ENVIRONMENTAL

Final Draft

SOCIAL

Efficient Water Management for Regional Sustainability in the Sacramento Valley

Prepared for

Northern California Water Association

ECONOMIC

July 2011

In 1992, NCWA was formed to provide water users throughout the Sacramento Valley with a strong and united regional voice on California water policy. NCWA's mission is "to advance the economic, social, and environmental sustainability of Northern California by enhancing and preserving the water rights, supplies, and water quality" in Northern California. More specifically, NCWA has a guiding principle that "Water districts' and companies' purpose is to provide landowners a reliable, affordable supply of irrigation, M&I [municipal and industrial] and environmental water of suitable quality for reasonable use within its boundaries for as long into the future as water is needed for these purposes."

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A Colusa Basin Efficiency Case Study

Acronyms and Abbreviations

AgWUE	Agricultural Water Use Efficiency
CVP	Central Valley Project
DWR	California Department of Water Resources
EE	effective efficiency
ET	evapotranspiration
maf	million acre-feet
NCWA	Northern California Water Association
QO	Quantifiable Objectives
SWP	State Water Project
TB	Targeted Benefits
TE	traditional efficiency
USDA	U.S. Department of Agriculture

SECTION 1 Introduction

Background

This report was commissioned by the Northern California Water Association (NCWA) to explore water use efficiency in the Sacramento Valley. The charge was to characterize the hydrologic setting in the Sacramento Valley and, in that context, develop a technical framework to guide water use efficiency efforts and provide water resources managers with tools to identify, assess, and pursue specific water use efficiency opportunities. The overarching goal is to improve water use efficiency to achieve regional sustainability with respect to water resources.

This report articulates a framework for addressing water use efficiency in the Sacramento Valley considering the valley's unique hydrologic characteristics and existing conditions, establishes a basis for identifying and assessing water use efficiency improvements, and offers a basis for constructive dialogue both within the valley and between the valley and others.

A Sacramento Valley Approach to Water Use Efficiency

Water in the Sacramento Valley is used for agriculture, municipal, recreation, wildlife refuge, instream flow, ecosystem, and other purposes. Combined, these uses derive a wide range of benefits, including highly productive agriculture enterprises that contribute to national and global food supply while supporting the region's economy and communities. Additionally, the valley's healthy ecosystems support a host of critical plant and animal species, and recreational opportunities abound, accessible to people within and outside the valley.

Among the valley's water uses, diversions for irrigation and environmental water supply are dominant. Evapotranspiration (ET) by crops and native vegetation causes water depletion. Diverted water that is not consumed returns to the hydrologic system because the physical characteristics of the Sacramento River Basin allow no other outcome. The valley is generally underlain by high-quality groundwater and, with certain localized exceptions, groundwater levels remain at near-historical levels. In many locations, groundwater is in communication with the hundreds of waterways – rivers, streams, sloughs, and drains – that course through the area. At certain times and locations groundwater is naturally discharged to streams to provide cool, steady, base flows. At other times and locations, streams leak water into underlying aquifers to replenish groundwater. Eventually, all unconsumed water makes its way through the system to become available for downstream use, either as surface flow or groundwater. Thus, agricultural and environmental water uses are inextricably linked to the basin hydrologic system, and any changes in how these uses are managed will unavoidably affect the system, either positively or negatively.

Additionally, water uses within the region are inevitably sequential at one scale or another. Many of the region's reservoirs serve as recreation destinations as well as supply sources; stored water releases are conveyed in rivers and streams that support recreation and ecosystem functions; diverted water is used for irrigation, environmental, municipal, and industrial purposes; and, as noted above, the unconsumed portions of these diversions are returned to groundwater aquifers or waterways that serve as supply sources and support further recreational and ecosystem functions. Sometimes the sequence of uses occurs within the span of a few miles and a few hours and, in other cases, over a range of many miles and much longer periods. All unconsumed water ultimately flows out of the region past the city of Sacramento and into the Bay-Delta.

On the basis of these factors, Sacramento Valley water resources managers have reached the following conclusions that shape the valley's approach to water use efficiency:

- ✓ Opportunities to produce additional water supplies for outflow from the valley are limited because all unconsumed water already flows out of the valley.
- ✓ Opportunities to enhance the productivity of and add value to existing water uses through management of flow paths, rates, and timing are appreciable.
- ✓ Analysis of potential water use efficiency measures must be sufficiently broad to account for the interconnections among water uses, users, and systems; and they must be sufficiently conclusive so that water use efficiency opportunities are not missed and undue risks are not incurred.
- ✓ Adverse impacts and unintended consequences, as well as intended benefits, may result from water use efficiency measures and should be carefully evaluated.
- ✓ Critical information gaps regarding the physical nature of the Sacramento Valley hydrologic system, ecosystem functions, and other factors exist and must be addressed to provide a platform for long-term sustainable management of water resources.

Implicit to this approach is recognition of the legitimacy of existing water uses to the extent that such uses are consistent with water rights and other laws.

As this approach suggests, water use efficiency in the Sacramento Valley must be defined within a framework formed by recognizing existing and possible future uses of water, an understanding of the physical characteristics of the hydrologic system and the interrelationships among water uses, and water management goals and objectives.

Finally, Sacramento Valley water resources managers have adopted a single, overarching water management goal to guide water use efficiency (as well as other) initiatives, which is, in a word, *sustainability*. It is important to all members of the valley's diverse community that the valley's water resources be managed in ways that ensure that existing economic, social, and environmental systems endure indefinitely.

SECTION 2 Sacramento Valley Environment

Overview

The Sacramento Valley lies within the Sacramento River Hydrologic Region (as defined by California Department of Water Resources [DWR, 2009]), which covers approximately 17.4 million acres (27,200 square miles) (see Figure 2-1). The Sacramento Valley constitutes the northern part of the California Central Valley, and hosts agricultural, urban, and environmental land uses extending from north of Redding to just south of the Sacramento metropolitan area.

The Sacramento Valley is bounded by foothills to the east and west, and generally overlies the Redding and Sacramento Valley Groundwater Basins as defined by DWR (see Figure 2-2), which combined, encompass approximately 4.3 million acres (6,700 square miles). Groundwater pumping from these basins has been developed to supplement surface water supplies. In some areas, groundwater is the sole or primary source for meeting water demands.

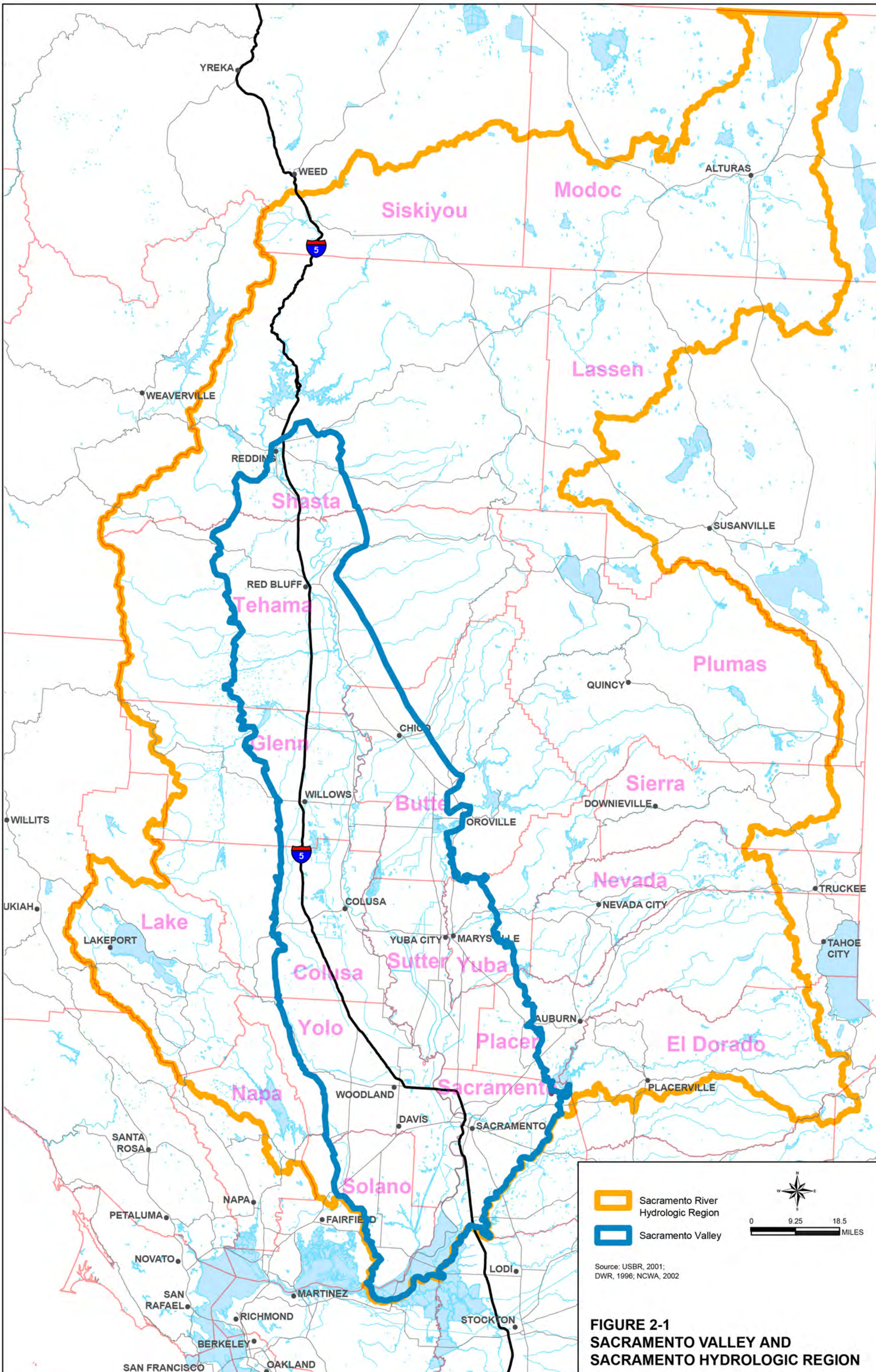
The Sacramento River, California’s largest river, originates in and flows through the region. The Sacramento River and its tributaries are the main water supply source for much of California’s urban and agricultural areas, including areas north and south of the Bay-Delta. Additionally, they provide instream and riparian habitat for aquatic and terrestrial species, and supply water to wildlife refuges. The unimpaired flow from the Sacramento River Hydrologic Region averages approximately 22 million acre-feet (maf) annually, representing nearly one-third of the state’s total annual runoff and the largest component of inflow to the Bay-Delta.

The flow of the Sacramento River and its major tributaries is managed to a significant degree by the facilities of the federal Central Valley Project (CVP) and California’s State Water Project (SWP). This system of reservoirs and conveyance facilities delivers river water for agricultural, urban, and environmental uses within the Sacramento Valley, and for agricultural and urban uses south of the Bay-Delta. Major tributaries to the Sacramento River include the Feather/Yuba and American Rivers, which flow into the Sacramento River from the Sierra Nevada foothills and mountains that border the eastern side of the valley. In addition to these tributaries, flows in the Sacramento River are influenced by the operation of Shasta (at the northern end of the valley) and Oroville (to the east) Reservoirs, local irrigation projects, climatic conditions, environmental flow requirements (including for fish-related temperature control), land use, water rights, and contractual allocations that govern surface water use and influence groundwater use.

Physical Setting and Water Uses

The Sacramento River Hydrologic Region extends from the Modoc Plateau and Cascade Range at the Oregon border to the Sacramento–San Joaquin Delta (see Figure 2-1). The Sacramento Valley lies at the center of this larger region and is bounded to the east by the Sierra Nevada and southern Cascades, and to the west by the crest of the Coast Range and Klamath Mountains. In addition to the CVP and SWP reservoirs discussed above, more than 40 major surface water reservoirs have been constructed in the Sacramento River Hydrologic Region. Most of these reservoirs are located along or just above the Sacramento Valley fringe where rivers and streams leave the foothills and enter the Sacramento Valley.

Municipal, industrial, and agricultural water demands in the region total approximately 8 maf annually, with surface water providing about 5.5 maf of the total, and groundwater providing the remaining 2.5 maf in a typical year. The portion of the water diverted for irrigation but not actually consumed by crops or other vegetation becomes recharge to the groundwater aquifer or



Sacramento River Hydrologic Region

Sacramento Valley

0 9.25 18.5 MILES

Source: USBR, 2001; DWR, 1996; NCWA, 2002

FIGURE 2-1
SACRAMENTO VALLEY AND SACRAMENTO HYDROLOGIC REGION

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FIGURE 2-2
SACRAMENTO VALLEY IN RELATION TO REDDING AND SACRAMENTO GROUNDWATER BASINS

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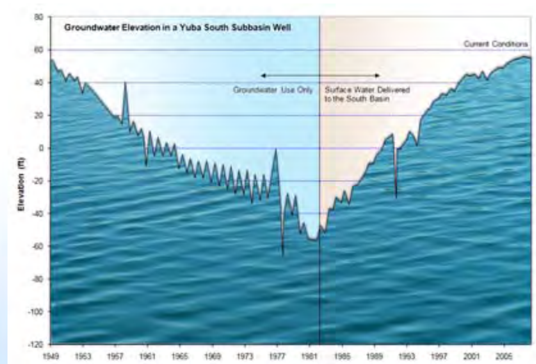
flows back to surface waterways and contributes to surface water supplies either within or downstream of the Sacramento Valley. Agricultural drains and their connection to natural streams play a major role in this process. The remainder of the total runoff stays instream, supporting various environmental requirements, including instream fishery flows and Bay-Delta flushing flows. The Sacramento River and tributaries provide critical aquatic habitat for species including winter-, spring-, and fall-run salmon, as well as steelhead trout and other sport and commercial fish species.

Large-scale irrigation in the Sacramento Valley began to increase significantly after 1910. Today, with the additional water supply made available by the construction of CVP and other projects, and the ongoing development of groundwater in areas without access to surface water supplies, irrigation in the Sacramento Valley has expanded to about 1.8 million acres (2,810 square miles). The Sacramento Valley contains over 11,000 farms ranging in size from 10,000 to less than 10 acres (U.S. Department of Agriculture [USDA], 2011).

The region's surface water supply is delivered through a complex system of interconnected natural and constructed conveyance systems. Thousands of miles of irrigation canals and drains interlace the valley, providing surface water supplies to thousands of customers. Over 90 irrigation water suppliers (including local public agencies and private companies[1]) own, operate, and maintain these systems to deliver water and provide drainage service to growers who cultivate a wide variety of permanent and annual crops. The major crops are rice, almonds, walnuts, alfalfa, wheat, and corn (USDA, 2011). The varied cropping pattern reflects the different soil types, climates, markets, water supply and drainage conditions, and other factors found in the valley, as well as the preferences of individual farmers.

In the mid- to late-1950s, farmers in Yuba County realized that groundwater conditions were headed for disaster. Groundwater levels in the Yuba South Subbasin, an area that had no surface water supplies, had been declining since the early 1940s, with no letup in sight. At the same time, Yuba County was experiencing repeated flooding with the 1950 Linda flood and the deadly 1955 Yuba City flood. In 1959, the Yuba County Water Agency was established by special act of the California Legislature. The Yuba County Water Agency's mission was to improve water supply and flood protection. This was achieved through the construction of New Bullards Bar Reservoir to reduce peak flood flow and store water for beneficial use.

Construction of New Bullards Bar Dam and Reservoir was completed in 1970. Because Yuba County's finances to fund the project were limited, it was another 13 years before surface water diversion and delivery systems were put in place to deliver water to the southern portion of the county. In 1983, water deliveries to the south began, and immediate recovery of the groundwater basin commenced. The graph below shows the dramatic change in groundwater levels with the project's surface water deliveries.



Because the groundwater basin has been replenished, nearing pre-pumping levels not seen since the turn of the last century, Yuba County Water Agency Member Unit farmers have implemented a conjunctive use program that provides groundwater substitution transfers to water-short areas of California. In the past 3 years, over 200,000 acre-feet of water have been transferred to south of Bay-Delta water users during this recent drought period.

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[1] Includes irrigation, water, and reclamation districts; mutual water companies; and other entities, generally referred to as suppliers or districts.

Groundwater

The Sacramento Valley overlies one of the largest groundwater basins in the state, and wells developed in the sediments of the valley provide excellent supply to irrigation, municipal, and domestic uses. Many of the mountain valleys within the region also provide significant groundwater supplies to multiple uses.

Approximately 30 percent of the region's urban and agricultural water needs are met by groundwater. Although surface water supplies provide the majority of the water used by the Sacramento Valley's agricultural sector, groundwater provides approximately 35 percent of the total water used to support agricultural uses, depending on water-year type. The typically high groundwater levels in the Sacramento Valley cause the major rivers and the lower reaches of many of the tributary streams to gain flow through groundwater discharge. These stream accretions generally have cool temperatures and provide steady base flows that contribute to favorable instream conditions for fish. Higher reaches of the tributary streams and rivers located near areas of locally depressed groundwater levels typically lose water to the underlying aquifer system. Groundwater in both the Sacramento Valley and Redding Groundwater Basins is typically replenished through stream leakage and the deep percolation of winter precipitation and applied irrigation water.

Although generally highly productive, Sacramento Valley aquifers are not limitless. As agricultural land use and water demands have intensified over time, groundwater levels in certain areas have declined because increases in pumping have not been matched by increases in recharge. This condition has been the motivating force for developing supplemental surface water supplies in numerous locales during the past 30 to 40 years, including Yolo County with its construction of Indian Valley Dam in the North Fork of Cache Creek; South Sutter Water District with its construction of Camp Far West Reservoir on the Bear River; and Yuba County, which constructed New Bullards Bar Dam and Reservoir on the North Yuba River (see inset above). These surface water supply projects have been critically important to recovering and sustaining groundwater levels and supplies in the face of increasing demands.

Today, groundwater levels are generally in balance valleywide, with pumping matched by recharge from the various sources mentioned above annually. Some locales show the early signs of persistent drawdown, including near Chico and in portions of Glenn and Tehama Counties where water demands are met primarily, and in some locales exclusively, by groundwater. These could be early signs that the limits of sustainable groundwater use have been reached in these areas.

Water Reuse

The Sacramento Valley can be broadly characterized as a "flow-through" system, wherein essentially, all of the water not consumed by crops and other vegetation or for other purposes eventually returns to the river via various tributaries or percolates to groundwater and recharges local aquifers. Additionally, outflow from one user or water supplier is often a source of supply for the next user or supplier downstream. Reuse of water occurs throughout the valley to maximize available supplies and is particularly prevalent in the Colusa Subbasin.

Because of the extensive water reuse within and among suppliers, water use efficiency throughout the Sacramento Valley is quite high at the regional level. In some instances, efficiency measures implemented in upstream areas have interrupted supplies to downstream areas that rely on recirculation and reuse of drainwater as a water source.

Pacific Flyway and Upland Habitat

In addition to hosting extensive agriculture, the Sacramento Valley lies near the southern end of the Pacific Flyway migratory route and is one of the most prominent wintering sites for migratory waterfowl. The valley's seasonal marshes and winter-flooded rice fields attract from 1 to 3 million ducks and roughly 750,000 geese each winter, or approximately 44 percent of wintering waterfowl using the Pacific Flyway (California

Rice Commission, 2011). The valley also provides habitat for 50 percent of the threatened and endangered species in California. This habitat consists of riparian zones and wetlands along the Sacramento River, and other significant tributaries to agricultural drains, wildlife refuges, and rice fields that provide food sources for a variety of species. Rice fields alone provide up to 150,000 acres of wetland habitat, including prime habitat for the threatened giant garter snake as well as migratory waterfowl.

Five national wildlife refuges, and more than 50 state wildlife areas and other privately managed wetlands provide habitat for waterfowl and other terrestrial species. Water supply sources for the refuges include surface water diverted from the rivers and streams, agricultural return flows, and groundwater. Local water suppliers have various agreements with the region's refuge managers to help ensure reliable water supplies to these areas.

SECTION 3 Sacramento Valley Water Management

Overview

This section presents a conceptual framework for water use efficiency in the Sacramento Valley and takes a more detailed look at agricultural water use, the valley's dominant water use sector, and refuge water use. These uses have profound effects on the valley's hydrology, and they are closely interrelated. The discussion regarding agricultural water use distinguishes between rice and non-rice water management because the two are very different and because rice is the valley's largest crop.

A Conceptual Framework for Efficiency in the Sacramento Valley

One of the challenges to dialogue on water use efficiency is that the term "water use efficiency" means different things to different people and groups. In the agricultural sector, years of research worldwide have led to accurate quantification of crop water requirements, and the industry has developed efficient systems for applying irrigation water precisely and uniformly. With this knowledge and capability, efficiency is generally taken to mean "minimizing water use relative to crop water requirements."

In the urban sector, water use is typically expressed on a per capita basis – the amount of water used by each person (on average) each day. Here, water use efficiency generally means "reducing per capita water use," typically through public education and adoption of devices and practices such as low-flush toilets and drought-tolerant landscaping.

The meaning of water use efficiency becomes fuzzy in the environmental sector because scientific understanding of ecosystem functions is lacking. As species have declined in numbers, the general response, mainly through application of environmental laws, has been to dedicate more water for environmental uses. Increasingly, higher efficiency in environmental water uses is being requested, but the means of defining and prescribing efficiency generally do not exist, and discourse becomes subjective. Recreation water use falls in a similar, subjective category.

It is doubtful whether comparable, quantitative means for defining water use efficiency across water use sectors will be developed anytime soon, possibly never. More likely, water use efficiency will continue to involve subjective values. In this sense, water use efficiency is not necessarily a prescription that can be calculated; ultimately, it is a process that enables reconciliation of different, subjective values.

Additionally, water use efficiency must account for the physical interrelationships that exist among water uses. Water uses rarely occupy a landscape in isolation; more commonly, water uses are several, and they are interrelated.

For example, stored water released from a reservoir into a stream for ultimate irrigation diversion downstream may support a variety of recreational uses and ecosystem functions along the way. Furthermore, the reservoir itself may provide additional recreational opportunities, and the return flows from the diverted (and applied) irrigation water may sustain ecosystem functions in drains or serve as recharge to underlying groundwater aquifers. Later, the groundwater may be discharged to surface streams, serving as a source of cool, steady, base flow.

Although hypothetical, the foregoing example describes the kinds of relationships that exist among water uses in the Sacramento Valley, and illustrates two important factors. First, analysis of efficiency in interconnected systems cannot be conducted with respect to any single use in a sequence of uses without also looking at the related upstream and downstream uses. It is necessary to keep the entire hydrologic system in view when working on its pieces (Keller and Keller, 1995).

Second, higher levels of water use efficiency can be achieved by better designing and managing sequential uses before water ultimately escapes the hydrologic system. In other words, managing *how* water flows through a basin is important.

A major challenge in designing and managing sequential-use systems is developing an adequate understanding of a system's physical characteristics and the physical interrelationships among uses within the system. With adequate understanding, the bounds of analysis can be set sufficiently wide, in both spatial and temporal terms, to ensure that all uses and relationships among them are accounted for. In this way, water use efficiency measures that achieve intended effects while deliberately avoiding or minimizing unintended consequences can be identified.

In characterizing a hydrologic system for purposes of assessing efficiency and evaluating interrelationships among uses (and for purposes of overall water management), it is necessary to distinguish between consumptive and nonconsumptive water uses, simply because nonconsumptive uses do not deplete the system of water. Unconsumed water returns to the hydrologic system and may become available for downstream uses. In contrast, consumptive uses do deplete the system of water, precluding any further use (to the extent of the consumption).

Additionally, unconsumed water may be recoverable or not, depending on its ultimate destination. Water flowing to locations where it is preserved and accessible for further use, such as groundwater aquifers and drains with suitable water quality, is recoverable; whereas, water flowing to unusable aquifers or water bodies is not. In this sense, irrecoverable flows are equivalent to consumptive uses from a water supply standpoint because they are lost to any further (freshwater) use.

A final point, possibly the most important, is that water use efficiency is not an end in itself but, rather, a means to an end. The common belief is that higher efficiency is always better; however, this is not always true with respect to water because of the interconnections previously discussed. Without an adequate understanding of the system, it is possible to apply efficiency measures in a manner that threatens not only other uses, as noted above, but also leads to long-term deterioration of hydrologic, ecologic, economic, and other functions. Thus, water use efficiency initiatives must be conditioned by objectives that reflect appropriately established water management and societal goals.

Without an adequate understanding of the system, it is possible to apply efficiency measures in a manner that threatens not only other uses, as noted above, but also leads to long-term deterioration of hydrologic, ecologic, economic, and other functions.

In summary, and as noted above, water use efficiency must be defined within a framework formed by recognizing existing and possible future uses of water, an understanding of the physical characteristics of the hydrologic system and the interrelationships among water uses, and water management goals and objectives. Because these factors vary among regions, each region should be allowed and expected to have a unique definition and approach to water use efficiency.

Agricultural Water Management

As noted in Section 2, about 5.5 maf are diverted from Sacramento Valley rivers and tributaries annually (with an additional 2.5 maf pumped from valley aquifers). The majority of these diversions are for irrigation. From an operational and water management perspective, the objective is to deliver the diverted water to individual farmers in a manner that is conducive to profitable crop production. In general, this means delivering water as follows:

- ✓ In sufficient amounts and with suitable quality to meet irrigation water requirements

- ✓ At the times and in flow rates matched to the requirements of on-farm crops and irrigation systems
- ✓ At affordable cost to maximize the potential for financially sustainable farm enterprises

Although there are many individual surface water diverters in the Sacramento Valley, their diversion quantities tend to be small, accounting for a small percentage of the total water used for irrigation. The majority of water is diverted by local districts formed under state law specifically for that purpose. Additionally, as previously noted, some individuals and districts depend on return flow from upstream irrigators and districts for some or all of their water supplies. Thus, there are three levels of agricultural water management: *fields* where water is actually used for irrigation, *districts* that divert and deliver water to farms (and in some cases drain water away from farms), and *basins* within which farmers and districts may cooperate to manage water discharge and reuse across jurisdictional lines.

Typical water management at each of these levels is discussed below, including the operational relationships among the levels. In particular, the manner in which districts deliver water to farmers has a strong influence on how well farmers are able to irrigate.

Most of the Sacramento Valley's agricultural development occurred in the late-1800s and early 1900s. Irrigation deliveries were made with "gravity flow systems" where water moved from higher to lower elevations under the force of gravity. As water moved to lower elevations, it was reused from one field to the next, from one district to the next, and from one region to the next. This was naturally accomplished because the constructed irrigation systems are intertwined with the valley's natural streams and sloughs so that water draining from one place could be recovered and reused by downstream water users. The system still operates this way today, although significant strides have been made to increase the ability to control water as it flows through the system and to screen major diversions to keep fish out of irrigation waterways.

In a system like this, where water is extensively reused, irrigation efficiency tends to increase as the spatial scale of analysis is increased from the field or farm level to district, subbasin, and basin scales. This relationship of increasing efficiency with increasing spatial scale is examined in Section 4, through a water balance analysis of the Colusa Subbasin, a hydrologic subunit of the Sacramento Valley.

Field-level Water Management

Advances in water application technology over the past 20 to 30 years have led to reductions in farm water delivery requirements to produce crops. Drip and micro sprinklers have replaced flood and furrow irrigation of trees and vines in many areas. More recently, buried drip tape is increasingly used for certain row crops such as tomatoes, reducing soil surface evaporation and percolation into the ground (while increasing crops yields and quality). For rice, which is flood irrigated, laser leveling, which began in the early 1970s, together with changes to shorter stature, shorter season varietals, and changes in farming practices has resulted in significant reductions in the average quantity of water applied to rice fields.

Although most growers in the Sacramento Valley rely on surface water, the surface water supply in some districts may be supplemented with groundwater pumped from privately owned wells or, in some cases, from district-owned wells. Most of the surface water delivered to fields and farms within the Sacramento Valley is delivered by irrigation districts or water companies. Surface water deliveries to fields are typically made by gravity from the district's conveyance canals through orifice gates or overpour structures. Additionally, some districts, most notably those served by the federal Tehama-Colusa Canal, deliver water through pipeline systems pressurized by gravity or by pumps.

Most districts within the valley provide water on arranged demand schedules, meaning that growers and distribution system operators work out water delivery schedules that are responsive to crops needs but do not exceed system capacity or other operational limitations. In some areas, the capacity of the delivery system limits peak-season deliveries, and districts may temporarily resort to supplying water to rotational distribution whereby growers are provided water on a fixed schedule established by the district. This typically lasts for short windows during the irrigation season, and only a handful of small districts continue to use rotational distribution all season long.

Water delivered that is not used by crops either runs off the field as surface drainwater or percolates to the groundwater basin. In some cases, water reaching the groundwater table may raise local groundwater levels, causing groundwater to flow into nearby drains. These drains carry surface runoff and groundwater inflow away from fields. Allowed to flow freely, this drainwater is eventually conveyed back to the Sacramento River and becomes supply available to downstream users.

District-level Water Management

Districts divert water from surface water sources for delivery to individual fields. Diversions need to be coordinated with CVP and SWP operations to ensure that minimum streamflow and other operational requirements are satisfied, which at times can constrain operational flexibility and the ability to respond in a timely manner to changing water demands.

Diversions from surface water sources are measured and reported valleywide in accordance with state requirements. Approaches to measuring deliveries to individual fields within districts vary depending on system characteristics, crop type, and other factors (see the Water Measurement section). Since the early 1990s, districts have been implementing programs within the valley to protect anadromous fish species. As a result, today, most district diversion facilities are equipped with state-of-the-art fish screens (see Section 4).

Other technologic advances include installation of supervisory control and data acquisition systems that allow districts to monitor irrigation system operations remotely and respond to changes in conditions on a real-time basis, sometimes remotely. Additionally, more and more districts are automating pumping plants and water control structures to maintain target water levels and flows as set by operators, and to reduce operations labor requirements. Together, supervisory control and data acquisition and system automation improvements have appreciably improved the reliability, accuracy, and steadiness of water deliveries to fields, which has allowed farmers to improve on-farm irrigation practices. These technologies are still evolving and hold significant potential for continued, long-term improvements in district water management.

Policies and practices for water ordering and water delivery vary appreciably among districts depending on many factors. However, as discussed above, most districts within the valley provide water to growers on arranged demand schedules, delivering water within 1 to 3 days of when it is ordered. With this degree of responsiveness, growers can easily anticipate irrigation needs and order water accordingly.

Many districts operate recirculation systems that collect and redistribute some or all of the drainwater from fields as well as operational spills from the district's supply canals and laterals. In these systems, the drainwater, which may include surface runoff from surface water deliveries and groundwater pumping, is lifted into the district's supply canals and is an integral part of water supply available to fields and farms within the district.

Basin-level Water Management

In most basins (and subbasins) within the valley, water reuse from one district to the next is "automatic," meaning that no overt management or control is asserted over the water. Rather, the pattern of drain outflow from upper users and districts is compatible with the downstream demands of other uses and districts. There are places where upstream districts take specific actions to ensure that they discharge sufficient water to meet the legal entitlements of down-stream users.

Crop Water Management

Rice Water Management

Overview

Rice is the most extensive crop grown in the Sacramento Valley, planted on about 585,000 acres (USDA, 2011) and spanning a distance of some 120 miles – roughly from Red Bluff to Sacramento. For the most part, rice is grown on the low-lying, fine-textured "adobe" soils that formed over geologic time as floodwaters intermittently covered the valley, allowing fine sediments to settle out. In the early 1900s, early pioneers who settled in these low-lying areas cleared and developed the land for agriculture. They soon discovered that crops that thrived elsewhere in the valley either failed or did not produce well because the soils became "sticky when wet and bone hard when dry" (Richvale Writing Group and Ward, 2006). Groundwater tables were generally high and encroached into the root zone, and crop roots could not penetrate the heavy soil. It was eventually discovered that rice was uniquely well adapted to these conditions, to the near total exclusion of other crops. The initial experiments with long-season rice were not successful because available varieties required growing seasons longer than that of the Sacramento Valley. When a Japanese rice variety with a growing season matched to that of the valley was introduced in 1908, rice production really took hold.

Rice is unique among Sacramento Valley crops for many reasons; however, from a water management perspective, rice is different mainly because it is grown under flooded conditions, which offers both crop production and environmental benefits. Flooding helps to control certain competitive weeds and enhances the availability of nutrients. Additionally, ponded water acts as a thermal buffer, gaining heat during the day and releasing it at night to protect against cool nighttime temperatures that can reduce rice yield at certain growth stages.

For non-rice crops, which are grown under aerated (non-flooded) conditions, the water requirement is composed mainly of ET[2]; but for rice, the water requirement includes deep percolation of water through the root zone as well as ET. This reveals a major management distinction between rice and non-rice crops – the irrigation requirements for non-rice crops (based primarily on ET) can be calculated from weather conditions and published crop coefficients. For rice, although the ET component of the irrigation requirement can be calculated in a similar manner as for non-rice crops, the deep percolation component is not known. Deep percolation depends on field-specific soil and subsurface conditions that are naturally variable throughout the valley and are practically impossible to predict. Thus, the irrigation requirements of rice fields must be empirically derived: a rice farmer knows how much water a rice field needs by visual observation of ponding. If ponding is maintained, the field is receiving enough water; if not, it needs more[3].

Percolation rates through rice fields are typically very slow because of the fine texture and compacted structure of the soils where rice is typically grown, and because of the formation of a compacted soil layer (or "plow pan") that results from years of shallow tillage and equipment traffic. DWR Northern District estimates that, on average, deep percolation is about 1 inch per month during the time that rice fields are flooded. However, the spatial variability of percolation rates among rice fields is high, depending on local soil and groundwater conditions.

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[2] Theoretically, leaching is also part of the irrigation requirement for non-rice crops; however, these requirements are generally small in the Sacramento Valley due to the low salinity of irrigation water in most locations. Leaching is generally not explicitly factored into the irrigation requirement because deep percolation of applied water and winter precipitation are sufficient for maintaining salt balance.

[3] This is among the reasons that field-level water measurement serves a different purpose for rice than for other crops. Water measurement does help to establish how much water was used to grow rice and to implement incremental flow increases and decreases to maintain ponding, but it does not help determine irrigation adequacy relative to a known requirement.

Rice Pond Management

Rice water management does not involve simply planting the crop into ponded conditions and maintaining that condition until harvest. Precise control of the depth and timing of ponding relative to rice growth stages and herbicide applications is critical from the standpoints of crop production and water use efficiency. Table 3-1 summarizes a schedule of water management objectives for a typical Sacramento Valley rice field based on the generally accepted ideal plant date of May 1. Of course, the thousands of rice fields in the valley cannot be planted all at once. Planting is typically spread over a period of several weeks between mid-April and early June, leading to unique water management requirements for each field depending on its plant date, weed control practices, types of herbicides used, weather conditions, and other factors. The general planting progression is from upstream to downstream (north to south).

The most critical rice water management factor is controlling the ponded water depth over time. In the example described in Table 3-1, the pond is created and drained just once between planting and harvest, but some fields are drained two or sometimes even three times depending on weather conditions and the herbicide being used. To the extent that draining is accomplished by allowing ponds to drop as a result of percolation, the applied water requirement is not appreciably affected. However, to the extent that draining is achieved by releasing stored water, draining will increase the applied water requirement.

Another significant factor is the timing of the final drain-down before harvest. In the example, flow is cut off 15 days before the field is drained, during which time the stored pond water is used to meet crop ET and deep percolation requirements. In this way, only a portion of the pond is discharged when the boards are pulled to drain the field, and the applied water requirement is reduced accordingly. Traditionally, it was common for growers to continue water delivery to maintain the full up to 7-inch ponded depth up until the time boards were pulled for drain-down. That practice is gradually being phased out in favor of the water-conserving practice described above. Some of the major rice-dominant Sacramento Valley water suppliers now offer incentives in the form of rebate payments to encourage growers to cut water off in advance of drain-down to reduce water demand. Growers receive rebate payments in exchange for the extra effort they expend in more closely monitoring and managing their pond levels.

While controlling the pond depth to achieve desirable growing conditions (see Table 3-1), farmers must also pay attention to how much water flows through their rice fields. Ideally, water delivery to rice fields would exactly match the ET and percolation requirements; however, this is nearly impossible to achieve in practice because ET requirements vary with weather changes and, in some cases, because of fluctuations in the delivery flow rate provided by the water supplier[4]. A more practical and generally accepted approach is to allow a minimal rate of through-flow to serve as a buffer against ET and water delivery fluctuations and, where needed, to limit salinity buildup (see next section, Managing Salinity). Most suppliers have rules that prohibit excessive rice through-flow, including the use of notched weir boards that physically limit the amount of through-flow depending on the size of the field. Furthermore, some suppliers offer financial incentives to growers to limit through-flow. There is an energy and cost savings to both the supplier and farmers when through-flow is reduced, especially where water supplies must be pumped from sources and excess drainwater must be pumped out.

From a water balance perspective, ET is the only component of the rice irrigation requirement that depletes water from the system, with the percolation and through-flow requirements returning to the system and contributing to downstream water supply and environmental benefits.

4 Recognizing that delivery fluctuations are problematic for rice growers and can lead to excessive flow-through, some suppliers are automating their systems to provide water level control in canals. Steady canal water levels enable the district to hold steady farm deliveries, which in turn allow growers to manage through-flow more precisely.

TABLE 3-1
Schedule of Water Management Objectives for a Typical Sacramento Valley Rice Field
Efficient Water Management for Regional Sustainability in the Sacramento Valley

May 1–3	Flood field to 1-inch minimum ponded depth; cut off water.
May 4–8	Fly on presoaked and germinated seed; seed sinks to soil surface and root attaches to soil. Pond drops gradually due to depletion by ET and deep percolation.
May 9	Drain remaining ponded water to promote deep root penetration.
May 16–19	Re-flood field to 4-inch depth.
May 20	Cut water off and apply weed-control herbicide. The 30-day “lockup” begins during which water cannot be discharged from the field because of pesticide label regulations.
May 20–30	Allow no inflow to ensure zero discharge from field. Pond level drops gradually due to depletion by ET and deep percolation.
May 31	Reintroduce low flow to prevent excessive drying while still maintaining zero discharge.
June 20	Increase flow to achieve 4-inch ponded depth and generate some outflow for maintaining ponded water quality (depending on several factors).
Late-July	Increase flow to achieve up to a 7-inch ponded depth to act as thermal buffer. (Note: average pond depth is about 5 inches.)
Late-July – August 15	Continue small flow to maintain up to 7-inch ponded depth and minimal outflow. (Note: average pond depth is about 5 inches.)
August 15	Turn water off.
August 15 – September 1	Pond drops gradually due to depletion by ET and deep percolation.
September 1	Pull boards to drain any remaining ponded water from field (typically 0 to 2 inches).
September 20 – mid- to late-October	Harvest rice.
Mid- to late-October	Replace boards and flood to a ponded depth of between 2 and 6 inches for rice straw decomposition and to provide waterfowl habitat.
Mid- to late-October through December	Maintain ponded condition relying on precipitation supplemented by water delivery; ponded depth varies according to grower preference, surface water availability, precipitation, and other factors.
January	Capture seasonal precipitation to maintain water levels for rice straw decomposition. Water levels may subside as hunting season comes to a close and system is opened to allow flow-through.
February	Allow water levels to subside as ponds are drawn down and flow through the system. High precipitation levels prevent any tillage of the soil.
March	Allow systems to remain open to allow flow-through of seasonal precipitation and rice decomposition water.
April	Begin tillage of field to prepare for planting, construction of levee checks, and installation of rice boxes (weirs) to control water flow between basins.

Managing Salinity

There are locations and circumstances in the valley where water quality considerations become an important factor in managing through-flow. In situations where rice drainage water is recycled multiple times, salts contained in the water supply may become so concentrated by ET[5] that rice growth is stunted and yields are affected. Rice is particularly sensitive to salinity during the seedling and pollination growth stages (University of California Cooperative Extension, 2009). Salinity must be managed by dilution with fresh water and maintaining sufficient through-flow from fields and districts to ensure a productive salt balance over the long term.

Over the more than 100 years that rice has been grown in the valley, all aspects of its production have steadily improved, including plant breeding, cultivation and weed-control techniques, harvesting, and water management. In particular, precision land leveling is now widely used to achieve nearly dead-level grading within rice checks, which allows farmers to manage rice ponds more precisely and eliminate water applied to compensate for uneven land surfaces. Techniques for on-farm water recycling have also been developed, but they are not as widely used, mainly because water reuse can be accomplished more efficiently at the district level rather than within fields and farms.

The ongoing advancement of on-farm rice water management practices has challenged water suppliers to provide increasingly higher levels of service to their customers, spurring a host of delivery system modernization upgrades. Many suppliers are investing in modernization so that they can provide the levels of delivery reliability, flow steadiness, and flexibility needed for modern rice cultivation and on-farm water conservation while reducing operational spillage from distribution systems.

[5] ET results in the depletion of pure water, concentrating dissolved salts in the unconsumed through-flow or deep percolation.

Environmental Values of Rice Cultivation

Over the past 30 years, the environmental values of rice cultivation have become better understood and documented, especially as they relate to habitat value for wintering waterfowl. Of the more than 500,000 acres planted to rice each year in the Sacramento Valley, about 350,000 acres are re-flooded following harvest, with most fields maintained in a ponded state throughout the winter by precipitation and supplemental water application (see Table 3-1). Although from the grower's perspective the objective of flooding is primarily to aid in decomposition of the rice straw (which otherwise requires burning or baling and removal), the flooded conditions, together with the crop residue, also create favorable conditions for waterfowl.

About 7 million birds use the Pacific Flyway, including the following species, nearly half of which are found in the Sacramento Valley: Tundra swan, trumpeter swan, greater white-fronted goose, snow goose, Ross' goose, Brant goose, Canada goose, cackling goose, wood duck, green-winged teal, mallard, northern pintail, blue-winged teal, cinnamon teal, northern shoveler, gadwall, Eurasian wigeon, American wigeon, canvasback, redhead, ring-necked duck, scaup, common goldeneye, bufflehead, merganser, and ruddy duck. Some species are more attracted to rice habitat than others.

Rice provides about 60 percent of all the food that wintering waterfowl consume in the Sacramento Valley each year; every 3 acres of rice is equivalent to about 2 acres of wetlands. Additionally, rice tailwater from the winter flood-up supplies 57 percent of water supplied to the area's 75,000 acres of wetlands. In total, rice lands support 230 species, as follows: 187 birds, 27 mammals, and 16 amphibians/reptiles. Of these, 31 are considered species of special concern by the conservation community (California Rice Commission, 2011).

Contemporary rice cultivation and water management practices provide substantial environmental benefits. Practices offered in the Conservation Stewardship Program and the

Environmental Quality Incentives Program aim to further enhance rice habitat values. The California Rice Commission is currently working with Audubon, PRBO Conservation Science, and The Nature Conservancy on six rice farms to test out new ideas to further progress toward this goal.

Rice provides about 60 percent of all the food that wintering waterfowl consume in the Sacramento Valley each year; every 3 acres of rice is equivalent to about 2 acres of wetlands.

Other Crop Water Management

About 1.2 million acres in the Sacramento Valley are planted to other crops, with roughly half this acreage planted to annual crops and half to permanent crops. Major annual crops include alfalfa, wheat, corn and safflower. Major permanent crops include almonds and walnuts, each with roughly 200,000 acres, and lesser acreage is planted to olives, grapes, and other tree and vine crops. The area planted to olives has been expanding in recent years, driven by an expanding market for California olive oil.

Water demands associated with other crops are composed predominantly of crop ET plus some application of water for cultural practices, such as frost protection during blossoming and pre-irrigation to condition soil for tillage, for germination of certain crops, and to replenish root zone soil water. Although leaching is theoretically part of the irrigation requirement, water and soil salinity levels in the Sacramento Valley are generally low, and leaching requirements are typically negligible. Thus, leaching is generally not factored explicitly into irrigation requirements.

Drip irrigation of tree and vine crops was introduced in the 1970s as the technology was being pioneered, and has steadily expanded. Nearly every new permanent crop planting within the past 10 to 15 years has been accompanied by installation of either drip or, more recently, micro-sprinkler irrigation systems. (Note: together, drip and micro-sprinkler irrigation are called micro irrigation). Although the original impetus for micro irrigation development was water conservation, early adopting growers quickly learned there were other significant production advantages. The ability to maintain and control soil moisture levels for optimum growth, coupled with the ability to apply fertilizers dissolved in the applied irrigation water, resulted in earlier production, significant yield increases, and improved fruit and nut quality. Growers quickly realized that the appreciable cost of micro irrigation, ranging from roughly $1,000 to $2,000 per acre in initial capital outlay (in today's dollars), was quickly recovered and paid dividends thereafter. Today, it is estimated that more than 90 percent of all permanent crops are irrigated with micro irrigation, driven strongly by the production advantages described above. Water conservation has generally not been a strong incentive in the Sacramento Valley because water supplies are generally adequate and reliable, and because applied water that is not consumed returns to the system.

One challenge that has confronted suppliers and growers is meeting the high-frequency, low-volume delivery requirements of micro irrigation systems with existing open canal distribution systems that were designed to deliver water infrequently for short durations at high flow rates for surface irrigation. For example, an 80-acre walnut orchard that might have been delivered water every 2 weeks at a rate of 10 cubic feet per second for 2 days for surface irrigation might require 2 cubic feet per second for 14 hours every day for micro irrigation. Some suppliers are modifying operations and implementing canal-control upgrades to accommodate these new requirements. Even with system upgrades, the micro irrigation requirements sometimes cannot be completely satisfied, and in some cases, growers convert to a groundwater supply source to maximize delivery flexibility in order to fully realize the potential benefits of micro irrigation. Additionally, a groundwater well is completely under the grower's control and produces clean water that needs minimal filtration, significantly simplifying irrigation management. With the conversion from surface water to groundwater supplies, deep percolation of applied surface water is reduced and groundwater pumping is increased, placing additional stress on the aquifer. In other regions of the state, notably the San Joaquin Valley, these effects driven by the same factors have contributed to groundwater overdraft.

Annual crops remain predominantly surface-irrigated with graded furrow and border strip methods being the most commonly used. Generally, graded borders are used with alfalfa, pasture, and other hay and forage crops; and furrows are used for row crops such as corn, safflower, and sunflower. Both methods, particularly furrows, require that some tailwater be generated in order to achieve adequate irrigation of the lower ends of fields. On-farm tailwater reuse systems are not commonly used in the valley, primarily because reuse occurs at the supplier and subregional scales, and is more cost effective compared to on-farm reuse.

As previously described, a significant new trend for row crop irrigation is the use of drip tape, or subsurface drip irrigation. The primary crop using drip tape has been processing tomatoes, for which, similar to permanent crops, the additional cost for the system is justified by increased yields and improved crop quality. Water conservation has not been a strong driver.

Refuge Water Management

In addition to rice fields and privately managed wetlands, a number of federal and state refuges provide important habitat, as well as hunting, education, and bird watching opportunities across the Sacramento Valley. Five national and four state refuges/wildlife areas provide over 40,000 acres of wetlands and associated uplands.

Seasonal, semi-permanent, and permanent wetlands are found on refuge areas. Maintenance of these wetlands requires that water be provided in the early fall for flood-up of seasonal marsh, and semi-permanent and permanent areas require water during a greater portion of the year. Flow-through of maintenance water levels is also required to decrease the potential for disease, including botulism, in species that use these habitats.

Prior to the signing of the Central Valley Project Improvement Act in 1992, many of the valley's federal and state refuge areas received either drain flows or water from upstream water districts through agreements that did not give these areas priority. Many of these agreements did not provide firm supplies, particularly during drought periods. The continued implementation of the Refuge Water Supply Program as part of the Central Valley Project Improvement Act has led to new facilities and the development of agreements with water districts to provide firm, secure supplies to the valley's refuges.

One completed element of the Program in the Sacramento Valley is the Glenn-Colusa Irrigation District Refuge Conveyance Project. Completed between 1998 and 2000, the project involved $15 million of capital improvements to Glenn-Colusa Irrigation District conveyance facilities, paid for with a combination of federal and local government funds. The project will expand the water supply to the Sacramento, Delevan, and Colusa National Wildlife Refuges from 60,000 acre-feet to a maximum of 105,000 acre-feet annually. Additionally, the project enables year-round water delivery for optimal management of the 20,000 acres of prime waterfowl and other habitat. This project exemplifies the close coordination and cooperation between agricultural water suppliers and the various wildlife refuges and areas within the valley. (Additional information can be found at (http://www.gcid.net/_documents/gcid%20brochure%20pdfs/Refuge.pdf.)

Water Measurement

It is universally acknowledged that water measurement is foundational to water management. Measurement is needed for real-time management of water conveyance and distribution systems in order to get the right amount of water delivered to the right places at the right times. Additionally, measurement is the only means of developing quantitative characterizations of existing hydrologic conditions, which provide the basis for evaluating water management adequacy and identifying opportunities for improvements.

All Sacramento Valley agricultural water suppliers presently measure water in a manner that supports their respective operational and administrative purposes, consistent with local water management objectives and policies adopted by their respective governing bodies. Existing measurement practices vary widely among suppliers, reflecting the variability in factors that influence water measurement (see inset). Some suppliers, particularly those who have water supply contracts with the Bureau of Reclamation, have accurate measurement at individual field turnouts (customer delivery points) and charge for water on a volumetric basis. Other suppliers charge on a per-acre basis and, therefore, can employ less sophisticated and less costly measurement methods and accounting techniques.

One of the challenges of water measurement is its seeming simplicity. It seems by now that simple, accurate, low-cost water measurement techniques would have been devised; however, water measurement is complicated, and measuring accurately over the wide range of conditions typically encountered in agricultural delivery systems is both technically challenging and costly. In general, the more accurate and consistent water measurement needs to be, the more it costs. In setting local water measurement policy, suppliers are faced with this tradeoff (between accuracy and cost) and must determine what measurement approaches at what cost are most appropriate for their conditions.

New state laws and regulations[6] are currently being developed that will establish new requirements for agricultural water suppliers for measuring deliveries to customers. The new regulations apply to water suppliers who serve 25,000 acres or more, and to suppliers serving between 10,000 and 25,000 acres provided that funding is provided for implementation. Essentially, the pending regulation would require suppliers to measure water deliveries to customers with an accuracy standard ranging between ±5 and ±12 percent depending on the type of measurement device and compliance approach. The regulation includes provisions for measuring to multiple customers if the supplier does not have legal access to customer measurement locations or if no practical measurement methods exist for the conditions at individual customer delivery points.

Sacramento Valley agricultural water suppliers engaged actively in the process of drafting the new regulation with the view of advancing water measurement practice in cost-effective ways to support local and regional water management objectives. However, it remains to be seen which suppliers will need to make improvements to achieve compliance, what approaches they will choose, and what costs will be incurred.

[6] Pursuant to SBx7-7, one of several bills comprising the "Comprehensive Water Package" passed in 2009, DWR has been drafting regulations applicable to certain water suppliers for measurement of water deliveries to customers.

Major Factors Affecting Water Measurement Methods and Practices

- Water Supply Source and Related Institutions. Suppliers operating under state or federal water supply contracts are required to measure water to individual customers with certain accuracy standards.
- Financial and Technical Capability. Customer delivery measurement is both costly and technically challenging. In relative terms, smaller suppliers tend to be more challenged because their financial means and technical capacity are more modest compared to larger suppliers.
- Water Supply Adequacy and Cost/Value. The need to account for water generally increases as supply becomes more limited and its cost increases or as water takes on higher value, such as in the case of water transfers. Thus, water measurement tends to become more accurate as water cost increases (with the cost of measurement also rising).
- Type of Distribution System. The two general types of distribution systems, open canal systems and pipeline systems, each have different technically viable measurement options.
- Customer Field Size and Delivery Volume. Many suppliers serve a wide range of customer field sizes, from large to very small. Sometimes it is most cost effective to measure large deliveries and simply estimate small ones.
- Water Quality. Many suppliers deal with trash, weeds, algae, sediment, and other solids suspended in the water, posing challenges to nearly all kinds of measurement devices. Where trash is an issue, devices that are less prone to plugging but may lower accuracy are more practical than highly accurate devices that must be constantly cleaned and maintained to operate properly.

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SECTION 4 Regional Sustainability and Water Use Efficiency

Sacramento Valley Regional Sustainability

Sustaining the Valley for Future Generations

The Sacramento Valley provides a wide range of ecological, economic, and social functions that are critical contributors to natural and human well-being within and beyond the valley's confines. The following description of the valley and its intrinsic values is from the *Sacramento Valley Integrated Regional Water Management Plan* (NCWA et al., 2006):

> *"The Sacramento Valley is a rich mosaic of farmlands, cities and rural communities, refuges and managed wetlands for waterfowl and shorebird habitat, and meandering rivers and streams that support numerous fisheries and wildlife. The natural and working landscape between the foothills of the Sierra Nevada and the Coast Range is dependent on the fertile lands of the Sacramento Valley floor, water supplies from rivers, streams, and the underlying groundwater basins to support and sustain a healthy and vibrant local economy and environment."*

Among the many resources that support these critical functions, water is undoubtedly the most central and important. The many natural rivers and streams that course through the valley interact with the valley's groundwater basins and provide water supplies that assist in meeting human as well as other terrestrial and aquatic species needs.

These resources are highly valued by the valley's residents who possess an innate desire to pass along to future generations a way of life unique to the valley, one based on strong connection to the land and natural environments. Rivers, streams, lakes, and reservoirs provide recreational and economic opportunities, as well as a sense of well-being.

"Sustainability" has been defined in various different ways. One widely accepted definition of sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations World Commission on Environment and Development, 1987). This broad definition is conceptually intuitive but begs for interpretation and translation into working principles that can guide decision making at all levels. This is the challenge to the Sacramento Valley – the need to recognize that sustainability is not a static condition but rather involves dynamic processes of monitoring and feedback, and the capacity to respond.

Sustainability is generally viewed as having three interrelated aspects, sometimes referred to as the "triple bottom line" or "three pillars." They are as follows:

- ✓ Economic or financial considerations
- ✓ Environmental protection and stewardship
- ✓ Society/community and individual human well-being

Over 2.2 million people inhabit the Sacramento Valley. Residents live and work in communities ranging from the metropolitan areas of Redding to the north and Sacramento to the south, smaller communities such as Colusa and Williams, and rural areas dotted throughout the valley (DWR, 2009). The economy is increasingly diversifying, and key sectors in addition to agriculture are health care, business/services, and tourism. Agriculture accounts for a majority of the economic production of the valley and is a key employer (USDA, 2008).

The valley's natural resources and quality of life continue to attract new residents in large numbers. The lack of congestion, Mediterranean climate, recreational resources, and range of rural and metropolitan opportunities are unique within the state and the nation. The region takes great pride that its agricultural output helps to feed, clothe, and shelter humankind throughout the United States and, increasingly, the world through market globalization.

The Sacramento Valley remains a key component of the Pacific Flyway as ricelands and associated irrigation canals and drains, as well as federal and state wildlife refuges, now provide important habitat. Diversions have required a number of fish passage improvements such as installation of fish screens and ladders to ensure a healthy aquatic system. Over 20 fish screen and dam modifications have been or are being made throughout the valley to reduce the entrainment of anadromous (and other) fish in irrigation diversions and to improve fish access to important production and rearing habitat. With the completion of the three large diversion fish screen projects that are being constructed and the one in its design phase, approximately 80 percent of the agricultural water diverted from the Sacramento River will flow through state-of-the-art facilities, including those listed below. Combined, over the past 2 decades, $574 million has been spent to screen irrigation diversions with a combined capacity of 13,000 cubic feet per second (Vogel, 2011) (*under construction; **in design phase):

- ✓ Anderson-Cottonwood Irrigation District
- ✓ Tehama-Colusa Canal Authority (17 member districts)*
- ✓ Glenn-Colusa Irrigation District
- ✓ M&T Chico Ranch/Llano Seco Rancho
- ✓ Gorrill Land Company (Butte Creek)
- ✓ Adams Ranch (Rancho Esquon [Butte Creek])
- ✓ Western Canal Water District (Butte Creek)
- ✓ Provident Irrigation District
- ✓ Princeton-Codora-Glenn Irrigation District
- ✓ Reclamation District 1004
- ✓ Davis Ranches (Sycamore Mutual)
- ✓ Maxwell Irrigation District
- ✓ Browns Valley Irrigation District (Yuba)
- ✓ Meridian Farms Water Company*
- ✓ Reclamation District 108
- ✓ River Garden Farms
- ✓ Pelger Mutual Water Company
- ✓ Sutter Mutual Water Company
- ✓ Pleasant Grove-Verona Mutual Water Company **
- ✓ Natomas Mutual Water Company *
- ✓ Reclamation District 2035**
- ✓ Reclamation District 999

In general, sustainable development approaches are ones that balance benefits among the interrelated economic, environmental, and social components. Depending on the area or issues at hand, it is generally true that focusing on only one of the three components will often be at the expense of one or both of the others. Tradeoffs or unintended consequences are typically the result. Such is the case in the Sacramento Valley, where agriculture is a key industry that drives much of the valley's economy and the well-being of many of its communities. The conversion of much of the valley for agriculture production beginning in the early twentieth century occurred within areas that were formerly marsh, seasonal wetlands, riparian, and valley grasslands. These areas provided habitat for various species including migratory waterfowl and numerous aquatic and terrestrial species.

Sustainability Indicators

Although specific objectives regarding sustainability in the Sacramento Valley are being defined and addressed, there is a near-term need to identify key indicators that, at a minimum, signal whether water resource conditions in the valley are improving or deteriorating, whether the water asset is being preserved over time, and whether current practices are converging with or diverging from sustainable outcomes. These indicators must consider that the hydrology of the valley has been dramatically altered through water resource development, partly by individual landowners and locally implemented projects that make water available for use within the valley and by the valley's two mega-projects, the CVP and SWP, designed primarily to export water from the Sacramento Valley to other regions in the state. These sustainability indicators must be identified and agreed upon in order to support and ensure a healthy, long-term future within the Sacramento Valley.

The following indicators are offered as a beginning point for broader dialogue within the valley and between valley and outside interests:

- ✓ Vibrant and growing economy to provide economic opportunity to the valley's growing number of residents
- ✓ Reliable, high-quality surface water and groundwater supplies to ensure that water remains adequate and suitable for the valley's beneficial uses
- ✓ Stable groundwater levels to ensure that there is no long-term overdraft of the valley's aquifers and that ecologically critical interactions between aquifers and streams are preserved
- ✓ Preservation and enhancement of aquatic and terrestrial habitats to ensure species recovery to acceptable numbers and geographic range
- ✓ Preservation of agricultural productivity and land fertility so that farming remains the mainstay of the regional economy

Water Use Efficiency

An approach and conceptual framework for water use efficiency are described in Sections 1 and 3, respectively. Their core premise is that, although opportunities to produce additional water supplies for outflow from the valley are limited, opportunities to enhance the productivity and sustainability of existing valley water uses through improved flow management are appreciable.

In general, flow management involves implementing water management practices – conservation, measurement, reuse, and conjunctive use, among others – in order to modify the location, timing, rate, and quality of flow to achieve specific purposes. One example of flow management is pumping groundwater instead of diverting surface water in order to sustain instream flows at critical times for fish. Another is to reuse drainwater for irrigation rather than to discharge it to a stream, in order to avoid or reduce streamflow warming.

This approach to water use efficiency is largely consistent with the concepts embodied in the CALFED Agricultural Water Use Efficiency (AgWUE) Program that was developed about a decade ago under the CALFED Program. The CALFED AgWUE Program, one of several integrated elements of the broader CALFED Bay-Delta Program, was the product of significant technical effort and lengthy public discourse supported by analysis of the best information available at the time. As discussed in Section 5, it is regarded as an appropriate conceptual model for water use efficiency advancement in the Sacramento Valley.

Analyzing Water Use Efficiency

Certain quantitative expressions are helpful in analyzing the characteristics and conditions of Sacramento Valley hydrologic systems and assessing possibilities for management change. These expressions are founded on the principle of conservation of mass. According to this principle, water is neither created nor destroyed as it is used, although its location and physical state over time may be altered appreciably. For analytic purposes, the principle of mass conservation is preserved through the careful application of water balances (see the Colusa Subbasin Efficiency Case Study section), a process that accounts for all inflows, outflows, and changes in water storage over time.

Historical Perspective

The concept of efficiency has long been applied to water resources and irrigation engineering. Implicitly at least, the idea of efficiency is reflected in water "duties" that were widely used in the early days of irrigation in the western states and remain in use in some areas yet today. Irrigation duties were intended to represent reasonable allowances for growing different crops under different conditions. Duties were based on the acknowledgement that, for example, long-season crops require more water than short-season crops, and that adequate irrigation of any particular crop on sandy soil required more water than for growing the same crop on heavy soil. This distinction among soils and other variable factors as they relate to the amount of water needed to grow a crop acknowledged differences in irrigation efficiency.

A wide variety of efficiency and efficiency-related expressions have been developed for irrigation design and evaluation purposes (see Table 4-1). These expressions have been developed to serve different analytic purposes and are generally distinguished by differences in the spatial and temporal scales of the efficiency analysis. Spatial scale can vary from a single irrigation furrow or border-strip to entire fields or groups of fields. Temporal scale can range from one irrigation set (typically a few hours) to an entire irrigation season, with each combination of spatial and temporal bounds being useful for certain purposes.

Efficiency Principles Applied to Water Resource Management

The initial utility of irrigation efficiency was mainly for design and management of irrigation systems at the field and project scales. The concept of efficiency has been increasingly applied over the past 2 or 3 decades to water resource management at regional and basin scales driven by the quest to close gaps between growing water demands and limited supplies. This shift has led to a strong focus on water conservation in order to reduce water demand.

One of the common assumptions about efficiency (or, more precisely, *inefficiency*) is that the portion of input not contributing to the desired output is "lost." A simple example is that of an electric motor that produces nine units of mechanical energy output for every ten units of electrical energy input. One unit of energy is lost to any further productive use primarily as heat dissipated to the atmosphere, and the motor has an efficiency of 90 percent.

Water systems do not necessarily behave like the electric motor in the example above. Water not actually consumed as it is used might or might not be lost for further productive use. As described by Seckler et al. (2003):

TABLE 4-1
Selected Common Efficiency and Related Expressions Used for Irrigation Design and Evaluation
Efficient Water Management for Regional Sustainability in the Sacramento Valley

Expression	General Definition and Utility
Conveyance Efficiency	Relates the volume of water delivered to fields or farms to the volume diverted into a conveyance facility. Used to assess the potential to reduce conveyance losses.
Application Efficiency	Relates the volume of water stored in the root zone and used by the crop to the volume applied to the field or farm. Used to assess potential to reduce irrigation application losses.
Seasonal Irrigation Efficiency	Relates the volume of water beneficially used by the crop (for ET and leaching of salts) to the volume applied to the field or farm. Used to assess the potential to reduce seasonal applied water.
Irrigation Uniformity	Relates the minimum water depth applied (usually the average of the low quarter) to the average depth applied. Used to assess the uniformity with which water is applied to an irrigated field. (Irrigation uniformity determines the potential to achieve high irrigation efficiency.)

Source: adapted from Howell (2002)

"One of the cardinal features of water use is that, when water is used, not all of it is "used up". Most of the [unconsumed] water remains in the hydrologic system, where it is available for reuse or recycling."

Despite the efforts and admonitions of many water resource researchers and practitioners (notably Willardson et al. [1994], Allen et al. [1996, 2005], Burt et al. [1997], Keller and Keller [1995], and Seckler et al. [2003], among others), the hydrologic effects of water reuse are still sometimes neglected, leading to misapplication of efficiency concepts, misunderstanding, and, in certain cases, vast overestimation of the potential of conservation to expand the useable water supply. One common mistake is to extrapolate potential *regional or basin* water savings from estimates of potential *local* efficiency improvements. This leads to the imperative that efficiency must be viewed in spatial and temporal context in order to draw valid conclusions for assessing water management practices and guiding water management policy. For purposes of conserving water that could be made available for other uses, the key question becomes, "where is water truly lost to further use?"

As described above, the Sacramento Valley, like many irrigated valleys, is a place where water reuse is not only possible, it is an intrinsic, automatic characteristic of the water delivery systems due to the way they were constructed. This "built-in" reuse feature is essential to the operation and analysis of Sacramento Valley water systems from the perspectives of water use efficiency and conservation.

Quantitative Water Use Efficiency Expressions

Certain efficiency expressions have been developed to explicitly account for water reuse in order to provide realistic estimates of potential water savings. Jensen (1977) suggested that the percentage of irrigation return flow that is reusable should be added to the irrigation outputs (in the numerator of the efficiency equation). Thus, for example, if irrigation efficiency were determined to be 60 percent, but half the 40 percent of water "lost" actually became available to downstream users, the "net efficiency" would be 80 percent (60 + 40/2 = 80%). Keller and Keller (1995) expanded this concept with their introduction of "effective efficiency" (EE) in which return flows are subtracted from the irrigation input (the denominator in the efficiency equation)[7]. Thus, in the example above, EE would be 75 percent (60/(100 - 20) x 100 = 75%). Although mathematically different, the concepts of net efficiency and EE are essentially the same, and their core principle of taking credit for irrigation return flows is pertinent to the Sacramento Valley where unconsumed water returns to the hydrologic system (surface streams or groundwater aquifers) and becomes available for use downstream, and generally does not mobilize salts or other pollutants affecting water usability.

Given these circumstances, and as previously asserted, opportunities for "real" (or "wet") water savings in the Sacramento Valley are limited to reduction of nonbeneficial consumptive water uses, such as soil evaporation and nonbeneficial weed and phreatophyte ET.

On the basis of the foregoing considerations, two quantitative water use efficiency expressions are presented here for use by Sacramento Valley water managers for evaluating agricultural (and refuge) water management. Both expressions are based on water balance principles and must be used in combination with additional information and professional judgment to provide useful guidance to water managers and policy makers; they are not complete analyses in and of themselves.

Figure 4-1 illustrates a typical water balance structure and serves as a general reference for discussion of the water use efficiency expressions. The blue box on Figure 4-1 depicts the water balance "domain" having a volume defined by horizontal and vertical bounds (which

[7] In their definition, Keller and Keller (1995) also introduced the concept of discounting water volume based on quality through the use of the leaching fraction. The idea is that as water becomes increasingly salty, it has less value for irrigation because more of it must be passed through the root zone to maintain favorable salt balance.

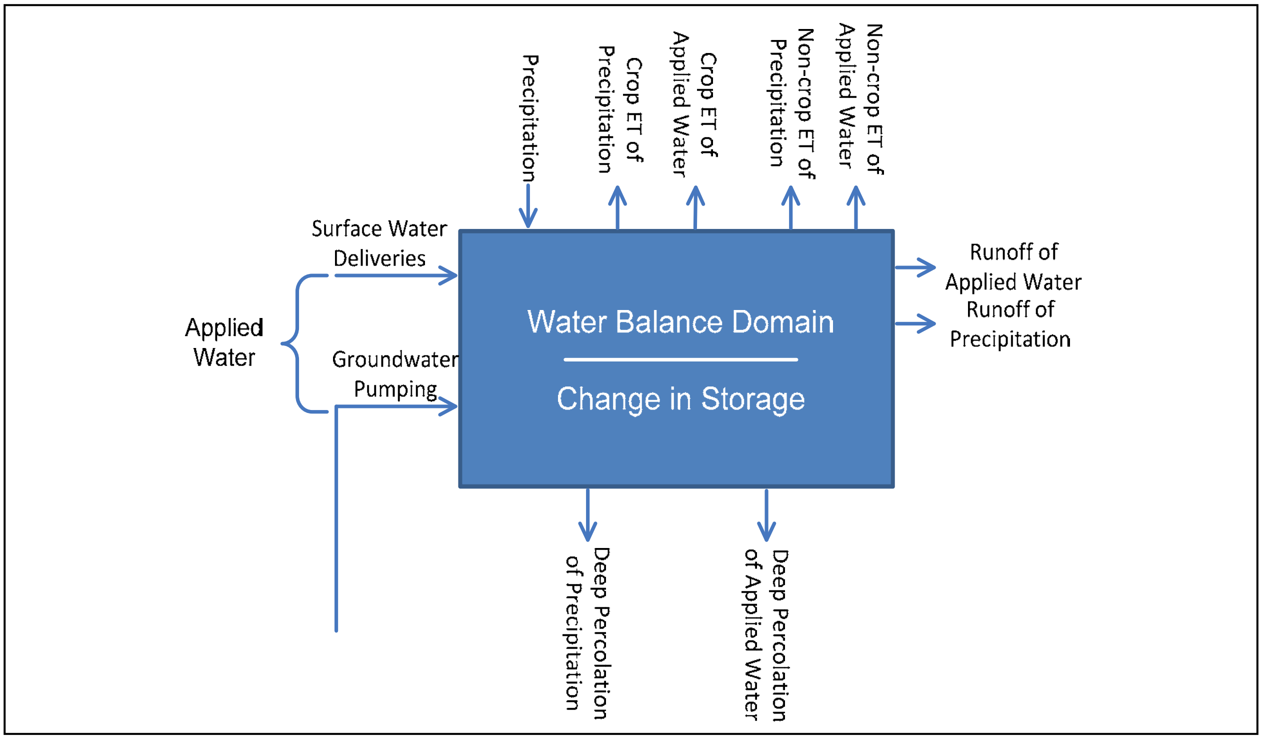

FIGURE 4-1
Typical Water Balance Structure

typically extend from the top of the plant canopy to the bottom of the root zone). The domain could represent a single irrigated field, a water supplier service area, a hydrologic subbasin, or an entire river basin. Each of the arrows represents a flow path into or out of the water balance domain.

The three inflow paths are Surface Water Deliveries, Groundwater Pumping, and Precipitation. Combined, Surface Water Deliveries, and Groundwater Pumping comprise "applied water" when working at the field or farm scale (equivalent to diverted water at the supplier scale). Outflow paths include Crop ET, which is partitioned into the portions derived from applied water and precipitation, respectively, and Non-crop ET, also partitioned into applied water and precipitation components. The other outflow paths are Runoff of Applied Water, Deep Percolation of Applied Water, Runoff of Precipitation, and Deep Percolation of Precipitation.

According to the principle of conservation of mass, over any specified time period, the sum of all inflows must equal the sum of all outflows plus or minus any change in storage within the water balance domain.

Traditional Efficiency

The first efficiency expression is referred to as "traditional efficiency" (TE), represented by the ratio of crop ET of applied water (Crop ETaw) to applied water (AW)[8] multiplied by 100:

$$TE = Crop\ ETaw / AW \times 100 \qquad (1)$$

TE indicates the percentage of applied water used for crop ET. It is useful for evaluating opportunities for re-routing flows for purposes of achieving identified Targeted Benefits (TB) and Quantifiable Objectives (QO) (see Section 5, Plan for Action, for definition and discussion of TBs and QOs). Essentially, high TE indicates that a large portion of applied water is being used by crops and, therefore, little opportunity exists for re-routing flows. Conversely, low TE indicates that a large portion of the applied water is not

[8] This ratio is also sometimes referred to as the Consumptive Use Fraction, or CUF.

being used for crop ET and that opportunities exist for re-routing flows.

Although TE is useful for revealing the potential for flow re-routing, it does not express the advisability of pursuing re-routing. This is because re-routing of flows unavoidably denotes tradeoffs: more flow at one location or time means less flow at some other location at another time. As noted above, additional analyses must be performed to reveal the environmental and economic tradeoffs involved, and then value judgments must be applied to assess the advisability of implementing efficiency measures to achieve re-routing.

Re-routing of flows unavoidably denotes tradeoffs: more flow at one location or time means less flow somewhere else, sometime.

For example, applying efficiency measures to reduce applied water to achieve increased streamflow in fish-sensitive streams or stream segments (a common and important environmental restoration objective) denotes reducing streamflow at other locations and reducing deep percolation to groundwater. What impacts will occur, and when, from these reductions in applied water? What are the related economic and environmental costs? How do the costs relate to the benefits? And, will the new streamflow and groundwater recharge regimes be sustainable? These questions must be answered through supporting analyses in order to make informed decisions regarding the advisability of pursuing the potential re-routing.

Effective Efficiency

The second efficiency expression is based on the concept of EE (discussed above) and is most useful for revealing the potential for real water savings. It has the following form:

EE = Crop ETaw/(AW – Runoff of AW – Deep Percolation of AW) x 100 (2)

EE is similar to TE, except that credit is taken for runoff and deep percolation of applied water because these flows return to the system and contribute to downstream supply either for water users in the Sacramento Valley or for Bay-Delta inflow. The higher the EE percentage, the lower the potential for real water savings. In fact, if non-crop ET of applied water is zero, and runoff and deep percolation of applied water are fully reuseable, then EE will be equal to 100 percent denoting zero potential real water savings.

Colusa Subbasin Efficiency Case Study

Water balances are gradually gaining acceptance among Sacramento Valley water managers as useful tools for analyzing system performance and revealing water management improvement opportunities. Most water balances have been prepared at the supplier level and use either an annual or monthly time step over a period of years. Correctly defining the spatial and temporal bounds of a water balance are critical first steps, taking into account the availability of historical data as well as the purpose of the analysis.

One hydrologic subregion of the valley that has a reasonably good historical data set is the Colusa Subbasin, which encompasses a total of about 1.1 million acres, including several large agricultural water suppliers, some small suppliers, and lands that are served by groundwater only. The irrigated area within the Colusa Subbasin averaged 563,800 acres (over the 1993 through 2003 period of analysis; see below) and receives water primarily from the Sacramento River through a number of major and minor diversions. Diverted water is used to irrigate crops and to supply managed wetlands and wildlife habitat areas, with all unconsumed water either percolating through the root zone into the underlying groundwater system or draining back to the river via the Colusa Basin Drain near Knights Landing (see Figure 4-2).

Given the availability of adequate data, a water balance was prepared for the irrigated portion of the Colusa Subbasin to demonstrate the analytic technique to readers and to reveal insights into regional-scale efficiency in the Sacramento Valley. The water balance was developed for the period 1993 through 2003 on a monthly time

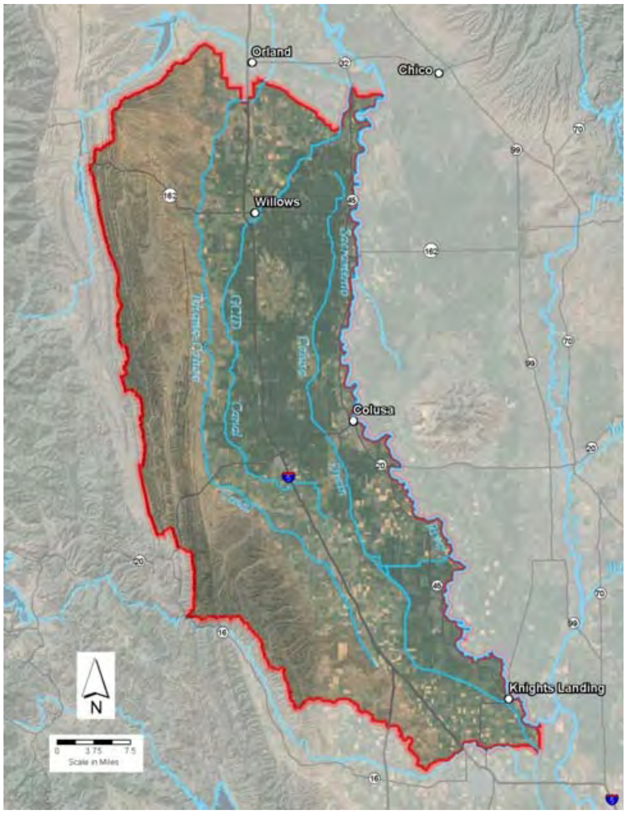

FIGURE 4-2
Colusa Subbasin

was prepared using readily available data for the Colusa Subbasin, including the following:

- ✓ DWR land use surveys
- ✓ Monthly surface water diversion and delivery data from the Bureau of Reclamation and DWR
- ✓ Flow data from DWR
- ✓ Reference ET from California Irrigation Management Information System
- ✓ Crop coefficients from the Cal Poly Irrigation Training and Research Center and other sources
- ✓ Daily precipitation data from California Irrigation Management Information System
- ✓ Onfarm efficiency estimates developed by DWR

In addition, certain assumptions were made regarding effective precipitation, groundwater pumping, root zone soil moisture available to meet crop water needs, and deep percolation.

Figure 4-3 illustrates a schematic diagram of the Colusa Subbasin water balance. The area was treated as one accounting center (or domain, shown within the dashed line on Figure 4-3), with the inflows and outflows as shown on the illustration and listed in Table 4-2. According to the principle of conservation of mass, the sum of inflows must equal the sum of outflows plus any change in storage within the water balance volume, with the volume defined as the surface area of the basin times the root zone depth. In this particular case, because of unknown winter tributary inflow from natural streams, the balance

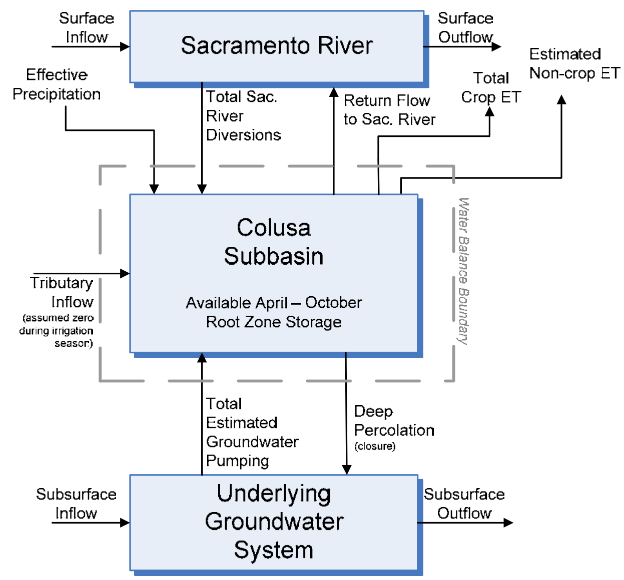

FIGURE 4-3
Schematic of Colusa Subbasin Water Balance

was completed for the irrigation season only, from April through October, corresponding to the period of diversion specified in most of the water supply contracts in the Colusa Subbasin.

Table 4-2
Colusa Subbasin Water Balance Inflows and Outflows
Efficient Water Management for Regional Sustainability in the Sacramento Valley

Inflows	Outflows
Total Diversions	Crop ET
Groundwater Pumping	Non-crop ET
Effective Precipitation	Return Flow
Tributary Inflow (assumed to be zero during the irrigation season)	Deep Percolation (closure)[a]
Root Zone Storage[b]	

[a] Conceptually, the closure term represents deep percolation, but it also includes any error in the estimated and measured values representing the other water balance terms.

[b] Regarded as an inflow source because root zone storage is depleted over the irrigation season and is recharged outside of the irrigation season.

Seasonal water balance results are summarized in Table 4-3, including the seasonal total of each inflow and outflow to the basin, estimated change in root zone storage, and calculated TE and EE values[9]. Over the 10-year period (excluding 1994, as discussed above), the average TE at the basin scale was 80 percent, ranging between 76 and 89 percent. These values suggest that, on average, about 20 percent of the water diverted into the basin is not consumed by crops, and either flows out of the basin, percolates to underlying groundwater, or is used for non-crop ET. Reduction in any of these flow paths through efficiency measures would allow diversions from the Sacramento River (or groundwater pumping) to be reduced. Reductions in diversions would be at the expense of reduced deep percolation to groundwater and basin outflow, and increased water salinity in the lower basin, which could become excessive.

Over the same period, EE averaged 94 percent, ranging from 91 to 95 percent. Note that the only factor preventing EE from reaching 100 percent is not taking credit for non-crop ET, which is a judgment call. To the extent that non-crop ET provides environmental or other benefits, it could be counted among the outflows, pushing EE toward 100 percent.

Although detailed, documented information on local (farm and water supplier) efficiencies within the basin is not available for comparison to the basin efficiencies described above, some useful general contrasts can be made. The most extensive crop in the basin is rice, which, as previously noted, has an average water delivery of 5 to 5.5 acre-feet per acre. Seasonal rice ET is typically about 3.3 acre-feet per acre, indicating an average traditional efficiency of between 60 and 66 percent. Other crops would be expected to have higher average efficiencies relative to rice, typically in the range of 70 to 75 percent. The fact that basin efficiencies are higher than field efficiencies within the basin is explained by water reuse, where water “lost” from upper fields is recovered and reused on lower fields. The Colusa Basin Drain is the principal waterway that serves to collect runoff from the upper basin and redistribute it to users lower in the basin.

Additional detail regarding the Colusa Subbasin water balance is provided in Appendix A.

[9] It is important to recognize the uncertainty in the water balance quantities and calculated TE and EE values. A detailed assessment of uncertainty was not made; however, based on professional judgment, the actual TE and EE values are likely to fall within ±10 percent of the values shown, with TE and EE being limited to a theoretical maximum of 100 percent.

TABLE 4-3
Colusa Subbasin Seasonal Water Balance Summary
Efficient Water Management for Regional Sustainability in the Sacramento Valley

Year	Total Sacramento River Diversions (AF)	Tributary Inflow (AF)	Estimated Total Groundwater Pumping (AF)	Total Crop ET (AF)	Effective Precipitation (AF)	ET of Applied Water (AF)	Apr-Oct Traditional Efficiency (%)	Return Flow to Sacramento River (AF)	Available Apr-Oct Root Zone Storage (AF)	Estimated Non-Crop ET (AF)	Deep Percolation Apr-Oct (AF)	Apr-Oct Effective Efficiency (%)
1993	1,122,413	0	423,034	1,473,969	96,596	1,377,373	89%	109,900	40,226	56,654	1,520	93%
1994	Shasta Critical Year not used in analysis											
1995	1,053,367	0	426,673	1,387,045	86,899	1,300,146	88%	110,300	60,930	53,876	15,718	92%
1996	1,152,640	0	428,810	1,402,794	110,576	1,292,218	82%	128,600	34,307	54,564	106,069	94%
1997	1,219,189	0	524,769	1,474,025	33,027	1,440,998	83%	190,500	18,119	57,357	55,103	95%
1998	1,037,572	0	421,885	1,338,386	138,115	1,200,271	82%	112,900	66,822	51,580	94,706	91%
1999	1,375,108	0	541,759	1,498,651	33,854	1,464,798	76%	235,000	21,956	58,117	158,952	95%
2000	1,315,856	0	509,146	1,462,566	63,034	1,399,532	77%	297,900	36,712	55,641	71,928	94%
2001	1,352,257	0	570,203	1,503,334	37,991	1,465,343	76%	348,300	29,424	57,218	51,598	94%
2002	1,363,630	0	546,094	1,482,387	19,448	1,462,939	77%	253,300	13,261	56,232	137,253	95%
2003	1,261,394	0	487,320	1,428,323	81,060	1,347,263	77%	190,874	20,722	53,997	156,580	95%
Average	1,225,343	0	487,969	1,445,148	70,060	1,375,088	80%	197,757	34,248	55,524	84,943	94%

Note:
AF = acre-feet

Framework for Advancing Agricultural Water Use Efficiency

As noted in the preceding section, the CALFED AgWUE Program is regarded as an appropriate conceptual model for advancing agricultural water use efficiency in the Sacramento Valley. An important feature of that program was its distinction between recoverable and irrecoverable water losses, and the acknowledgment that opportunities to produce appreciable additional water supplies through efficiency measures in the Sacramento Valley are limited. Emphasis was appropriately placed on water use efficiency as a means of managing flows within the valley to achieve primarily environmental benefits. Additionally, the program employed a sound technical methodology for estimating the extent to which agricultural water users (suppliers and producers) could contribute to meeting identified goals. These essential features are attractive to Sacramento Valley water managers because they allow for sustained, undiminished agricultural water supplies and production while seeking meaningful environmental restoration and enhancement. This balance is foundational for regional sustainability.

Targeted Benefits and Quantifiable Objectives

Potential advancements in water use efficiency are defined by TBs and QOs (CALFED, 2000). In general, TBs represent changes in existing hydrology that would help to achieve environmental enhancements or address known environmental issues. Typical TBs include increasing stream flows and improving water quality at particular places and times to benefit certain species. QOs are the nexus between TBs and water management. They are quantitative estimates of the extent to which water use efficiency measures could potentially contribute to achieving the TBs without infringing on agricultural water supplies.

Table 5-1 provides a list of the TB categories by Sacramento Valley subregion as they were identified during CALFED planning. The subregions are illustrated on Figure 5-1. TBs fall into three broad categories, with two of the categories being further divided into subcategories. A brief description of each of the broad categories follows:

- ✓ Flow Timing – improving instream conditions primarily for anadromous fish species by increasing streamflow at critical times and locations. (This TB implies conjunctive operation of surface water and groundwater systems, and overlaps to some extent with “Water Quantity” benefits below.)

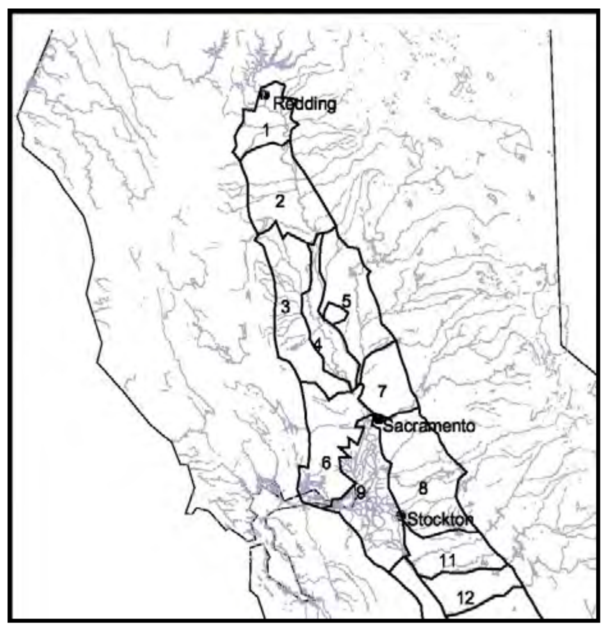

FIGURE 5-1
Sacramento Valley Targeted Benefit Subregion Boundaries

TABLE 5-1
Categories of Targeted Benefits with the Sacramento Valley by Subregion
Efficient Water Management for Regional Sustainability in the Sacramento Valley

		Abbreviated Categories of Targeted Benefits											
			Water Quality							Water Quantity			
Subregion		Flow/Timing	Nutrients	Group A Pesticides	Pesticides	Salinity	Native Constituents	Temperatures	Sediment	Long-term Diversion Flexibility	Unproductive Evaporation	Short-term Diversion Flexibility	Flows to Salt Sinks
1	Redding Basin	✓								✓	✓		
2	Sacramento Valley, Chico Landing to Red Bluff	✓			✓			✓		✓	✓		
3	Sacramento Valley, Colusa Basin	✓		✓	✓	✓				✓	✓		
4	Mid-Sacramento Valley, Chico Landing to Knights Landing	✓			✓	✓				✓	✓		
5	Lower Feather River and Yuba River	✓		✓	✓	✓		✓		✓	✓		
6	Sacramento Valley Floor, Cache Creek, Putah Creek, and Yolo Bypass	✓			✓					✓	✓		
7	Lower Sacramento River below Verona	✓			✓	✓		✓		✓	✓		

✓ Indicates one or more TB in the subregion and category.

Source: http://calwater.ca.gov/content/Documents/library/WUE/qo_detail.pdf at page 8.

- Water Quality – protecting or improving water quality to support beneficial uses and to restore or enhance instream ecology.
- Water Quantity – generating additional water supplies through "Diversion Flexibility," which denotes conjunctive operations, and by reducing unproductive evaporation and flows to salt sinks. (No water is lost to salt sinks in the Sacramento Valley.)

The TBs and QOs identified during CALFED planning were based on the best data available at that time and were widely recognized as needing refinement pending acquisition of better data. Together with state and federal agencies, Sacramento Valley water managers are moving ahead with the adaptation and refinement of TBs and QOs over time. NCWA has compiled the following principles to guide this process:

- TBs and QOs should be established through the cooperative efforts of representatives from within and outside the Sacramento Valley.
- TBs and QOs should be continually reviewed and refined through application of best available, objective science, supported by

adequate levels of data collection, monitoring, and research.

- ✓ TBs should be placed into the realm of agricultural water use efficiency only if a clear mechanistic connection between a TB and agricultural water use efficiency measures can be demonstrated.
- ✓ Defining and achieving QOs should not imply or result in any net reduction in agricultural water supply relative to recent baseline conditions.
- ✓ Defining and achieving QOs should not imply or result in adverse impacts that threaten the regional sustainability or self-sufficiency of the Sacramento Valley.
- ✓ To the extent that water use efficiency measures that can contribute to achieving QOs are locally cost effective, those costs should be borne by local interests; beyond the threshold of local cost effectiveness, costs must be borne by other beneficiaries.

Progress, Challenges, and Next Steps

The *Sacramento Valley Integrated Regional Water Management Plan* (NCWA et al., 2006) was a collaborative effort among Sacramento River Settlement Contractors, the Bureau of Reclamation, and DWR to address certain water management issues. One element of the regional plan was identification of 18 specific efficiency measures that certain contractors could implement to contribute to achieving 21 different TBs (note that some measures contribute to multiple TBs). The water use efficiency measures generally fall into the following categories:

- ✓ Canal lining or piping measures to reduce distribution system seepage and leakage
- ✓ System automation and regulating reservoirs to reduce system spills
- ✓ New groundwater production wells to expand conjunctive management capacity
- ✓ Drainwater recycling

Although none of these measures would generate additional water supplies at the basin scale, they all would enable the re-routing of flows and increase the capacity to temporarily generate additional water supplies at critical times. Some of the 18 identified measures have been implemented, but most are held up pending acquisition of funding and environmental permitting.

Recognizing that potential water use efficiency improvements have statewide as well as local and regional benefits, a challenge to Sacramento Valley water managers is to develop coalitions within and outside the valley to garner the necessary resources to advance water use efficiency for achieving regional sustainability and statewide benefits.

NCWA has identified a number of near-term priority actions that will enhance the technical basis for moving ahead with water use efficiency initiatives as resources are made available. They are as follows:

- ✓ Developing water balances for the Sacramento Valley and its hydrologic regions and subregions in order to better define and understand the valley's hydrology and existing water management effectiveness
- ✓ Cooperating with and contributing to research initiatives with University of California Cooperative Extension, the California Rice Commission, and others to better define the valley's water requirements and supplies, and objectives for sustainable development
- ✓ Complying with new regulations for measurement of water deliveries to agricultural water users
- ✓ Continuing efforts to develop regional and subregional groundwater models to better define groundwater conditions and conjunctive water management parameters, including the valleywide SACFEM, various local (typically county scale) applications of the Integrated Groundwater and Surface Water Model, and others

- ✓ Continuing collaborative efforts with CVP and SWP operators and others to identify and implement re-operation of Sacramento Valley reservoirs for regional and statewide water supply and environmental benefits
- ✓ Implementing recommendations for recovery of anadromous fisheries identified by Dave Vogel in his recent report prepared for NCWA (Vogel, 2011)

SECTION 6 Conclusions

The Sacramento Valley hosts environmental, agricultural production, recreational, and social functions that are strongly water-dependent. Maintaining these functions to achieve regional sustainability and self-sufficiency is the overarching goal of Sacramento Valley water managers, demanding wise water stewardship and maximum water use efficiency.

Environmental, agricultural, and recreational water uses in the Sacramento Valley are highly inter-dependent, linked through the process of water reuse, where return flows from upper water users become the supplies for users lower in the basin. Reuse is the result of constructed water conveyance systems being intertwined with natural systems that collect surface runoff. Additionally, the valley is generally underlain by high-quality groundwater aquifers that are recharged in part by deep percolation of water applied for irrigation of crops and wildlife habitat areas. Given this “built in,” automatic reuse feature, the only water lost in the valley is water consumptively used. All other water remains available for use and eventually contributes to outflow into the Bay-Delta.

Other than through reducing consumptive water use, which denotes diminished economic production and environmental values, opportunities to produce additional outflow from the Sacramento Valley are limited. In fact, the only way to increase valley outflow without compromising productivity is to reduce consumptive uses that have little or no value, such as soil evaporation and nonbeneficial ET.

Although opportunities to increase Sacramento Valley basin outflow are limited, appreciable opportunities exist to restore and enhance environmental quality by implementing water use efficiency measures designed to modify the way that water flows through the valley as it is used. This includes changing flow routing, timing, and quality to achieve environmental benefits. Additionally, by exercising groundwater storage within defined, acceptable limits, it is possible to temporarily increase surface water supplies at critical times for in-valley environmental or economic uses, or for increased Bay-Delta inflow.

Founded on conventions developed under the CALFED AgWUE Program about a decade ago, Sacramento Valley water managers have adopted TBs and QOs as a basis for guiding water use efficiency initiatives. Water managers have dedicated themselves to a process involving ongoing cooperation with various state and federal agencies to develop and refine TBs and QOs according to certain working principles. Considering that achieving the potential environmental and water supply values defined by TBs and QOs would have statewide as well as local and regional benefits, the challenge to Sacramento Valley water managers is to develop coalitions within and outside the valley to garner the necessary resources to implement water use efficiency measures.

Looking forward, the valley’s water managers – farmers and suppliers – recognize the need to continue to improve water use efficiency within a framework formed by the foundational principles of regional sustainability and self-sufficiency, and acknowledgement of the physical conditions that define the range of possible water management improvements. In adopting this broad definition of water use efficiency, valley water managers reject narrow definitions that fail to account for the multiple physically and economically interrelated uses that exist in the valley. Such definitions are not adequate because, in general, they fail to consider the tradeoffs that can occur among uses and users when efficiency measures are implemented.

Working policies and conventions that embody regional sustainability and self-sufficiency principles need to be developed by valley water managers working together with local and state governments. In the meantime, valley water managers have identified the following sustainability indicators to serve as guides:

- ✓ Vibrant and growing economy to provide economic opportunity to the valley’s residents
- ✓ Reliable, high-quality surface water and groundwater supplies to ensure that water remains adequate and suitable for the valley’s beneficial uses
- ✓ Stable groundwater levels to ensure that there is no long-term overdraft of the valley’s aquifers and that ecologically critical interactions between aquifers and streams are preserved
- ✓ Preservation and enhancement of aquatic and terrestrial habitats to ensure species recovery to acceptable numbers and geographic range
- ✓ Preservation of agricultural productivity and land fertility so that farming remains the mainstay of the regional economy

All Sacramento Valley water use efficiency initiatives should contribute to maintenance or improvement of these conditions.

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Appendix A
Colusa Basin Efficiency Case Study

Colusa Subbasin Efficiency Case Study

A water balance was prepared for the Colusa Subbasin using available data from multiple sources. The water balance was developed for the period 1993 through 2003 on a monthly time step, with 1994 excluded because of limited land use data and deficient water supplies in that year[10]. The water balance was prepared using readily available data for the Colusa Subbasin, including the following:

- ✓ 1993, 1997, 1998, and 2003 land use surveys prepared by California Department of Water Resources (DWR)
- ✓ Monthly surface water diversion and delivery data from the Bureau of Reclamation and DWR
- ✓ Flow data from DWR
- ✓ Reference evapotranspiration (ETo) from California Irrigation Management Information System (CIMIS)
- ✓ Crop coefficients from Cal Poly Irrigation and Training Research Center and Davids Engineering
- ✓ Daily precipitation data from CIMIS
- ✓ On-farm efficiency estimates developed by DWR

In addition, certain assumptions were made regarding effective precipitation, groundwater pumping, soil moisture in the root zone available to meet crop water needs, and deep percolation. These assumptions and a description of the data used in the analysis are described below.

Data

Land use surveys conducted by DWR identified the acreage for the various crops grown within Colusa and Glenn Counties for 1993, 1998, and 2003, and within Yolo County for 1997. These surveys also identified, to the extent possible, the acreages served by surface water, groundwater, or mixed water sources. For the purposes of the water balance, data for the years between 1993, 1998, and 2003 were estimated using linear interpolation.

Surface water diversion and delivery data were obtained from the Bureau of Reclamation and DWR. These data include diversions from the Sacramento River for all district and individual Settlement Contractors and all water service contractors within the Colusa Subbasin.

Discharge data for the Colusa Basin Drain at the Knights Landing Outfall Gates were obtained from DWR. During the irrigation season, the majority of the outflow from the Colusa Subbasin returns to the Sacramento River through these outfall gates. However, during high-flow periods, outflow from the Colusa Subbasin may also flow through the Knights Landing Ridge Cut to the Tule Canal and the Yolo Bypass returning to the Sacramento River near Rio Vista.

Monthly ETo data were developed for the years 1993 through 2003 on the basis of daily ETo data for CIMIS stations at Davis, Gerber, Durham, Nicholas, Colusa, and Orland. The daily values for the six CIMIS stations were averaged in order to estimate the average daily ETo within the Colusa Subbasin. These daily values were then summed to determine the average monthly ETo.

Crop coefficients based on SEBAL data developed by Davids Engineering were used together

[10] 1994 was a Shasta Critical Year, triggering supply curtailments under the Sacramento River Settlement Contracts and the Discretionary contracts administered by the Bureau of Reclamation. Settlement Contractors were limited to 75 percent of their Contract Supplies, and Discretionary Contracts such as those within the Tehama-Colusa Canal Authority and the Colusa Drain Mutual Water Company received only 35 percent of their Contract Supplies.

with the CIMIS ETo data to estimate monthly evapotranspiration (ET) for each crop. For crops where the SEBAL coefficients were not available, coefficients developed by the Cal Poly Irrigation and Training Research Center (ITRC) were used.

Daily precipitation data recorded at CIMIS Stations Davis, Gerber, Durham, Nicholas, Colusa, and Orland were obtained. These data were used to develop estimates of effective precipitation and soil moisture content, as discussed further below.

On-farm efficiencies developed by DWR were obtained. These on-farm efficiencies together with estimated crop water requirements were used to estimate groundwater pumping.

The on-farm efficiencies developed by DWR range from approximately 57 percent for rice to approximately 80 percent for vineyards and certain tree crops. According to DWR's on-farm efficiency estimates and the 1993, 1998, and 2003 land use survey data, the average on-farm efficiency within the Colusa Subbasin is approximately 65 percent.

Water Balance

A schematic diagram of the Colusa Subbasin water balance is illustrated on Figure A-1. The area was treated as one accounting center (shown within the dashed line on Figure A-1), with the inflows and outflows as shown on the illustration and listed in Table A-1. According to the principle of conservation of mass, the sum of inflows must equal the sum of outflows plus any change in storage within the water balance volume, with the volume defined as the surface area of the basin times the root zone depth. In this particular case, because of unknown winter tributary inflow from natural streams, the balance was completed for the irrigation season only, from April through October, corresponding to the period of diversion specified in most of the water supply contracts in the basin.

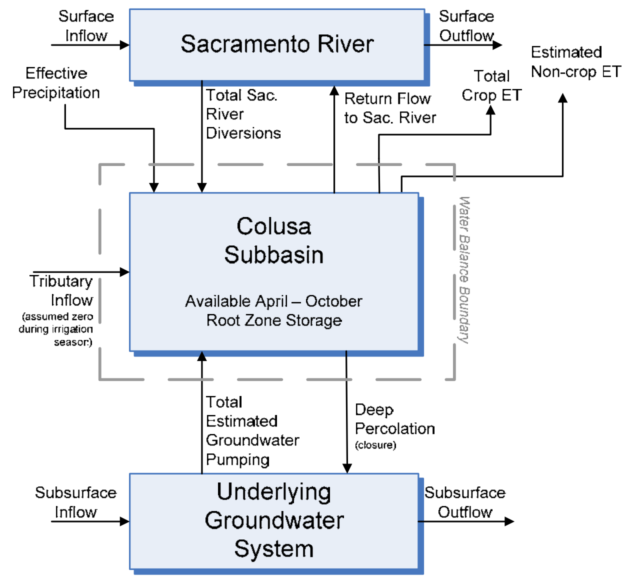

FIGURE A-1.
Schematic of Colusa Subbasin Water Balance

TABLE A-1
Colusa Subbasin Water Balance Inflows and Outflows
Efficient Water Management for Regional Sustainability in the Sacramento Valley – Appendix A

Inflows	Outflows
Total Diversions	Crop ET
Groundwater Pumping	Non-crop ET
Effective Precipitation	Return Flow
Tributary Inflow (assumed to be zero during the irrigation season)	Deep Percolation (closure) [a]
Root Zone Storage[b]	

[a] Conceptually, the closure term represents deep percolation, but it also includes any error in the estimated and measured values representing the other water balance terms.

[b] Regarded as an inflow source because root zone storage is depleted over the irrigation season and is recharged outside of the irrigation season.

Inflows

Total Diversions – Total diversions were developed by using the monthly records of diversions from the Sacramento River obtained from Bureau of Reclamation and DWR.

Groundwater Pumping – Groundwater pumping was estimated by using crop water requirements and DWR's estimated on-farm efficiencies, and the water source information from the DWR land use surveys. For lands identified as receiving both surface water and groundwater, it was assumed that surface water was augmented by groundwater on a portion of the lands. The portion of lands receiving surface water was assumed to be equal to the supply available under the contract of the water supplier providing water to the lands.

Effective Precipitation – Effective precipitation was estimated by using average daily precipitation data from CIMIS. Irrigation season precipitation was considered effective if daily precipitation were equal to or greater than 0.25 inch. Because rice is grown in flooded basins, precipitation falling on rice fields generally results in either increased runoff or reduced deliveries to fields. Therefore, precipitation falling on flooded rice fields was not included in the estimates of effective precipitation.

Tributary Inflow – For the purposes of the water balance, tributary inflow was considered to be zero during the irrigation season.

Water or moisture stored in the soil profile from precipitation or irrigation events prior to the irrigation season that remains within the root zone is available to meet crop ET requirements. For the purposes of the water balance, root zone storage was estimated by using CIMIS precipitation data assumptions for the amount of pre-irrigation season rainfall remaining in the root zone. It was assumed that a portion of the precipitation falling in January, February, and March does not run off or percolate beyond the root zone and is available to meet crop ET in April.

Outflows

Crop ET – Total crop ET was calculated by using crop data from the DWR land use surveys, monthly ETo developed from the CIMIS data, and the SEBAL and ITRC crop coefficients.

Non-crop ET – Non-crop ET includes surface evaporation from canals and ditches within the Colusa Subbbasin and ET by non-crop vegetation along those canals and ditches. Non-crop ET was estimated using CIMIS data and crop coefficients, and assuming a portion of the cropped lands is either open water or riparian vegetation.

Return Flow – Return flow is based on the discharge to the Sacramento River through the Knights Landing Outfall Gates reported by DWR. Return flows do not include water discharged to the Tule Canal and Yolo Bypass via the Knights Landing Ridge Cut.

Water Balance Summary

Seasonal water balance results are summarized in Table A-2 with column headings defined in Table A-3. The seasonal total of each inflow and outflow to the basin, estimated change in root zone storage, and calculated basin efficiency are included. Efficiency was calculated using a traditional definition according to which no credit is taken for the return flow to the Sacramento River or deep percolation to groundwater. Effective efficiency, according to which credit for outflows is taken, was also calculated. Over the 10-year period (excluding 1994, as discussed above), the average traditional efficiency at the basin scale was 80 percent, ranging between 76 and 89 percent. Over the same period, effective efficiency averaged 94 percent, ranging from 91 to 95 percent.

TABLE A-2
Colusa Subbasin Seasonal Water Balance Summary
Efficient Water Management for Regional Sustainability in the Sacramento Valley – Appendix A

Year (A)	Total Diversions (B)	Tributary Inflow (C)	Groundwater Pumping (D)	Crop ET (E)	Effective Precip. (F)	ETAW (G)	Traditional Efficiency (H)	Return Flow (I)	Root Zone Storage (J)	Non-Crop ET (K)	Deep Percolation (L)	Effective Efficiency (M)
1993	1,122,413	0	423,034	1,473,969	96,596	1,377,373	89%	109,900	40,226	56,654	1,520	93%
1994	Shasta Critical Year not used in analysis											
1995	1,053,367	0	426,673	1,387,045	86,899	1,300,146	88%	110,300	60,930	53,876	15,718	92%
1996	1,152,640	0	428,810	1,402,794	110,576	1,292,218	82%	128,600	34,307	54,564	106,069	94%
1997	1,219,189	0	524,769	1,474,025	33,027	1,440,998	83%	190,500	18,119	57,357	55,103	95%
1998	1,037,572	0	421,885	1,338,386	138,115	1,200,271	82%	112,900	66,822	51,580	94,706	91%
1999	1,375,108	0	541,759	1,498,651	33,854	1,464,798	76%	235,000	21,956	58,117	158,952	95%
2000	1,315,856	0	509,146	1,462,566	63,034	1,399,532	77%	297,900	36,712	55,641	71,928	94%
2001	1,352,257	0	570,203	1,503,334	37,991	1,465,343	76%	348,300	29,424	57,218	51,598	94%
2002	1,363,630	0	546,094	1,482,387	19,448	1,462,939	77%	253,300	13,261	56,232	137,253	95%
2003	1,261,394	0	487,320	1,428,323	81,060	1,347,263	77%	190,874	20,722	53,997	156,580	95%
Average	1,225,343	0	487,969	1,445,148	70,060	1,375,088	81%	197,757	34,248	55,524	84,943	94%

Note:
All quantities in acre-feet except as noted.

TABLE A-3
Colusa Subbasin Seasonal Water Balance Summary – Column Explanation
Efficient Water Management for Regional Sustainability in the Sacramento Valley – Appendix A

Column	Column Title	Description
A	Date	Month and year
B	Total Diversions	Total diversions from the Sacramento River to the Colusa Subbasin as measured and reported by Bureau of Reclamation or DWR.
C	Tributary Inflow	Inflow from tributaries to the Colusa Basin Drain. Assumed to be zero for the months April through October.
D	Groundwater Pumping	Estimated total groundwater pumping for irrigation purposes within the Colusa Subbasin.
E	Crop ET	Total April to October ET for crop and refuge lands within the Colusa Subbasin. Calculated by using daily reference ET from CIMIS and crop coefficients developed by Davids Engineering or the Cal Poly ITRC.
F	Effective Precip	Precipitation occurring during the irrigation that is available to meet crop ET. For the purposes of this analysis, precipitation is considered effective only when the average daily precipitation is greater than 0.25 inch. Precipitation falling on flooded rice fields is not considered to be effective.
G	ETaw	Evapotranspiration of applied water calculated as crop ET minus effective precip limited to the total amount of applied water. ((E-F) ≤ (B+D))
H	Traditional Efficiency	Calculated as ETaw divided by total diversions plus groundwater pumping. (G ÷ (B+C+D)
I	Return Flow	Total outflow from the Colusa Subbasin returned to the Sacramento River flow at the Knights Landing Outfall Gates as reported by DWR.
J	Root Zone Storage	Moisture stored in the root zone available to meet crop ET. Estimated by summing 20 percent of total March precipitation, 10 percent of total February precipitation, and 5 percent of January precipitation. Although moisture stored in soils of rice fields affects the amount of water required to be delivered to the field; for the purposes of this study, it is assumed root zone storage is not available to meet crop ET for rice.
K	Non-crop ET	Estimated evaporation from water surface of conveyance and drainage canals and ET of vegetation in and adjacent to canals and ditches.
L	Deep Percolation	Closure term for Colusa Subbasin mass balance. Calculated as the difference between total irrigation season inflow (total diversions plus tributary inflow plus groundwater pumping) minus total irrigation season outflow (ETaw plus return flow plus non-crop ET). ((B+C+D)-(G+I+K))
M	Effective Efficiency	Effective efficiency assumes that in addition to ETaw, flow returning to the Sacramento River and percolating to usable groundwater aquifers is beneficial. Therefore, effective efficiency is calculated as ETaw divided by the sum of total diversion, groundwater pumping plus root zone storage, minus return flow and deep percolation. (G ÷ (B+C+D+J-I-K)

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