensure the set of project tasks are executed timely and with the adequate level of scientific accuracy. Zaccaria will lead the activities proposed in WP1, with specific focus on the applied research activities for collecting field datasets and information on water use of annual and perennial crops. Upon conclusion of the work, he will be responsible for reporting and disseminating the project's findings. As project lead, he will also prepare and submit all project reports, including the final financial and performance reports. No salary support is requested.

Doug Parker, Project Technical Coordinator
Dr. Parker is the Director of the California Institute for Water Resources at the University of California, Agriculture and Natural Resources. As Project Technical Coordinator, Parker will facilitate the management and timely execution of all work packages and activities, and ensuring the accomplishment of expected project outcomes and the fulfillment of performance criteria. The Project Technical Coordinator will liaison with the seven (7) crop-specific workgroups, and will be responsible for setting meeting schedules, facilitating meetings, recording meeting minutes, and assuring that workgroups adhere to timelines and deadlines. This role will also serve as the liaison between the workgroups and the Expert Advisory/Review Committee. The Project Technical Coordinator will provide regular updates at the Expert Advisory/Review Committee meetings. The Project Technical Coordinator will be responsible for working with workgroups to organize and integrate outputs into a comprehensive final report. As project co-lead, Project Technical Coordinator will assist in the preparation of all project reports, including the final financial and performance reports. No salary support is requested.

Geographic Information Systems Programmer 3
One (1) Programmer position will be employed for the project in each year. At Level 3, the position will be employed at an annual salary rate of $54,400. The position is to-be-named. Funds in the amount of $84,009 are requested in salary support over the three-year project. The position will be critical for the execution of WP2, making Kc information available to enhance capability for modeling/forecasting agricultural water demand and irrigation scheduling. Specifically, in year 1, the Programmer will work to develop a database schema and associated Application Programming Interface (API) to manage and provide access to the collected and updated Kc information for various users. They will review existing tools (models and interactive maps) that water managers and other stakeholders can use to model/ forecast agricultural water demand (ex. CupPlus, SimETaw, CalSimETaw, ETo Zone Map, Spatial CIMIS, etc.), and devise irrigation scheduling decisions (ex. CropManage, Basic Irrigation Scheduling, Aquacrop, etc.) (T2.2). The role will develop and demonstrate compatibility of Kc information with these existing applications, as well as test and validate selected tools to ensure water demand estimations and irrigation scheduling can be reliably devised and informed (T2.3 and T2.4). Ultimately, the role will develop a user-friendly web repository of updated Kc information and tools (T3.1).

The task breakdown is as follows:

Activity	Allocation of Effort (%)	Hourly rate ($)	Requested funds ($)
Year 1: 06/20 – 05/21 [5 calendar months at 20% effort]			
T2.3	213.72	26.1538	3,726.33
T3.1	213.72	26.1538	3,726.33
Total	**427 hrs**		**11,179**
Year 2: 06/21 – 05/22 [12 calendar months at 75% effort]			
T2.2	825.50	26.1538	21,590
T2.3	275.16	26.1538	7,196.67
T2.4	275.16	26.1538	7,196.67
T3.1	275.16	26.1538	7,196.67
Total	**1651 hrs**		**43,180**
Year 3A: 06/22 – 09/22 [1 calendar months at 50% effort; 4 calendar months at 50% effort]			
T2.2	113.37	26.1538	2,965
T2.3	113.37	26.1538	2,965
T2.4	340.10	26.1538	8,895
Year 3B: 06/22 – 05/23 [12 calendar months at 50% effort]			
T3.1	566.84	26.1538	14,825
Total	**1133 hrs**		**29,650**

Fringe Benefits: Fringe Benefits are calculated using the UC ANR composite rates developed by the UC Davis Costing and Policy office as required per institutional policy. Rates are applied by title code and fiscal year. The UC Davis Composite Fringe Benefit rates for the Geographic Information Systems Programmer 3 position are 54.8%, 56.4%, and 58.1% respectively, beginning with year 1. Funds in the amount of $49,005 are requested in fringe benefits support over the three-year project. An escalation rate of 3% per year has been applied to all salaries and fringe benefit rates. These costs are based on published University rates. University benefits covered may include leave, retirement, insurance (legal, health, disability, life, accident). Please reference the UC ANR federally approved rate agreement dated August 13, 2019.

Travel: Funds in the amount of $33,285 are requested for trips to convene workgroup meetings over the duration of the project. Crop-specific workgroup members will travel regionally to conduct two in-person meetings per year for each of the seven (7) workgroups. Travel funding is requested to cover mileage for workgroup members to attend the meetings. Mileage will be calculated at a rate of $0.58 per mile. For this purpose, $1,585 will be allocated per workgroup annually. Requested funds amount to $11,095 per year.

Equipment: No funds are requested.

Materials and Supplies: Funds in the amount of $52,500 are requested in materials and supplies over the duration of the project.

- *Workgroup leader honorarium*. Work group leaders will devote time and effort towards convening regular meetings, reviewing workgroup deliverables, and preparing and evaluating reports and other written materials generated by the project. For workgroup service, members will be given $1,700 in both year 1 and 2 of the project. Workgroup leaders will be selected from the pool of research collaborators participating in the project. The workgroups are as follows: 1) Nut Crops (almond, pistachio, walnut); 2) Stonefruits (peaches, nectarines, prunes); 3) Subtropical (citrus, avocado, olive); 4) Vine Crops (winegrapes, tablegrapes, raisins, strawberries); 5) Vegetables (celery, artichokes, broccoli, etc.); 6) Field and Agronomic Crops: (alfalfa, corn, rice, cotton, processing tomatoes); 7) Urban and Natural Landscapes. Funds in the amount of $23,800 are requested for this purpose.

- *Outreach and Education events*. In years 2 and 3, outreach and education events will be hosted by the UC ANR, California Institute for Water Resources to engage and train water planners, managers and irrigation water users on updated Kc information and enhanced tools for modeling/forecasting of water demand and irrigation scheduling. Two events are planned per year. The events will also serve to disseminate study results to partnering and stakeholder organizations and individuals that participated in the project. Funds are requested to cover facility rental and event coordination ($3,500 per event). Costs will also include professional design and printing of educational materials ($2,225), parking arrangements ($1,000 at $10 per vehicle), signage ($250), and supplies (such as name tags at $1.00 per person, lanyards at $1.00 per person). At least 100 participants are anticipated per event. Requested funds total to $28,700 ($14,350 per year).

Contractual: For this project, services to support the installation and maintenance of evapotranspiration stations will be obtained Land IQ. Fees will include services for regular quality check of ET data acquisition and troubleshooting of sensors and communication during the ongoing research studies on annual and permanent crops GIS mapping services will be acquired from a service provider such as Land IQ. The work will require analysis and quality check of remotely collected data and troubleshooting sensors and communication devices at the ongoing research studiesto generate GIS-based land use maps for the entire state of California. A proposal with pricing/terms was obtained in writing for these services, amounting to $9,500 per year for project years 1 and 2.

Third-party In-Kind Contributions: The project will leverage support from varied stakeholders across the state of California. Third-party in-kind contributions in the form of staff support will be committed by LandIQ, California Pistachio Research Board, California Avocado Commission, The Wine Group, and The Grapery.

In conjunction with UCANR, LandIQ will provide in-kind labor and direct financial investments to measure ETa and update Kc values. This support is valued at $20,000 and will be available over the three-year timeframe of this project. The California Pistachio Research Board will enlist growers to provide appropriate research locations and pistachio processors to provide harvest quality inspections. The California Pistachio Research Board will support training sessions for growers upon completion of the project. The in-kind and cash value of this support is estimated

at $100,000 to be available for the full duration of the project. The California Avocado Commission is happy will offer access to avocado growers and their groves, and expertise in avocado production and irrigation practices. The Wine Group commits to allowing the installation of an evapotranspiration station at the Almaden Vineyard as part of this project. Access will be available for the full duration of the project. Additionally, the Grapery will offer support in the form of site access available for the duration of the project.

Indirect Costs: Indirect costs were estimated in accordance with the UC ANR approved Indirect Cost rate agreement for off-campus research at the federally-negotiated indirect cost rate of 26%. The rate agreement was approved by DHHS, the Federal Cognizant Audit Agency for UC ANR dated August 13, 2019. The rate base is MTDC. Funds in the amount of $61,828 are requested in indirect costs.

3. LITERATURE CITED

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