Methods to Assess Co-Benefits of California Climate Investments

Water Supply and Availability

Center for Resource Efficient Communities, UC-Berkeley
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I. Background

Under California's cap-and-trade program, the State's portion of the proceeds from cap-and-trade auctions has been deposited in the Greenhouse Gas Reduction Fund (GGRF). The Legislature and Governor enact budget appropriations from the GGRF for State agencies to invest in projects that help achieve the State's climate goals. These investments are collectively called California Climate Investments (CCIs).

Senate Bill 862 requires the California Air Resources Board (CARB) to develop guidance on reporting and quantification methods for all state State agencies that receive appropriations from the GGRF. Guidance includes developing quantification methodologies for greenhouse gas (GHG) emission reductions and other non-GHG outcomes. Non-GHG outcomes are the positive or negative social, economic, and environmental impacts of projects, which are collectively referred to as "co-benefits." Some agencies use a competitive process to select CCI projects and they require applicants to estimate co-benefits when they submit a request for funding.

This document is one of a series that reviews the available methodologies for assessing selected co-benefits for CCIs at two phases: estimating potential project-level co-benefits prior to project implementation (i.e., forecasting of co-benefits), and measuring actual co-benefits after projects have been implemented (i.e. tracking of co-benefits). The assessment methodology at each of these phases may be either quantitative or qualitative. As with CARB's existing GHG reduction methodologies, these co-benefit methodologies will be developed to meet the following standards:

- Apply at the project level
- Align with the project types proposed for funding for each program
- Provide uniform methods to be applied statewide, and be accessible by all applicants
- Use existing and proven tools or methods where available
- Reflect empirical literature

CARB, in consultation with the State agencies and departments that administer CCIs, has selected ten co-benefits to undergo methodology assessment and development. This document reviews available empirical literature on the ***water supply and availability*** co-benefit and identifies:

- the direction and magnitude of the co-benefit,
- the limitations of existing empirical literature,
- the existing assessment methods and tools,
- knowledge gaps and other issues to consider in developing co-benefit assessment methods
- a proposed assessment method for further development, and
- an estimation of the level of effort and delivery schedule for a fully developed method

II. Co-benefit description

Climate change, species endangerment, groundwater depletion, and population growth, among other stressors, are challenging the sustainability of California's current water supplies. Water scarcity has created the need for greater efficiency in water use and management of available supplies.

Water supply and availability refers to the maintenance of sufficient supplies of freshwater to sustain human life and property as well as critical ecosystems. Water supply and availability are affected by water demand, including both water use (the total amount of water withdrawn from its source to be used) and consumption (the portion of water use that is not returned to the original water source after being withdrawn).

To address this challenge, the State of California has issued a variety of policies to improve both the quantity and availability of water supplies within the state, and to minimize water consumption. These include potential improvements to water conveyance infrastructure, urban water use efficiency, groundwater management, and watershed management.

California Climate Investments (CCIs) may have effects upon these water policy objectives. Certain CCIs have a co-benefit of expanding overall water supplies or their availability, generally by managing land in a manner that may increase the water retention capacity of soils and watersheds. Other CCIs have a co-benefit of minimizing water use and consumption, generally by using water more efficiently. These co-benefits may be direct (defined as a primary objective of the CCI program), or indirect (as a by-product of the program's stated objective). The "water supply and availability" co-benefit therefore may apply to any situation where a CCI project applicant is able to demonstrate that it will a) reduce water use by the project applicant relative to a no-project alternative, or b) improve the water retention capacity of soils and watersheds in a manner that is likely to lead to reduced irrigation usage or increased dry-season baseflows in streams relative to a no-project alternative. Other CCI projects could reduce overall water supplies or their availability by managing watersheds or forests in a manner that decreases water yields relative to a no-project alternative, while certain other CCI projects may increase water use and consumption by a) converting urban parcels (developed or undeveloped) into vegetated open spaces that require irrigation above the baseline water use, or b) planting trees or other aboveground biomass that requires increased irrigation.

Table 1, below, illustrates the Fiscal Year 2016-17 CCI programs for which one or more of these water supply and availability co-benefits (either positive or negative) are most likely to accrue.

***Table 1**: CCI Programs Affected by Co-Benefit*

Program	Project	Likely directionality of co-benefit
Transportation and Sustainable Communities		
SGC	*Affordable Housing and Sustainable Communities Program (AHSC)*	**+**
	Sustainable Agricultural Lands Conservation Program (SALC)	**+ / -**
	Transformative Climate Communities (TCC)	**+ / -**
Clean Energy and Energy Efficiency		
CDFA	*Dairy Digesters and Research Development Program (DDRDP)*	**+**
	Alternative Manure Management Practices (AMMP)	**+**
	State Water Efficiency and Enhancement Program (SWEEP)	**+**
	Healthy Soils Program	**+ / -**
DWR	*Water-Energy Grant Program*	**+**
Natural Resources and Waste Diversion		
CNRA	*Urban Greening Program*	**+ / -**
DFW	*Wetlands and Watershed Restoration*	**+ / -**
CAL FIRE	*Forest Health Program*	**+ / -**
	Urban and Community Forestry (UCF)	**-**
CalRecycle	*Waste Diversion Program*	**+**

III. Directionality of the co-benefit

Water supply and availability can be affected positively or negatively by various activities funded by CCIs. Projects funded by the SWEEP and Water-Energy Efficiency programs will result in positive co-benefits, as increased efficiency in water consumption is a direct project objective. Projects funded by the CalRecycle Waste Diversion, CDFA Dairy Digesters and Research Development Program (DDRDP) and Alternative Manure Management Practices Program (AMMP) may have indirect positive water supply co-benefits if they result in the production of compost or other biosolids that, when applied, increase the water-holding capacity and infiltration of soils. Urban tree-planting projects funded by the CAL FIRE Urban and Community Forestry program are likely to produce negative co-benefits because the irrigation needs of the new vegetated landscapes are likely to exceed that of the previous uses of the land. Certain greening and reforestation projects funded by the CNRA Urban Greening and CAL FIRE Forest Health programs could possibly have this effect as well depending upon the particular circumstances of the project. Other projects funded by the Forest Health, Wetlands and Watershed Restoration, SGC Transformative Climate Communities, and Healthy Soils programs may produce either positive or negative co-benefits depending on the specific management actions undertaken by the projects. Projects funded by the Sustainable Agricultural Lands Conservation program may produce either positive or negative co-benefits depending upon whether the development displaced to a different location by the project can be expected to use less water than it would in the conserved location.

IV. Magnitude of the co-benefit

CCI programs will have widely varying effects on water supply and availability in California, although it is unlikely that net effects will be significant when compared to the scale California's overall water supply, use and consumptions patterns. Investments in GHG-reducing projects that also increase water efficiency could result in a large amount of water saved per dollar of investment at the program level, whereas other programs have only indirect, and relatively minor, effects on water supply.

CCI programs that impact water supply and demand can do so either directly or indirectly. Within each of these categories, both positive and negative co-benefits can accrue.

i. Projects with direct positive benefits

Some of the CCI programs listed above will fund projects that impact water supply and availability directly as a primary objective, and are likely to have important effects within the program's geographic scope, though these effects are small when viewed in the context of California's overall land area and water supply.

a. Projects with direct water supply and availability impacts

The DFW Wetlands and Watershed Restoration program funds projects that protect and improve water quality and quantity in Delta coastal wetlands and mountain meadows. These projects will have direct positive co-benefits on water supply and availability within their program's geographic scope. Relevant projects include those that entail restoration and enhancement of wetlands, improving flood protection, reducing or reversing land subsidence, increasing late-season flows downstream of mountain meadows, reducing and delaying peak stream flows, decreasing sedimentation, and increasing water storage capacity in mountain meadows.

Some agricultural practices within the CDFA Healthy Soils Program also have direct positive co-benefits on water supply and availability, including improved drainage and stream restoration projects. Certain CNRA Urban Greening projects may include stormwater capture and/or infiltration components that could increase available stocks of irrigation water within the project.

b. Projects with direct water use and consumption impacts

A majority of projects funded by the SWEEP and Water-Energy Efficiency programs will likely result in positive residential water use and consumption co-benefits as a direct project objective. The SWEEP program provides financial assistance to farmers seeking to implement new irrigation systems that reduce greenhouse gases and save water. Water efficiency project types include the installation of weather, soil, or plant-based sensors for irrigation scheduling; and micro-irrigation or drip systems. The DWR Water-Energy Efficiency program provides financial incentives for residential, commercial, or institutional water efficiency projects such as commercial dishwashers and ice machines, or residential clothes washers.

Some CDFA Healthy Soils projects will also likely have positive co-benefits on water use and consumption, if they entail increased efficiency in agricultural irrigation. Agricultural irrigation is the largest end-use of water in the State of California, comprising as much as 60 percent of the state's total water use by some estimates (Maupin et al 2014). Irrigation technologies vary significantly in their water application efficiency, ranging from a statewide average of 70 percent efficiency for certain kinds of sprinkler systems, to as high as 86 percent for drip irrigation (Sandoval-Solis 2013), though the extremes of these ranges are at about 60 percent (low end of sprinkler efficiency) and 95 percent (high end of drip efficiency). These figures imply that irrigation technology upgrades may be able to conserve as much as 50% of applied water on a given farm under optimal project conditions, but most savings rates are likely to be considerably lower than that.

Major California crops differ significantly in their demand for irrigation water. For example, the USDA (2013) Farm and Ranch Irrigation Survey reported a wide range of application rates, from an average of 0.6 acre-feet per acre (af/ac) of irrigation water applied for berry production, to an average of 4.5 af/ac for rice. Vegetables, tomatoes, and orchard crops (i.e. fruit and nuts) were all reported to average either 2.7 or 2.8 af/ac of irrigation water application. Hence, the potential water savings from irrigation efficiency investments could vary substantially depending upon what crop is being grown by a given applicant for CCI funds.

However, other Healthy Soils projects may have negative co-benefits to water use and consumption, including practices that require increased water use on irrigated land due to the planting of aboveground biomass (cover crops, alley cropping, contour buffer strips, herbaceous wind barriers, etc.) used as windbreak or for carbon sequestration.

ii. Projects with indirect impacts (positive and/or negative)

Several other CCI programs produce indirect impacts to water supply and availability and/or water use and consumption as a by-product of the project's stated objectives. Projects within these programs vary in the direction and magnitude of impact.

a. Projects with indirect water supply and availability impacts

There are two kinds of CCI projects with indirect water supply and availability impacts:

- forest management projects
- projects that reduce sedimentation of reservoirs.

Forest management projects. Most of California's major rivers rise in the forests of the Sierra Nevada and flow into one or more large reservoirs, where their discharge is stored for subsequent conveyance to agricultural, industrial and urban water users. CAL FIRE Forest Health Programs that include forest management strategies designed for other purposes, such as fire risk reduction, habitat enhancement or carbon sequestration, could have indirect water supply co-benefits if they can be shown to affect the timing and quantity of water flows out of the mountains and into reservoirs in a manner that is beneficial for water users.

For example, Bales et al (2011) have focused on the water yield benefits of additional snow accumulation enabled by forest thinning for fire risk reduction. They found that "[forest harvesting] treatments that would reduce forest cover by 40% of maximum levels across a watershed could increase water yields by about 9%" in the west-side mixed-conifer forests at elevations between 5,000 and 12,000 ft (Bales et al 2011). Synthesis studies by Bosch and Hewlett (1982), Stednick (1996), Marvin (1996) and Sahin and Hall (1996) found water yield increases ranging between 13 and 40 mm (0.51 to 1.57 in) per 10 percent removal of conifer cover. Podolak et al (2015) converted these findings to a volumetric quantity of 0.14 – 0.41 acre-feet per acre of expanded water yield attributable to forest treatments that reduce total basal area of trees by 10 percent.

Boisrame et al (2016) found that 40 years of managed wildfire in Yosemite National Park (which reduced forest cover by 22 percent and replaced it with meadows and shrublands) had resulted in a zero to thirteen percent higher runoff ratio (total streamflow divided by total precipitation) for the relevant stretch of the Upper Merced River, whereas control watersheds had experienced declining ratios over the same time period. Higher runoff ratio is generally regarded as a benefit from the point of view of water availability for human use, since it means that less of the water being used by vegetation is subsequently being evapotranspired into the atmosphere and instead is ending up in streams where it becomes available for human use downstream. Restoration of degraded alpine meadows may also increase groundwater recharge and shift a greater proportion of streamflow to the dry summer months. Tague et al (2008) found that flows in Trout Creek were 11 percent higher in June and 24 percent higher in July after meadow restoration, and that this result was most pronounced in dry years.

However, some experts have cautioned that any increased water yields from forest thinning may simply be taken up by other vegetation during the rainless summers characteristic of California's Mediterranean climate, that water yield responses to forest thinning are highly variable in different watersheds, and that any increases in water yield observable in initial years after treatment may disappear over ensuing years as vegetation growth continues (Bosch and Hewlett 1982). Cosandey et al (2005) reviewed French research on the hydrological impact of Mediterranean forest management and found that differing forest management techniques had very limited effects on watershed discharge or flood peaks, but that flood peaks did rise notably in watersheds after fires had created large areas of bare soil.

With respect to flood peaks, other work in the Sierra Nevada and other western mountain ranges has documented that burn areas left after large wildlfires produce very large amounts of runoff (and sediment, as described below) after subsequent rainfalls (Sierra Nevada Conservancy 2014). Despite the larger amount of total runoff, this phenomenon often has negative consequences for human water supply, as some runoff that would otherwise infiltrate into soils and be discharged slowly into streams and reservoirs instead runs off too rapidly to be effectively captured in reservoirs. Projects of the CAL FIRE Forest Health program that reduce wildfire risks through fuels reduction, sponsor reforestation after wildfires or other catastrophic events, prevent conversion and fragmentation of forests through the use of conservation easements, or reduce pest infestations to prevent tree mortality may therefore enhance water supply benefits over multi-decade time scales by reducing the incidence of landscape-denuding wildfires.

Reduced sedimentation of reservoirs. In some parts of California, forest management to avoid catastrophic, landscape-denuding wildfires may also create water supply benefits through reduced sedimentation of reservoirs. For example, the Sierra Nevada Conservancy (2014) reports that the Bagley Fire of 2012 resulted in the deposition of 110,000 m^3 of sediment in the immediate watershed of Lake Shasta, California's largest water supply reservoir. Loomis et al (2003) found that reducing fire intervals from 22 years to an average of five years through prescribed burns would reduce the sediment load into Los Angeles County reservoirs by two million m^3/yr. Buckley et al (2014) estimated that fuel-reduction treatments in the Mokelumne watershed could avoid sedimentation of Pardee Reservoir that would otherwise displace $1.2 million of water storage space over 30 years. This estimate is much lower than in the Los Angeles case because sedimentation rates in the granitic soils of the Sierra Nevada are much lower than the loosely consolidated soils of Los Angeles County.

b Projects with indirect water use and consumption impacts

There are three kinds of CCI projects that can have indirect water use and consumption impacts:

- reforestation, restoration and greening projects;
- projects that improve soil health;

- projects that entail land use conversion or conservation.

Reforestation, restoration and greening projects. To the extent that forest thinning may increase water yield from watersheds in the short term, the converse may be true for certain reforestation, forest restoration and urban greening projects, especially in the early years of plant establishment and growth (Hibbert 1967, Trimble et al 1987). However, as noted above, these same forest projects may have beneficial long-term water supply co-benefits if they limit wildfire risk, premature tree mortality, and forest fragmentation.

CDFA Healthy Soils practices that plant aboveground biomass as a windbreak or for carbon sequestration on irrigated land, including cover crops, alley cropping, contour buffer strips, or herbaceous wind barriers, can increase water use. DFW Wetlands and Watershed Restoration projects that increase vegetative cover could also increase short-term water consumption relative to the pre-existing condition, though their long-term effects may be neutral or beneficial.

Similarly, urban greening programs such as CAL FIRE’s Urban and Community Forestry (UCF) and CNRA’s Urban Greening program could also have indirect negative impacts on water use and consumption if they involve planting of new grass, trees or other vegetation that requires irrigation. The net water consumption effects of any particular reforestation, restoration, or greening project will vary widely depending upon what type of land cover is being replaced, what the climate is, and what species are selected for planting. The University of California Division of Agriculture and Natural Resources’ irrigation estimation for urban trees and horticulture in California uses a “plant factor,” which is a unitless proportion (e.g. 0.5 for trees) by which the local evapotranspiration (ET) rate may be multiplied to estimate irrigation water demand. For example, in Fresno, which has an ET rate of 51 in/yr, street trees would require roughly 25.5 in/yr of irrigation. Plant factors for turfgrass range from 0.6 to 0.8; other herbaceous perennials and groundcovers are collectively estimated at 0.5 (UC DANR 2017). Projects funded by the UCF and Urban Greening programs are required to select water efficient and drought-tolerant species that may require minimal or no irrigation once the plants are well established. However, even plant species considered by the California Department of Water Resources to be in the “low” water use category have plant factors ranging from 0 to 0.3, indicating that there can be non-zero irrigation demand even for water-efficient plants, at least in the early years of establishment (see Figure 1 on page 15). Whether any potential initial irrigation needs for plant establishment are counterbalanced by the removal of pre-existing water-consumptive land uses, or by features of the project that may capture stormwater for irrigation supply, must be evaluated on an individual project basis. Infiltration of stormwater into the groundwater within UCF and Urban Greening projects will not generally serve to expand water supply in urban areas, since urban groundwater is rarely extracted for human use.

Soil health projects. Some agricultural projects within the CDFA Healthy Soils Program may have an indirect positive impact on water supply and availability by improving soil health through the application of soil amendments, or the implementation of practices such as reduced tillage. Soil properties have an indirect effect on water usage, including infiltration rate, infiltration capacity, and water-holding capacity.

Similarly, projects funded by the Waste Diversion, Alternative Manure Management Practices (AMMP) and Dairy Digesters and Research Development (DDRDP) programs may indirectly result in positive water supply co-benefits via the production of compost or other biosolids that, when applied, may increase organic matter in California soils.

In unpaved land surfaces, most precipitation or applied water infiltrates into the soil, where most of it is either taken up by plants or is conducted downward into groundwater aquifers. A soil's infiltration rate is the rate (in inches per hour) at which water enters the soil from the surface. Typical soil infiltration rates can vary by a factor of twenty or more depending upon texture, from 0.04 – 0.2 in/hr for clays, to 0.2 – 0.4 in/hr for loams, and >0.8 in/hr for sands (Hillel 1982). Infiltration capacity refers to the maximum rate at which infiltration can occur (also called infiltrability).

Soil crusting and compaction reduce the infiltration capacity and rate of soil and lead to more water (either rainfall or applied water) running off over the surface rather than being made available to plants or groundwater aquifers (NRCS 2008). Some CDFA Healthy Soils practices can minimize soil crusting and compaction at certain depths, such as continuous no-till with application of cover crops. Application of soil amendments such as compost can also reduce crusting and compaction and improve soil infiltration rates. Experiments by CalTrans (2012) have shown that additions of various proprietary compost products (which have high levels of organic matter) decreased infiltration time across all soil types tested.

Water-holding capacity (the total amount of water a soil can hold) is also affected by soil texture and organic matter (Hudson 1994). Higher water-holding capacities for soils reduce irrigation needs because more of the water falling upon, or applied to, the land is available in the soil, for a longer time, for plants to uptake in their growth. Increasing the organic matter content of soils can increase water-holding capacity. For example, increasing the organic matter content of silty loam soils, for example, from 2 percent to 5 percent by weight would increase the water-holding capacity of the soil by more than 50 percent (Hudson 1994).

Land use and land conversion projects. Programs that entail land use conversion may have an indirect impact on water supply and availability, as well as water use and consumption. Some CDFA Healthy Soils practices may increase irrigation needs by converting land to water-intensive agricultural purposes. Conversely, conversion of agricultural or vegetated land to paved surfaces reduces soil infiltration to virtually zero unless constructed stormwater infiltration facilities are built, and also reduces recharge of groundwater aquifers in that area commensurately (Dunne and Leopold 1978). Some CNRA Urban Greening projects, on the other hand, can entail conversion of concrete cover to non-irrigated permeable surfaces that would increase water-holding capacity.

Similarly, land conservation projects may have an indirect impact on water supply and availability. SGC Sustainable Agricultural Lands Conservation Program (SALC) and some Transformative Climate Communities (TCC) projects conserve farmland that would likely otherwise be developed into residential and commercial land uses. These projects could produce positive or negative water supply co-benefits depending upon the overall anticipated water demand of alternative development locations and the net water use difference between the two development scenarios. Some SALC projects may incentivize or require improved irrigation practices on conserved lands, or protect riparian corridors through conservation easements, each of which could serve to generate positive water supply co-benefits.

V. Limitations of current studies

With respect to irrigation and residential consumption water savings, it is important to note that water use avoided by a specific water user due to efficiency improvements may or may not be “saved” from the point of view of the larger water systems that supply water to various users around California. Most major California water supply systems – including rivers and groundwater basins as well as engineered conveyance systems – are over-subscribed, in the sense that in most years, there is more demand for water than there is supply during the irrigation season (Grantham and Viers 2014). Any amount of water not used by a particular water rights holder is likely to be consumed or stored by another water rights holder farther downstream in the system (or elsewhere in the groundwater basin) if it is available.

In addition, many major California rivers have specified allocations for environmental flows established by the State Water Resources Control Board. This too can be thought of as a downstream “use” of water to which any additional water made available by improved irrigation efficiency may be devoted. Thus, each increment of water saved by enhanced irrigation efficiency may be thought of as “new” supply or availability in the sense that it reallocates that increment across more potential users in the current system, but it may not constitute “new” supply or availability in the sense of being able to provide for an expansion of allocations of California’s water supplies to new parties or uses.

Similarly, while some CCI programs in the transportation and sustainable communities sector increase the volume of residential housing, these projects may not increase net residential water consumption, because the same people who will move into those residential units would likely live elsewhere in California in the absence of the project. Indeed, these projects may produce positive water supply co-benefits compared to likely alternative scenarios since residents of higher density urban centers use less water per-capita than other residential environments due to lesser need for landscape irrigation.

With respect to soil water holding capacity, the literature review revealed no studies or guidance documents that directly relate soil organic matter content to irrigation demand for major crop types. This is likely because there are a wide range of other soil characteristics and conditions (beyond organic matter content) that will also affect water holding capacity and irrigation demands. For instance, soil water holding capacity also varies substantially based on soil texture (sand, loam, clay, etc) and pore size, and the relative importance of these factors in shaping irrigation demand may vary by crop type. A generalizable linear correlation between organic matter content and irrigation demand (and hence water use savings) therefore appears to be untenable. However, CCI project applicants may provide estimates of water use savings by measure or practice, specific to crop type, which could be aggregated at the project level.

Forest and watershed management studies are limited by the relative scarcity of watershed-scale study sites and controlled experimental conditions that would allow definitive exclusion of other variables that may be affecting the relationship between watershed or forest management and water yields. Existing results were all drawn from regression modeling of several watershed-scale results, not all of which were located in California. The results also show that watershed-scale forest management – generally ten percent reduction of forest cover or more across an entire drainage area – is necessary to achieve detectable effects on water yields. Smaller forestry projects are unlikely to produce effects large enough to be observable. In addition, any increased water yield produced by forestry projects in the higher elevations of watersheds may subsequently be consumed by trees and vegetation in the lower elevations of the watershed, rather than flowing to reservoirs where it could be allocated for human use. However, this can still be interpreted as a water supply benefit, as it provides lower watershed vegetation with ample water to protect the urban interface from the impacts of drought, pests, and fire risk.

VI. Existing quantification methods/tools

Given the range of possible linkages between CCI programs and water supply impacts, a range of quantification methods and tools may be applicable, summarized below.

i. Methods to estimate direct benefits

The State Water Efficiency and Enhancement Program (SWEEP) and DWR Water-Energy Grant Programs both require reporting of anticipated water savings by applicants as part of the CARB quantification methodology for estimating GHG emissions reductions. These reports can simply be compiled to document water savings that are expected to result from those projects for the prediction phase. Tracking of these water savings after a CCI investment may require direct reporting of activities by the funding recipient.

The SWEEP program provides financial assistance to farmers seeking to implement new irrigation systems that reduce greenhouse gases and save water. This program provides its own **Irrigation Water Savings Assessment Tool**[1] that calculates irrigation savings on a per-acre (and percentage) basis. In this tool, users select from pull-down

[1] Available online at: https://www.cdfa.ca.gov/oefi/sweep/

menus to indicate predominant soil type, major crop, geographic location, and irrigation practice in both the “before-project” and “after-project” conditions. The tool then calculates the water savings expected to result. The results are expressed in acre-inches per acre, and thus would have to be multiplied by acreage (also provided by tool users) to convert the results to a volumetric quantity of water (e.g. acre-feet, gallons, etc).

The DWR Water-Energy Efficiency program provides financial incentives for residential, commercial, or institutional water efficiency projects such as commercial dishwashers and ice machines, or residential clothes washers. This program provides its own Excel-based **Water-Energy Grant Program GHG Calculator Tool**[2] that calculates water savings as a function of water consumption under the conventional measures used prior to the program, minus water consumption under the new measures implemented with CCI funding. In this tool, users input use data such as flow rate (gallons per minute), percentage of hot water used, and building water heater fuel type. The tool then calculates the water savings expected to result (in gallons) at an annual and project-level.

The SGC Affordable Housing and Sustainable Communities Program (AHSC) and Transformative Climate Communities programs fund the development of new residential housing. If these new residential developments adhere to the most recent water efficiency standards, the consequence of new development could be a decrease in net water consumption per household (from the baseline of staying in existing older, non-efficient homes).

ii. Methods to estimate indirect benefits

a. Methods to estimate water savings from forest management and restoration

Water and sediment yields from large forested watersheds can be modeled with the **InVEST model**[3], a free, open-source modeling suite developed by the Natural Capital Project at Stanford University. For water yield, this model works by breaking a watershed into grid cells and solving equations that require user input of the evapotranspiration rates for different land cover types, the plant available water capacity, and rooting depth for dominant plant species, among other data (Sharp et al 2016). The model characterizes land cover only by the dominant vegetation type (e.g. evergreen needleleaf forest, open shrubland, grassland, etc), not the density of that vegetation. Hence, only the water yield changes resulting from major changes in land cover type, as opposed to tree thinning, could potentially be modeled. For sediment yield, the InVEST model relies upon the Universal Soil Loss Equation, which was originally derived from studies of agricultural land in the Midwest and does not capture all forms of erosion that may be important in California watersheds, especially in mountainous areas.

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[2] Available online at: https://www.arb.ca.gov/cc/capandtrade/auctionproceeds/quantification.htm
[3] Available online at: http://www.naturalcapitalproject.org/invest/

A simpler approach would be to adopt the **Marvin regression equation** derived to estimate water yield changes from vegetation-runoff relationships in the Sierra Nevada (Marvin 1996). This equation is expressed as:

$$y = 1.3x + 18.6$$

Where:

Y = increase in annual watershed runoff (mm)
X = percent reduction in tree coverage of watershed

This equation was developed using watersheds with annual precipitation ranges characteristic of the Sierra Nevada. As Marvin notes, this simple equation has a low explanatory power ($r^2 = 0.14$), but performed as well as in runoff prediction as multiple regression equations incorporating more independent variables. Within the precipitation ranges of the Sierra, the equation is likely more accurate for relatively wet watersheds (i.e. >1000mm of annual precipitation, characteristic of forests dominated by Douglas fir and Sierra Nevada lodgepole pines) and for wet years across all types of watersheds. Marvin also notes that "extreme caution" should be used in applying the model to modest changes in forest cover (i.e. <25% reduction in coverage).

Tracking of water yields after a CCI has made an investment in forest or watershed management would be extremely difficult. Because each watershed possesses unique soil and vegetation characteristics, and the patterns or precipitation within and between each water year(s) are different, even the direct measurement of the flows of receiving streams or inflows into receiving reservoirs would likely not be sufficient to distinguish the effects of a management action from other factors shaping watershed-scale water yield response. Any such method would have to compare the actual flow measurements with a model or estimation of what would have been the case in the absence of management actions.

b. Methods to estimate landscape irrigation demand

The Urban Greening and Urban and Community Forestry programs both involve planting of trees and other vegetation within urban areas. In cases in which these plantings are replacing pavement, hardscape, or un-irrigated land surfaces, these projects may result in new irrigation water demand rather than water savings.

Both of these programs use the free, publicly available **i-Tree Streets** software program to calculate GHG reduction benefits of new urban tree and vegetation plantings. This software produces estimates of stormwater-related impacts of new tree plantings, but does not generate before-project estimations of anticipated irrigation demand. Urban stormwater-related impacts, such as potential decreases in quantities of urban runoff, do not generally impact water supply and availability except in extremely limited circumstances. A companion i-Tree Hydro software program is a tree species-specific urban hydrologic model that models how changes in land cover affect the volume and quantity of runoff. As with i-Tree Streets, it does not estimate irrigation needs of the new trees in question, but focuses on stormwater-related hydrological impacts on streams and other receiving waters of urban stormwater discharge.

A set of on-line calculators for estimating these water demands has been developed by the **University of California's Center for Landscape and Urban Horticulture**[4]. These calculators allow users to estimate irrigation demand for several common types of vegetated urban landscapes:

- Lawns and turfgrass
- Individual trees and shrubs (where canopies cover less than 80% of the ground)
- Groupings and mass plantings of trees and shrubs (where canopies cover at least 80% of the ground)
- Non-turf perennial groundcovers
- Mass plantings or beds of herbaceous perennial flowers and similar plants
- Mass plantings or beds of annual flowers and bedding plants

For each of these calculators other than the lawn and turfgrass calculator, the user must enter the planted area in square feet (or canopy diameter for individual trees and shrubs) and the local rate of evapotranspiration (ET_o) in inches per day. ET_o rates may be found through a hyperlink embedded within the tool, or estimated by consulting historical data archived by the California Irrigation Management Information System (CIMIS)[5]. The calculators then provide an estimate of the gallons per day, gallons per week, and inches per week that will be required to irrigate the planted area. Any of these amounts may be converted to a volumetric measure by multiplying by the number of days or weeks that the irrigation will be applied.

The lawn and turfgrass calculator requires the user to select from pull-down menus whether the planting will be warm-season and cool-season turf, the region of California in which the planting will take place, the water application rate of the sprinklers to be used, and the month. The tool then provides an estimate of how many minutes per week of irrigation the lawn or turfgrass will require. This can be converted to a volumetric quantity using the sprinkler rate previously selected by the user.

Another tool for estimating the irrigation demand of newly created vegetated urban areas is the **California Department of Water Resources' Water Budget Workbook for New and Rehabilitated Non-Residential Landscapes**[6]. This tool calculates a Maximum Applied Water Allowance (MAWA) and an Estimated Total Water Use (ETWU) for the purposes of compliance with California's 2015 Model Water Efficient Landscape Ordinance. CCI applicants would need to use the ETWU estimator only. It

[4] Available online at: http://ucanr.edu/sites/UrbanHort/Water_Use_of_Turfgrass_and_Landscape_Plant_Materials/Water_Demand_Calculators/)
[5] Available online at: http://www.cimis.water.ca.gov
[6] Available online at: http://www.water.ca.gov/wateruseefficiency/landscapeordinance/

relies upon a measure known as Plant Factor, a number ranging from zero to 1.0 that indicates the typical water demand of a given plant type. The user is asked to identify "hydrozones" that are planted areas that share common characteristics across the columns shown in the example table in Figure 1 below. The user provides data only for the blue cells (irrigation system selection, plant factor, and hydrozone area) and the tool fills in the rest. Plant factors for typical types of urban landscape plantings are available from the UC Center for Landscape and Urban Horticulture.[7]

Hydrozone	Select System From the Dropdown List click on cell below	Plant Water Use Type (s) (low, medium, high)	Plant Factor (PF)	Hydrozone Area (HA) (ft^2) Without SLA	Enter Irrigation Efficiency (IE)	(PF x HA (ft^2))/IE
Zone 1	**Overhead Spray**	**High**	0.80	6,000	0.75	**6,400**
Zone 2	**Overhead Spray**	**Medium**	0.50	1,000	0.75	**667**
Zone 3	**Overhead Spray**	**Medium**	0.50	1,000	0.75	**667**
Zone 4	**Drip**	**Low**	0.30	17,000	0.81	**6,296**
Zone 5	**Drip**	**Low**	0.30	10,000	0.81	**3,704**
Zone 6	**Drip**	**Low**	0.20	13,000	0.81	**3,210**

Figure 1 – Example input table from California Department of Water Resources' Water Budget Workbook for New and Rehabilitated Non-Residential Landscapes

A more species- and context-specific approach to estimating irrigation demand is in the **Landscape Coefficient Model**, jointly produced by the University of California Cooperative Extension and the CA Department of Water Resources (UC Cooperative Extension 2000). Users of this method calculate a landscape coefficient that is a product of a species factor (obtained from a look-up table provided with the method), a density factor for the planting, and a microclimate factor (both derived from guidance in the method manual). This landscape coefficient is then multiplied by the reference evapotranspiration to calculate landscape evapotranspiration, which is then divided by irrigation efficiency (typically assumed to be about 70 percent) to achieve the estimate of total water to apply, expressed in inches. For projects that contain several different species of plants, this method would potentially require users to sum together a number of individualized calculations.

All of the landscape irrigation demand methods are intended to assist users in projecting irrigation needs, and therefore are best suited for the prediction phase. Post-award tracking of water use may require direct reporting of water consumption activities by the funding recipient. Urban open spaces that require irrigation may have water meters (or billing records) that measure water flow into the irrigation system, or it may be possible to derive the total water use from sprinkler schedules if the flow rate of each sprinkler is known. Urban street trees, especially when they are young, may be watered through drip irrigation lines or even by hand until they are well established. The amount of water used for this purpose may be obtainable through irrigation schedules or maintenance records.

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[7] Available online at: http://ucanr.edu/sites/UrbanHort/Water_Use_of_Turfgrass_and_Landscape_Plant_Materials/Plant_Factor_or_Crop_Coefficient__What%E2%80%99s_the_difference/

c. Methods to estimate water savings from improved soils

The CDFA Healthy Soils program funds a variety of practices that improve soil-water function, including those that apply soil amendments, or reduce soil compaction and surface crusting.

Projects that increase organic matter in California soils either directly or indirectly can estimate the water savings from improved soils by calculating soil water content. These projects include Healthy Soils practices such as cover cropping and compost application. Saxton and Rawls (2006) present regression equations for predicting soil water content as a function of sand, clay, and organic matter content of soils for two different soil water tension conditions (1500 kPa and 33 kPa). These equations are the basis of the **SPAW (Soil-Plant-Air-Water) model**[8], which simulates the daily hydrologic water budgets of agricultural landscapes, and can be used to define irrigation requirements (Saxton et al 2006).

Use of the SPAW model, or the stand-alone regression equations, would require applicants to identify sand, clay and organic matter content (along with several other input variables in the SPAW model) before the application of any additional organic matter or implementation of other healthy soils practices, and then to estimate the anticipated change in these concentrations after the practice implementation. Comparison of pre-treatment and post-treatment scenarios in the SPAW model may enable the applicant to identify the difference in irrigation requirements between the two scenarios, and thus estimate the water savings.

Tracking of these water savings after a CCI has occurred may require direct reporting of water consumption activities by the funding recipient.

Projects under the Waste Diversion, Alternative Manure Management Practices (AMMP) and Dairy Digesters and Research Development (DDRDP) programs fund the production of compost or other biosolids that, if applied to soils, can result in water savings. These projects could estimate the number of acres of soil to be potentially indirectly improved by these practices.

d. Methods to estimate avoided water use increases from avoided development

The Sustainable Agricultural Lands Conservation (SALC) program, and possibly the forthcoming Transformative Climate Communities program, fund projects that conserve farmland that would likely otherwise be developed into residential and commercial land uses. These projects can produce water savings co-benefits if the avoided land use would have used more water than the existing agricultural activity, if the project incentivized or required improved irrigation practices on conserved lands, or if the conservation easement protected riparian corridors.

[8] Available online at: https://hrsl.ba.ars.usda.gov/SPAW/SPAWDownload.html

Applicants could quantify avoided water use savings from conservation easements by subtracting the estimated existing water usage (in agriculture) from the estimated avoided usage (from anticipated development).The water use in the existing agricultural land use may be known to the applicant, or it could be estimated on the basis of typical irrigation water application rates for the crops being grown. For instance, as noted above, many common orchard and vegetable crops in California use about 2.7 af/ac of irrigation water, or about 880,000 gal/ac/yr.

Applicants could estimate the avoided water usage in one of two ways. Applicants to the SALC program already use the **California Emissions Estimator Model (CalEEMod)** to generate estimates of the GHGs avoided by the project investment, assuming that the development avoided in the SALC project area would occur elsewhere in a more compact form or a more location-efficient site. Because people living in compact development and urban infill development generally use less water per capita than those living in more suburban environments, the displacement of development to these locations by a SALC project may be expected to reduce water use by these residents. CalEEMod also contains assumptions about residential and commercial water use drawn from Gleick et al (2003), and these estimates could be generated for the same avoided development scenarios used to estimate GHG savings.

Alternatively, applicants could use more recent estimates of water use for typical residential and commercial buildings in California. A widely cited study of single-family residential water use in California (DeOreo et al 2011) found that the average single-family residence in California uses 362 gal/day, or about 132,000 gal/yr, for indoor and outdoor uses combined. For commercial office property in California, Eisenstein et al (2016) reviewed estimates from Gleick et al (2003) and Dziegielewski et al (2000) and arrived at an estimate of 108 gal/sf/yr. Indoor water usage in other types of commercial buildings, such as retail, schools or institutional buildings, could be estimated by counting the number of plumbing fixtures and toilets, and multiplying them by the use frequencies, occupant loads and flow rates in the 2016 California Plumbing Code.

Because the SALC program conserves land in its existing use, tracking of post-award water savings would use the same methods as pre-award estimation.

VII. Knowledge gaps and other issues to consider in developing co-benefit quantification methods

As noted, CCI programs vary widely in their potential impact on water supply and availability.

The SWEEP and Water-Energy Efficiency programs will likely produce significant water supply co-benefits at both the project and program scales because reduced water use is a core purpose of both programs. These benefits should be readily quantifiable through adaptation of information already provided as part of the existing GHG quantification guidance.

The SALC program could produce significant water supply co-benefits at both the project and program scales, though it will vary substantially based on the specific attributes of each project. As noted above, irrigation for typical agricultural uses in California is in the range of 880,000 gal/ac/yr, enough water to accommodate about 6.67 units of residential development per acre, about 8,150 sf of commercial office space per acre, or a roughly comparable amount of other commercial construction. These are relatively low densities for new construction projects in California, so for any higher density development proposal, especially one that covers a large acreage, the avoided water use co-benefits of agricultural land conservation could be substantial. These benefits should also be quantifiable through adaptation of the CalEEMod modeling process already performed as part of the existing GHG quantification guidance.

The Healthy Soils and Waste Diversion programs are unlikely to have significant water savings co-benefits at the scale of individual projects, since the increases in organic matter content of soils resulting from these projects are only one contributing factor to the overall water holding capacity of soils, and a change in the water holding capacity of a given soil body may have only an indirect effect on irrigation demand. These effects may be more significant at the program scale, but will be difficult to quantify given the complexity and uncertainty of modeling.

The Wetlands and Watershed Restoration and Forest Health Restoration programs may or may not have significant water supply and availability co-benefits, and the benefits may be either positive or negative, depending upon the specific management actions being undertaken. Generally speaking, the literature supports the conclusion that projects to reduce wildfire risks by thinning forests may have positive water supply co-benefits, particularly due to increased snow capture, but only if they are undertaken fairly aggressively (e.g. removal of at least 10 percent of forest cover) over a watershed scale. Projects to re-forest or re-vegetate previously denuded areas may have a positive or negative effect on water yields from that particular watershed. Such projects may expand water supply yield for human purposes by slowing down runoff velocities, increasing soil infiltration and reducing reservoir sedimentation in areas with erosive soils, but could also increase uptake and evapotranspiration of water by vegetation. The specific balance of these competing water uses may vary substantially by watershed and by the particular physical circumstances and management actions of a given project. In general, water supply and availability co-benefits of these programs are likely to be positive and significant at the level of the entire CCI programs, but at the level of individual projects, where co-benefit assessment methods would apply, these general relationships may disappear or be reversed given other plausible characteristics and conditions of watersheds across California.

The Urban Greening and Urban Forestry programs are likely to have a negative effect on water supply and availability, because they introduce new vegetation into urban landscapes that likely did not require irrigation previously. These negative co-benefits could be significant at the project scale for proposals to create large areas of vegetation or to create irrigation-intensive landscapes such as turfgrass lawns. They are likely to be significant at the program level as well. These effects can be quantified readily through existing and widely accepted irrigation estimation methods.

Overall, water supply and availability co-benefits are only moderately significant when considered across the entire CCI portfolio. Though two CCI programs explicitly seek to save water through efficiency improvements, other programs are likely to result in increased water usage and others may have complex cross-cutting effects that will be difficult to assess.

iii. Practice duration

Another consideration for assessing a project’s magnitude of impact on water supply and availability is the duration of time a practice is implemented, and the lag between implementation and observable changes in water supply, which may be many years. Some practices, such as land use conversion and easements, are generally implemented over many years and take even longer to accrue the full benefits. Others, such as the residential, commercial, or institutional water efficiency projects, may happen once but have relatively immediate impacts on water consumption.

iv. Permanence

Permanence refers to the level of certainty that the benefits of water supply and availability practices will persist over time and not be reversed. Holding practice duration equal, some agricultural practices, such as easements or planting trees, have greater levels of permanence than others, such as reducing tillage. A subsequent change in practices may result in the reversal of these benefits.

VIII. Proposed method/tool for use or further development, schedule, and applicant data needs

Given these findings, we offer the following recommendations for methods and tools for assessment of water supply and availability co-benefits, schedule for development of guidance documents, and applicant data needs.

Methods for estimation prior to award of CCI funds (Phase 1):

- Calculation of direct water savings from projects funded by the SWEEP program already performed by applicants using the SWEEP Irrigation Water Savings Assessment Tool in existing GHG quantification guidance

- Calculation of direct water savings from projects funded by the Water-Energy Efficiency program using the calculations through the use of the CARB GHG Calculator Tool in existing GHG quantification guidance

- Estimation of net irrigation water use from projects funded by the Urban Greening and Urban and Community Forestry programs by using the DWR Water Budget Workbook for New and Rehabilitated Non-Residential Landscapes.

Methods for measurement after award of CCI funds (Phase 2):

- Reporting of annual water usage in project area, one year after completion of project, by awardees from the following programs:
    - SWEEP
    - Water-Energy Efficiency
    - Urban Greening
    - Urban and Community Forestry

We do not recommend development of any guidance to assess water supply and availability co-benefits for the Healthy Soils and Waste Diversion programs at this time. Given the uncertainty of the direction and magnitude of water-related benefits from these programs, the development of quantitative or qualitative assessment methods would require substantial additional research and development effort on the part of UC-Berkeley, would likely place substantial additional information burden onto the applicants to CCI programs, and would likely document only modest water supply and availability co-benefits relative to the scale of these programs.

We also do not recommend development of any guidance to assess water supply and availability co-benefits for the Sustainable Agricultural Land Conservation (SALC) program or the Affordable Housing and Sustainable Communities (AHSC) program. In both cases, requiring applicants to develop counterfactual scenarios in the water module of CalEEMod for anticipated water usage in the absence of the project is likely too burdensome given the modest scale of anticipated co-benefits.

We also do not recommend development of any guidance to assess water supply and availability co-benefits for the Wetlands and Watershed Restoration and Forest Health Restoration programs at this time. Though these programs are likely to produce positive water supply and availability co-benefits in the aggregate and over the long term, assessing these co-benefits at the individual project level is very difficult given the numerous physical and temporal variables that affect water yields from watersheds. The only available assessment methods that are applicable across the broad diversity of physical conditions in California watersheds, and can project impacts over multi-decade time scales, are complex models that would require project applicants to assemble a wide range of data and execute multiple modeling runs to compare with-project and without-project outcomes.

Simple qualitative assessments of water supply and availability co-benefits are likewise infeasible at the project level because project-related and non-project-related physical conditions that affect potential water supply co-benefits are too variable across projects, across time, and across California's watersheds to permit qualitative generalizations on the likely effect of a given project actions unless project applicants are required to provide substantial data on these conditions. These data would likely need to include the anticipated climatic patterns in the watershed (i.e. the relative preponderance of dry versus wet years), the stream-flow and groundwater-flow distance between a project and a water supply reservoir receiving runoff from the project area, the characteristics of soils and vegetation in the project area and the rest of the reservoir's watershed, and the time-sensitive operating rules of the reservoir in question, among others. Finally, there is debate in the literature about the permanence of any potential water supply benefits from forest management and restoration actions, given that vegetation will continue to grow and change over time in project areas, and in the watershed between the project area and the receiving reservoir, after projects have been completed.

Schedule

Because these methods and tools are generally straightforward modifications of tools and guidance that already exist, we anticipate that we could develop draft co-benefit assessment methodology guidance within two months of CARB's instruction to proceed.

Data needs

Applicants are already required to use the SWEEP Irrigation Water Savings Assessment Tool, for which they must provide the following inputs, for both the "before" and "after" scenarios, by selecting from drop-down menus in Microsoft Excel:

- Predominant soil (sand, sandy loam, silt, clay, etc)
- Crop (alfalfa, almonds, apples, etc)
- Baseline, township and range of project location
- Irrigation practice (surface irrigation, drip irrigation, center pivot irrigation, etc)

For the Water-Energy Efficiency program, applicants are already required to use the CARB GHG Calculator Tool, which automatically calculates anticipated water savings for proposed projects.

For the Urban Greening and Urban and Community Forestry programs, applicants will have to provide:

- Total square footage of plantings for each combination of irrigation type (overhead spray or drip) and plant factor associated with plant water use type (low, medium, high or Special Landscape Area).
- Total square footage of Overhead Spray Irrigation, Drip Irrigation, and Special Landscape Area, derived from above.
- Total annual precipitation (optional).

- Annual water use of land use previously occupying project site (optional)
- Estimated annual quantity of stormwater captured and reused for irrigation within the project site (optional)

UC-Berkeley will provide needed references and definitions (such as the definition of a Special Landscape Area), drawn from the relevant DWR user manual, in the forthcoming assessment methodology document.

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