Phase 2: Draft Study Plan

Almond Field Study

Revised Draft

Subject to Revision

SAN JOAQUIN RIVER
RESTORATION PROGRAM

Revised Draft
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List of Abbreviations and Acronyms

ac	acre
Act	San Joaquin River Restoration Settlement Act
Cal Poly	California Polytechnic State University, San Luis Obispo
cm	centimeter
CF	capillary fringe
Court	United States Eastern District Court of California
CVP	Central Valley Project
ET	evapotranspiration
FWA	Friant Water Authority
g	grams
GPS	global positional system
lb	pound
meq	milliequivalents
mmhos	millimhos
NRCS	Natural Resources Conservation Service
NRDC	Natural Resources Defense Council
PG	Parcel Group
ppm	parts per million
Reclamation	United States Bureau of Reclamation
RWA	Recovered Water Account
SCTFG	Seepage and Conveyance Technical Feedback Group
Secretary	United States Secretary of the Interior
SJRRP	San Joaquin River Restoration Program
SMP	Seepage Management Plan
SWRCB	State Water Resources Control Board
TDR	time-domain reflectometry
UC	University of California
UCCE	University of California Cooperative Extension
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture

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1.0 Background

In 1988, a coalition of environmental groups, led by the Natural Resources Defense Council (NRDC) filed a lawsuit, known as NRDC, et al., v. Kirk Rodgers, et al., challenging the renewal of long-term water service contracts between the United States and the Central Valley Project (CVP) Friant Division contractors. On September 13, 2006, after more than 18 years of litigation, the Settling Parties, including NRDC, Friant Water Authority (FWA), and the U.S. Departments of the Interior and Commerce, agreed on the terms and conditions of a Settlement subsequently approved by the U.S. Eastern District Court of California (Court) on October 23, 2006. The San Joaquin River Restoration Settlement Act (Act), included in Public Law 111-11 and signed into law on March 30, 2009, authorizes and directs the Secretary of the Interior (Secretary) to implement the Settlement. The Settlement establishes two primary goals:

- Restoration Goal – To restore and maintain fish populations in "good condition" in the main stem San Joaquin River below Friant Dam to the confluence of the Merced River, including naturally reproducing and self-sustaining populations of salmon and other fish

- Water Management Goal – To reduce or avoid adverse water supply impacts on all of the Friant Division long-term contractors that may result from the Interim and Restoration flows provided for in the Settlement

To achieve the Restoration Goal, the Settlement calls for releases of water from Friant Dam to the confluence of the Merced River (referred to as Interim and Restoration flows), a combination of channel and structural modifications along the San Joaquin River below Friant Dam, and reintroduction of Chinook salmon. Restoration Flows are specific volumes of water to be released from Friant Dam during different water year types, according to Exhibit B of the Settlement and began on January 1, 2014. The Water Rights Order dated October 21, 2013 is a long-term authorization to modify the Bureau of Reclamation's (Reclamation) water rights to implement Restoration Flows. Interim Flows were experimental flows that began in 2009 and continued until Restoration Flows were initiated, with the purpose of collecting relevant data concerning flows, temperatures, fish needs, seepage losses, recirculation, recapture, and reuse, pursuant to Order WR 2009-0058-DWR from the State Water Resources Control Board (SWRCB) and continued under Orders WR 2010-0029-DWR and the Order dated September 30, 2011.

Both Condition 7 of the long-term Water Rights Order and Environmental Commitments EC-7 and EC-8 of the San Joaquin River Restoration Program (SJRRP) Programmatic Environmental Impact Statement / Environmental Impact Report require compliance with the Seepage Management Plan (SMP) for release of Restoration Flows. Reclamation developed the SMP to: (1) limit Interim and Restoration Flows to reduce or avoid material adverse groundwater seepage impacts through setting thresholds in over 200 groundwater monitoring wells, and (2) to identify a process to increase flows through construction of seepage projects. The seepage control projects may include a variety of realty (i.e., non-physical) and/or physical actions.

The SMP includes the methods to ensure that agricultural lands adjacent to the SJRRP area are not adversely affected. Root zone depth of crops and field conditions that affect them, such as capillary rise of water from depth, are an integral part of this determination. Scientific information from a wide variety of sources was aggregated to determine the root zone and capillary fringe buffers selected in the SMP. These estimates represented a range of almond root depth.

However, there is little scientific literature available from within the SJRRP area on crop root zones and capillary fringe in tree crops. This lack of documented local information on root zones is largely because of the difficulty, time and expense associated with studying tree roots and associated field conditions in situ.

2.0 Introduction

In an effort to develop a further understanding of almond root zone characteristics, Reclamation initiated a two-phased Almond Root Zone Study. Phase 1 was conducted in summer of 2015 and is briefly summarized below. A potential outline for Phase 2 of this study (a field investigation) is described in this study plan. The execution of Phase 2 will be discussed and planned in collaboration with stakeholders to ensure any proposed work is both useful and acceptable to all parties.

2.1 Phase 1 Study Results

Phase 1 of the Almond Root Zone Study was conducted in summer of 2015 and included a literature review and consultation with University of California (UC) researchers and Cooperative Extension agents on almond tree growth, tree roots, and impacts of water and salinity on root systems. The results of the Phase 1 Study indicated that there is general consensus on almond root zone depth and on the different types of roots and where they reside in the soil. The Phase 1 report, *Almond Root Zone Study Plan, Phase 1* (Administrative Draft, June 2015) documented the information collected in this phase of study. This report was posted to the SJRRP website for public comment (http://www.restoresjr.net/monitoring-data/groundwater-monitoring/). The report findings were also presented at the Seepage and Conveyance Technical Feedback Group (SCTFG) meeting on August 6, 2015 in Los Banos, California. The SCTFG meeting presentation is available at: http://www.restoresjr.net/get-involved/technical-feedback-meetings/seepage-and-conveyance/.

Phase 1 findings and input from stakeholders also indicated that though there is general consensus on almond root zone depth, there is less certainty on the height of capillary rise (i.e., the upward movement of water from the water table). Both the root zone depth and the capillary rise are components of the agricultural threshold that Reclamation manages to per the SMP. The upper limit of this capillary movement, called the capillary fringe (Figure 2-1), is highly variable between soil textures, sites with different groundwater levels, years and seasons. Though capillary fringe was addressed in the SMP, stakeholders have identified a need to refine estimates of capillary fringe in the project area for almonds.

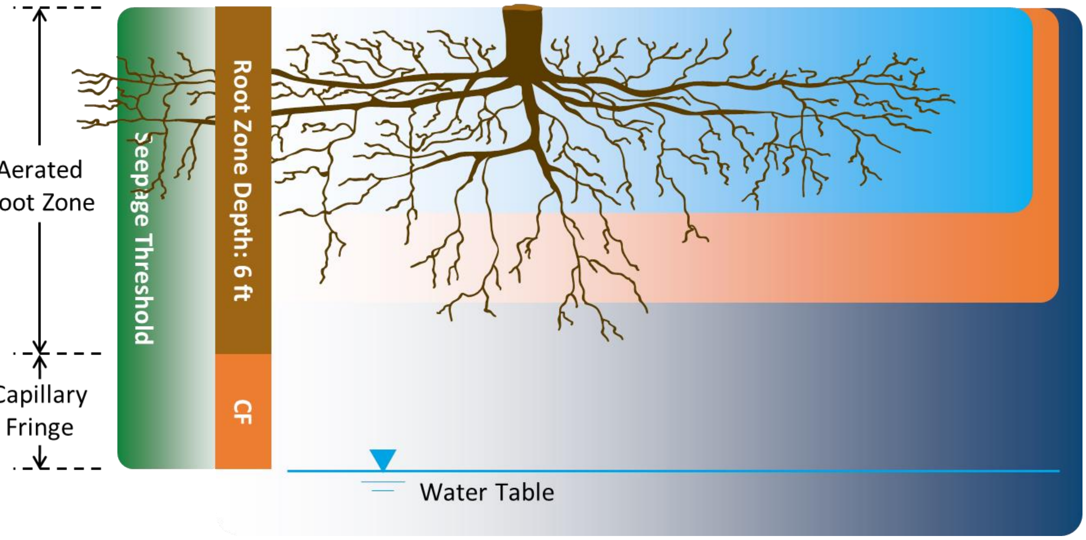

Figure 2-1.
Root Zone and Capillary Fringe as Components of the Seepage Threshold.

3.0 Capillary Fringe Study Plan

3.1 Purpose and Objectives

The primary purpose of the Capillary Fringe Study is to further understand and characterize capillary fringe in different site conditions within the project area. The study approach seeks to characterize the range of variability in capillary fringe to provide a more complete representation of capillary fringe in the SJRRP area.

The objectives of the Phase 2 Capillary Fringe Study are:

- Gather information on the nature, extent and study methods of capillary fringe;
- Evaluate existing data and identify data gaps that need to be addressed;
- Design a field and/or lab study to address these data gaps; and
- Develop specific guidelines for the range of capillary fringe in various soils and site conditions, to be used in conjunction with root depth estimates to protect almond roots from seepage in the project area.

3.2 Approach

The approach to the Capillary Fringe Study Plan (Study Plan) was informed by:

- Review of existing data from previous field investigations conducted by Reclamation staff;
- Review of a California Polytechnic State University, San Luis Obispo (Cal Poly) capillary fringe study in the project area; and
- Literature review on the nature, extent and methods of study of capillary fringe.

The Study Plan includes three main components for implementation:

1. Consultation with literature and experts to gather information on (1) the nature and extent of capillary fringe in field soils and (2) methods of studying capillary fringe in the field and in the laboratory;
2. Identification of data gaps using data collected during previous field investigations in the project area, such as groundwater monitoring well boring logs, EM38 data, capillary fringe observations, soil data and any other pertinent field data; and

3. Development of study method to address identified data gaps in a project-specific study.

Each of these components of study is discussed in the sections that follow.

3.3 Literature Review and Expert Consultation

The literature review for the Almond Root Zone Study was presented in Phase 1, as described in Section 1; however, no background information on capillary fringe has been presented to date. The literature review on capillary fringe, though a smaller effort, was conducted for the purpose of providing some guiding information for this conceptual plan. The specific objectives of the literature review were as follows:

- Define capillary rise and capillary fringe as it is described in scientific literature;
- Summarize findings on:
  - Characteristics of capillary fringe;
  - Influences on capillary fringe;
  - Typical heights of capillary fringe in fine soil types;
  - Spatial and temporal variability of capillary fringe; and
  - Methods used to measure capillary fringe in the field along with their accuracy, feasibility, applicability in various soils, etc.;
- Determine applicability of existing data to interpretations in current literature; and
- Recommend potential approaches to refine estimates of capillary fringe specified in current SMP protocols.

3.3.1 Key Literature Review Findings

The key findings of the literature review are summarized below. A more detailed summary of the literature review, including citations for sources of information, on capillary fringe is included in Appendix A.

- The definition of capillary fringe has differed among experts for decades. Capillary fringe is more commonly defined as the tension-saturated zone, while some define it as a transition zone between the water table and the unsaturated zone, which includes water content that varies from essentially saturated to whatever the water content is when it meets water infiltrating from above. Therefore, it is important to clarify what definition of capillary fringe is assumed when capillary fringe values are reported (see Figure A-4 in Appendix A).

- Capillary rise is defined as the movement of pore water against the flow of gravity. Capillary rise depends on: soil type; soil moisture depletion in the root zone; depth to the water table; and recharge. The zone of tension saturation typically referred to as the capillary fringe is discrete or “compact,” meaning that soil moisture decreases abruptly above its upper limit.

- Typical capillary fringe in fine soils is estimated up to several yards in several sources (see Appendix A). These estimates of capillary fringe are observed in labs or modelled, but may not represent field conditions. Estimates of capillary fringe in the SMP are generally lower than reference sources.
- Capillary rise varies spatially and temporally within relatively short distances (a few feet) and seasons.
- Capillary rise can be measured in the field with portable soil moisture instruments that measure in situ soil moisture, or by extracting cores and conducting measurements on them. However, soil moisture measurements must be related back to saturation percentage to determine what level of saturation is present in a particular soil. Portable instruments that measure soil water content are convenient but precision is questionable, especially in some soil types. Capillary fringe has been measured in the past using coring techniques proposed in the Almond Root Zone Study Plan (Phase 2) and other common soil property measurements.

3.3.2 Consultation with Experts

Conversations with experts from UC Davis, UC Cooperative Extension (UCCE), and Cal Poly in May 2016 contributed to the body of knowledge on capillary rise conditions in the project area. Conversation notes were documented and sent to respective experts for review to ensure that their opinions were captured accurately. These conversation notes are provided in Appendix B.

Expert interviews were conducted with the following California experts:

- Dr. Jan Hopmans, Associate Dean International Programs Office Soil Physicist Professor of Vadose Zone Hydrology, UC Davis;
- Dr. Robert Hutmacher, UCCE Specialist and Center Director West Side Research and Extension Center;
- Dr. Charles Burt, Retired Professor, Bioresource and Agricultural Engineering, Cal Poly San Luis Obispo; Chairman of Irrigation Training and Research Center; and
- Dr. Mark Grismer, Professor of Hydrology and Biological and Agricultural Engineering, UC Davis;

The following comments and recommendations were noted per these interviews:

- The problem of determining capillary rise is difficult. There is no simple solution.
- There is no published literature on the exact level of oxygen that almond roots require. In this situation, the tension saturated zone is the only practical measurement of capillary rise that affects roots. This can be observed in the field or in the lab.

- A bench study using soil columns placed in water for the purpose of observing the wetting front is a viable option for validating published values of capillary rise at sites where the water table is too deep to observe the wetting front in the field.
- Published values of capillary rise in various soil types (Table B-1) are applicable to the SMP purpose, are a good starting point, and should definitely be used to inform field investigations.
- Published values for coarse soils are likely accurate, whereas values for fine soils may not be as accurate. However, in cases where the capillary fringe is expected to move on the order of inches or one or two feet, published values are still a very good approximation and field investigation data may only improve these estimates incrementally.
- The height of the capillary fringe might be different in the same soil with the same groundwater level because of evapotranspiration (ET), therefore it is important to do field observations in the winter.
- The best way to get volumetric water content across various site conditions is with a neutron probe. Any kind of device that measures water content can be used without calibration if only abrupt changes in soil moisture are sought, but the resolution of the instrument is an important consideration. For example, a neutron probe measures the water content in a relatively large volume of soil (about the size of a football) and finer resolution may be desired.
- If field sampling cores are collected, soil types should be segregated by small increments as necessary (or six inches or so) so soil types are known. Natural Resources Conservation Service (NRCS) soil survey data is not enough information because it only goes down to five feet, and soils beneath that will influence capillary fringe and drainage; stratification of soils affects capillary fringe in unknown and highly variable ways.
- Capillary fringe measurements will always be approximations because of variability; it is difficult to find specific thresholds to apply generally because of site-specific conditions.
- The upward movement of the salt shelf may be mitigated by the dilution of less saline river water that is causing seepage. The only way to know this is by monitoring field crop vigor when seepage occurs during flood releases.

In summary, the expert interviews confirmed that field investigations using instrumentation (to determine abrupt changes in soil water content) and detailed soil profile evaluation are reasonable approaches to determining capillary fringe. All experts agreed that in determining general values for capillary fringe from field investigations, site-specific variability is significant and should be considered. All experts also agreed that field investigations should be informed by published capillary fringe values; however, each soil type for which a capillary fringe is estimated rarely exists in isolation and the stratification of soil types impacts the capillary fringe of a given location. In addition, any field investigation done for the purpose of determining capillary fringe should be done in the winter when ET is from almond trees is minimal.

3.4 Data Review

Reclamation has conducted numerous field studies to collect various types of data on project soils, site conditions, and groundwater levels in addition to direct observations of capillary fringe. Monitoring continues to provide pertinent data, and this data should be used where possible to minimize study development efforts. This effort is an integral step in focusing the study to ensure that previous observations are not duplicated and the study yields meaningful data.

Appendix H of the SMP describes the procedure that was used to determine and observe capillary fringe. This part of the SMP also includes summarized results of these findings. While these findings are still valid, there may be an opportunity to further evaluate and expand upon the representativeness of these findings with additional field data. For example, many of the capillary fringe observations were limited by the level of the groundwater at the time of the field work.

The objectives of this data review include:

- Review previous capillary fringe observations;
- Review project area soil conditions observed within the depth range of interest;
- Evaluate raw data associated with current SMP capillary fringe estimates based on a broader range of soil textures and conditions;
- Assess soil data to identify soil/site conditions that are not well represented by current capillary fringe data; and
- Use results to guide field study development so that resources are spent on collecting the most meaningful data.

3.4.1 Preliminary Results

The results of field investigation efforts to date were preliminarily reviewed. These field investigations included DWR well boring logs and SJRRP well boring logs and soil/salinity sampling events. This data is preliminarily summarized as follows:

- Preliminary data review indicates that of the soil logs taken during SJRRP field investigations that included capillary fringe estimates, only seven of those logs were in almond orchards. The average thickness of the capillary fringe in these logs was 30 inches.
- Most of these observations were in the three to six foot depth range in Reaches 4A and 4B, and, therefore, the full range of groundwater depth was not well represented. However, it was observed that deeper capillary fringes were thicker

than shallower ones. One reason for this difference could be indicated by the observation that deeper soils had less structure.

Additional well boring logs are available; however, there is insufficient data to determine capillary fringe from these logs. Table 3-1 is a summary of existing data.

Table 3-1. Capillary Fringe Existing Data in SJRRP area

Data Type	Approximate number of sites	Depth (feet bgs)	Notes
SJRRP Exploration borings	40	5-17	Most borings have capillary fringe observations
SJRRP Observation well logs	100	0 to 40	Logged with Unified Soil Classification System (USCS) class system; some soil moisture data.
Testing by SJRRP Contractor	150	10-25	Some have capillary fringe estimates. US Department of Agriculture logs. Emphasis on hydraulic conductivity testing
DWR	40	10-40	Most sites on or near levees; less useful for capillary fringe evaluations. USCS class logs.
Testing by Reclamation Staff	50	7-25	Not much capillary fringe data but some soil moisture data; USDA logs.
Cal Poly	2	8	Capillary fringe evaluations on two backhoe pits.

3.4.2 Data Needs

It is evident that both deep and shallow groundwater sites should be sampled and represented in determining the range of capillary fringe thickness within a typical seepage threshold zone in the project area. This is necessary because there is preliminary evidence that capillary rise, on average, changes in thickness with depth. The preliminary data review indicates that the existing data does not represent deeper seepage threshold/groundwater depths. Therefore, field soil investigations should encompass sites and soils with groundwater depths not represented by the existing data.

It is also clear from the literature review and preliminary expert consultation that published values for capillary rise in coarse soils is likely accurate, whereas published values for capillary rise in fine soils need field validation. Therefore, fine soils should be the primary focus of field validation efforts, and should be represented in field studies if they are not already represented adequately by existing data.

Literature and preliminary expert review also indicate that tree roots affect capillary rise because of the action of water uptake. It is unclear at this time if capillary fringes are changed in thickness by the presence of tree roots. This may also vary with groundwater depth.

3.5 Study Method Development

Study method development focused on soil/site conditions identified in data review efforts that are not well represented by current capillary fringe data. Depending on the spatial distribution and conditions within such areas, the study approach will be designed to better characterize the associated capillary fringe.

It is anticipated that multiple approaches will likely be required to characterize capillary fringe where site conditions are not suitable for field observations. A bench scale test in which conditions are imposed will likely be needed for sites where the capillary fringe is not directly accessible because of groundwater depth.

The capillary fringe study would be centered on observation and instrumental measurement of relative soil moisture and capillary fringe using one or more proven methods. Some methodology options are presented in Section 4.5.1, each with its advantages and disadvantages. While the field study would ideally capture the variability of capillary fringe between almond orchards, ideal site conditions may not be found for every soil type at the time the study is conducted. For example, groundwater levels, which fluctuate seasonally, may not be found at the desired depths (preliminarily estimated at two to ten feet below the effective root zone) for all soil types when field work would occur. Therefore, a combination of approaches may be appropriate.

3.5.1 Study Methods - Alternatives

Capillary Fringe Study Methods

A number of field study methods are possible (see literature review summary in Appendix A), including:

1. Laboratory soil column methods;
2. Field methods using portable instruments to make measurements directly where conditions are suitable;
3. Methods that combine basic soil property measurements from field soil samples to indirectly determine the profile of the saturated zone; and
4. Chemical tracer methods.

Based on preliminary review of these methods and their applications, some combination of the first three methods would likely be appropriate for this study purpose. These methods are described briefly below.

Laboratory Soil Column Experiments

Though it has been widely documented that re-compacted column studies (using disturbed soil cores) may not accurately represent field conditions, especially for fine-textured soils, evaluation of intact cores may yield valuable results where field conditions are inadequate to evaluate capillary fringe. Laboratory or bench-scale column experiments have two main advantages. First, they can be conducted any time. Second, the desired conditions (in this case, groundwater depth) can be imposed.

Intact cores are likely a better alternative to packed columns if laboratory studies are pursued. Intact soil cores can be extracted from field sites in acetate sleeves and transported to a laboratory. Acetate sleeves are transparent and allow the observation of moisture profiles in intact soil cores that have been placed in died water, for example. In this case, instrumentation wouldn't necessarily be required to observe capillary fringe.

Care must be taken in combining laboratory and field study results. However, column experiments, particularly if care is taken to use intact cores, may be able to provide relative capillary fringe comparisons between soil types where field studies cannot.

This method would likely be used to evaluate capillary fringe in targeted soil conditions that only exist where groundwater conditions are inappropriate for field observations/measurements.

Portable Instruments that Measure Soil Moisture

Portable instruments have been used successfully to evaluate relative soil moisture but their accuracy and precision are sometimes called into question. They would, however, likely produce good comparisons between sites, although they should be calibrated for each different type of soil. Cal Poly used a portable time-domain reflectometry (TDR) instrument to measure soil moisture content and estimate the extent of capillary fringe, but no saturation percentage was conducted on soil samples. Ideally, to determine the tension saturated zone, and therefore the capillary fringe, the saturation percentage of the soil must be known in addition to moisture content. There has been some evidence of decreased precisions and accuracy in fine soils. Therefore, it may be determined that instrumentation is not the best option for this study because of the focus on fine soils.

Core Sampling for Basic Soil Property Measurements

Basic soil property measurements (such as saturation percentage) conducted on soil cores extracted from the field are generally inexpensive and simple to conduct, and can provide accurate results provided that sampling is adequately representative. This method can be combined with portable instruments mentioned in the previous section, to characterize core moisture conditions and capillary fringe. This approach would likely be the most accurate and the least complicated; however, as in all field methods, desired site conditions must exist at the time of sampling. If other field study efforts, such as those discussed in the almond root zone study plan, were concurrently ongoing, there may also be an opportunity to realize some concurrent efficiencies in selected core locations. A tractor mounted hydraulic probe such as the Geoprobe 6610 DT shown in Figure 3-1 would be well suited to extracting cores from a wide range of sites and depths and would be appropriate for this type of effort.

This method, in combination with portable instruments mentioned above, could be used to evaluate targeted soil conditions that exist where groundwater depths are suitable to make field observations of capillary fringe.

Figure 3-1.
Tractor Mounted Hydraulic Probe (Geoprobe 6610 DT)

Chemical Tracers

Tracers are usually chemical compounds injected into the subsurface in order to indirectly estimate flow and storage properties. Tracers are potentially expensive and difficult to work with. They also require appropriate field conditions and testing can be time consuming. In-situ tracer experiments would therefore be limited and may last several days, weeks or even months. Chemical tracers are not likely best suited for the purposes of this study due to cost and field limitations.

3.5.2 Study Method Selection

The advantages and disadvantages of the study methods described above are summarized in Table 3-2. Considering these advantages and disadvantages, the objectives of the study, and the expected field conditions, two methods are likely the most appropriate and have the greatest potential to complement one another.

Soil sampling using a hydraulic soil probe to extract intact cores would be useful to make observations and conduct basic analysis of soil water properties where groundwater is shallow enough that the zone of capillary rise is expected to be accessible. In other cases, where groundwater is deeper and the tension saturated zone is not accessible, a bench-scale study could be conducted on intact cores taken from these sites. Capillary rise can be imposed on these cores and wetting fronts/saturated zones can be observed. The bench-scale study could also be used on cores from shallow groundwater sites to validate the field sampling results from those sites.

Chemical tracers are not considered appropriate for this study. Portable field instruments have been used before in the project area and may remain a possibility; however, their precision in fine soils would need to be confirmed.

Table 3-2. Capillary Fringe Study Method Alternatives

Study Method	Advantages	Disadvantages
Laboratory soil columns/bench scale study	• Easy to impose treatments • Easy to test any type of soil • Can be conducted anytime	• May not be representative of field conditions
Portable field instruments	• Easy to use • Can be used to evaluate various soil types relatively quickly	• May be more accurate/precise in certain types of soils, especially fine soils
Soil property measurements and observations on field soils	• Inexpensive • Requires only basic soil sampling expertise • Can be used in combination with soil columns or instrument results	• Cannot stand alone – needs additional information to interpret results
Chemical tracers	• Has potential to be very accurate	• Expensive • Materials may not be readily available • Difficult to work with • May require specific field conditions

4.0 Study Methods

Two types of studies intended to complement one another, a field study and a bench-scale study, are described below and summarized in Table 4-1.

Table 4-1. Summary of Study Preliminary Experimental Methods

Study Type	Method	Equipment	Number of Samples	Duration
Field	Intact soil core extraction/possible instrumentation	Hydraulic coring equipment, core sleeves, basic sampling supplies such as plastic bags.	To be determined based on data gaps/needs.	To be determined based on number of soils types and sites to fill data gaps/needs.
Bench-scale	Imposed hydraulic gradient on intact soil cores	Indoor location, intact soil cores, trays, water.	To be determined based on data gaps/needs.	To be determined based on expected rate of capillary rise on specific soil types.

4.1 Field Study – Intact Soil Core Extractions

Subsurface soil cores can be extracted using a hydraulic coring device mounted to a small diesel powered tractor, such as the Geoprobe hydraulic probe. With this device, cores up to 3.25 inches in diameter can be extracted to a depth of 14 feet. Excavation depths for each core would depend on the root depths encountered but would likely exceed five feet to fully characterize capillary fringe.

- There are minimal safety concerns;
- Equipment required can operate in densely planted orchards with full canopy without significant damage to the canopy;
- Excavation to a depth of 10 to 15 feet depth is feasible, safe, and relatively quick;
- Root damage is limited and trees need not be destroyed;
- The location of individual cores can be adjusted in the field if necessary based on the subsurface conditions encountered (e.g., hardpan, cobbles); and
- Several cores can be taken at a given tree in a relatively short period of time to achieve the desired sample size.

The soil cores would be examined using USDA soil characterization criteria for root and soil characteristics. Cores would be evaluated for physical properties, stratification, and moisture.

4.1.1 Equipment

The following equipment would be proposed to implement the methods described above:

- Field truck for transporting field personnel, soil samples, and other equipment;
- Tractor-mounted hydraulic probe for extracting cores for root observation;
- Safety equipment, such as hard hats, safety glasses, etc.;
- Shovels and hand soil excavation equipment for observing soil profile characteristics;
- Munsell soil color evaluation book for determining soil color including redoxomorphic features and indicators of gleying, etc.;
- Sample bags and boxes to collect and store soil samples;
- GPS and camera for logging tree locations and recording soil profile and root observations; and
- Soil moisture meter and or soil matric potential meter for field soil moisture status measurement.

4.2 Bench-scale Study – Soil Core Extraction, Description and Lab Experiment

The bench-scale study would serve two purposes:

1. Establish a range of capillary fringe in deeper zones where water table is too deep to do observed and/or instrumented measurement of capillary rise in pits; and
2. Validate instrumented measurements in intact soil cores.

In the bench-scale study, intact soil cores (extracted during field sampling) will be transported from the field to an indoor location where cores will be vertically placed in trays of water that will serve as a “water table”. The movement of water up the cores will be observed and recorded regularly. The frequency of these observations will depend on and be informed by published values of the rate of capillary rise for different soil types.

4.2.1 Equipment

Equipment for the bench study includes transparent sleeves, usually made of acrylic, which can be used to contain and store extracted soil cores. Cores would be extracted with the equipment described above. The bench study would also require trays for holding water, and an undisturbed table or bench for placing the trays and soil cores. Upward movement of water can be observed and may also be determined using instruments, depending on their operability in small diameter cores.

5.0 Site Selection

Study site locations (and their quantity) will be refined with stakeholder input. The criteria for initial site selection should be focused on variables that influence capillary fringe, such as soil texture and groundwater elevation. Other factors related to cultural practices and landowner cooperation are also important. Anticipated site selection criteria are listed below.

- Soil type: This study should include investigations that cover the range of soil types expected in the SJRRP area, with a focus on fine-textured soils. Soils can be categorized to best represent the range of conditions using soil survey information and boring logs throughout the study area. This approach would allow the characterization of a range of conditions in the project area and realize efficiencies in time and cost by grouping site conditions.

- Preexisting Salinity or Groundwater Monitoring Data: This criterion would not be a requirement for site selection, however, suitable sites located near previous salinity or groundwater monitoring locations may be preferential for data comparisons and added richness in the study dataset.

- Groundwater Elevation: Orchards located near potentially higher groundwater conditions may be preferred to make field observations of shallower ground water and/or capillary fringe conditions within a targeted depth range (below the effective root zone). Site selection efforts should be aimed to locate a portion, but not all, of selected sites in these areas.

- Spatial Distribution: An effort should be made to distribute preliminary sites across the spatial extent of the SJRRP area in order to represent the range of spatial conditions and assess spatial variability within soil categories.

- Location Relative to Orchards and Irrigation: Unlike a root zone evaluation, study site locations may not need to be within orchards. Representative soil characteristics are most important. These may be independent of crop production since most cultural practices that alter soil characteristics would be above (shallower than) the zone in which testing and observations would be focused. There are also advantages to observing conditions where irrigation is not occurring in order to avoid confusion in sources of soil moisture.

- Site Accessibility/Previous Environmental Clearance: Sites should be located near access roads or farm roads to allow access for field study. In addition, suitable sites near points that have had previous environmental clearance should be given priority in order to reduce the degree of permitting effort that may be required.

Study sites would be selected within regions representing targeted soil and ground water conditions and may or may not include agricultural production areas. Sites would comprise a representative area rather than a single point. Figure 5-1 shows an example area of a study site. The specification of a study area rather than a single point allows for study sampling efforts to be adjusted within each area based on field conditions to avoid anomalous conditions (e.g., leaking irrigation lines, declining tree, etc.).

Figure 5-1.
Example Study Site Area

6.0 Grower Coordination and Involvement

Grower coordination is important for reviewing and refining study objectives, gaining input on the study plan, as well as verifying study site locations and access. Grower input will occur through public meetings and/or direct contact with growers. During this step, background data will also be collected for each of the sites to be evaluated. Information about site conditions and almond production would be collected including:

- Orchard age and history;
- Tillage practices;
- Salinity toxicity or waterlogging experienced;
- Irrigation methods and methods; and
- Other site specific practices or characteristics/challenges.

The results from this effort would be used to finalize a study implementation plan including study site locations.

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7.0 Schedule

The schedule for implementation of Phase 2 study efforts is not yet defined. However, timing would involve the following sequence of tasks, some of which may overlap partially with concurrent efforts.

1. Landowner Coordination and Preliminary Data Collection: This task includes meetings and outreach with landowners. The purpose of this coordination would be to gather input on a Phase 2 study implementation plan and engage participating growers. This effort is under way with intended SCTFG meeting scheduling and would also include compilation of existing field information.

2. Data Review: This task would include data review and data gap analyses (primarily in the case of the capillary fringe study) to guide the refinement of study plans.

3. Core Excavation Pilot: This task would include a pilot trial of core excavation method(s) if intended for Phase 2 study. A small subset of sites would be characterized in preparation for full study implementation to verify feasibility of selected approach(es).

4. Field/Lab Data Collection: This task includes implementation of field and/or bench-scale study efforts and data collection.

5. Data Compilation and Interpretation: This task includes compiling preliminary and field data into appropriate databases and interpretation of those data based on the objectives of the refined study. Interpretations would be focused on developing refined understanding of the characteristics of root zone and/or capillary fringe within the project area per the objectives of the intended studies.

6. Reporting: This task includes documentation of field work and data analysis as well as input from reviewers and involves development of official documentation of study results.

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Appendix A
Capillary Fringe Literature Review
Summary

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A.1 Purpose

This document summarizes a literature review focused on capillary movement of water in soils as it relates to the thresholds for crop root zone protection in the Seepage Management Plan. The specific objectives of this effort were as follows:

- Define capillary rise and capillary fringe as it is described in scientific literature
- Conduct a scientific literature review and summarize findings on:
  - Influences on and characteristics of capillary fringe;
  - Typical heights of capillary fringes in fine soil types;
  - Spatial and temporal variability of capillary fringe; and
  - Methodologies used to measure capillary fringe in the field – accuracy, convenience, applicability in various soils, etc.
- Identify additional illustrations of capillary fringe used in reference materials and refereed studies to improve understanding among stakeholders
- Determine applicability of existing data to interpretations in current literature
- Recommend potential approaches to refine estimates of capillary fringe specified in current SMP protocols.

A.2 Key Findings

The key findings of the literature review are summarized below. More details on each of these topics are provided in Section 3.

- **The definition of capillary fringe differs among experts.** Some define it as the tension-saturated zone; others define it as a transition zone between the water table and the unsaturated zone, which includes water content that varies from essentially saturated to whatever the content is when it meets water infiltrating from above. *Capillary rise* is defined as the movement of pore water against the flow of gravity.
- **Capillary rise depends on multiple factors.** These include soil type, soil moisture depletion in the root zone, depth to the water table, and recharge.
- **The zone of tension saturation typically referred to as the capillary fringe is discrete or "compact."** This means that soil moisture decreases abruptly above its upper limit.
- **Typical capillary fringe in fine soils varies, but can be large.** Capillary fringe in fine soils is estimated up to several yards in several sources. These estimates of capillary fringe are observed in labs under compacted conditions or modelled, and

likely do not represent common field conditions. Estimates of capillary fringe in SMP are low compared to reference sources.

- **Capillary rise varies spatially and temporally.** This is true within relatively short distances (a few feet) and seasons.

- **Capillary rise can be measured in the field.** Portable soil moisture instruments are available that measure in situ soil moisture, or soil cores can be extracted and measurements made on them. However, soil moisture measurements must be related back to saturation percentage to determine what level of saturation a particular soil moisture in a particular soil represents. Portable instruments that measure soil water content are convenient but precision is questionable, especially in some soil types. Capillary fringe has been measured using the coring technique proposed in the Almond Root Zone Study Plan (Phase 2) and other common soil property measurements.

A.3 Literature Review

The findings of the literature review are presented below in order of the key points presented in Section 2.

A.3.1 Definition of Capillary Fringe

Ronen et al. (2000) note that the definition of the capillary fringe is not uniform in literature. "*It is restricted by some authors to that part of the profile above the water table where water content is equal to the saturated water content value and pressure is negative.*"

In a presentation from the University of Colorado, Boulder, experts state that "*Soil profile can also be described in terms of hydrologic horizons. The ground-water zone (also called the phreatic zone) is saturated. Above the water table is a tension-saturated zone (vadose zone) where the soil is saturated due to capillary rise. Water enters the intermediate zone as infiltration from above (from a precipitation event) and leaves by gravity drainage. Water content may temporarily rise above field capacity. The intermediate zone may extend over many tens of meters (or may be absent in other soil regimes).*"

Alley et al. 1999 describe the water below the subsurface in two principal zones: the unsaturated zone and the saturated zone. Between the unsaturated zone and the water table is a transition zone, the capillary fringe. In this zone, the voids are saturated or almost saturated with water that is held in place by capillary forces. Cloke et al. 2006 define capillary fringe as tension saturated zone. Salem and Hampton 2012 state, "The capillary fringe is the area above the water table occupied by water rising under tension against gravity. The tension-saturated capillary fringe is that part of the capillary fringe which is nearly saturated with a wetting fluid. The wetting fluid rises to partially wet a much larger area." This definition distinguishes between saturated and unsaturated capillary fringe.

Holtzer (2010) described the differences in interpretation of saturated and unsaturated terminology/soil physics. Holtzer submits that the water table is incorrectly defined as "*the atmospheric pressure surface that is coincident with the top of the zone of saturation*". This is incorrect because "*the potential for saturated conditions above the water table in violation of the definition is generally accepted and frequently described in groundwater textbooks*" (and also because non-saturated conditions can exist below the water table). Holtzer (2010) also argues that "*the water table should be defined only as the pressure surface where pore-water pressure is at local atmospheric pressure. Its definition should not refer to saturation. The top of the zone of saturation may be above, at, or below this surface.*" He notes that "*engineers apply the phrase 'unsaturated soil mechanics' to the capillary fringe with full awareness that the capillary fringe is essentially saturated".* To support this claim, he cites two sources: Gillham (1984) and Fredlund (2006).

Summary

The definition of capillary fringe in the literature ranges between the tension saturated zone *only* and the zone that includes a saturated zone but also includes regions of water content lower than saturation. The significance of this is not necessarily to determine which definition is correct, but to clarify which definition is used when capillary fringe is determined in the field. Equally important is to determine which definition of capillary fringe is used when estimates are published in reference materials, studies and field investigations, so that comparisons of capillary fringe may be made correctly.

A.3.2 Characteristics of and Influences on Capillary Rise

Capillary flow depends on soil type, soil moisture depletion in the root zone, depth to the water table, and recharge (Tanji and Keilen, 2002). It is also influenced by timing of irrigation and initial soil content. Capillary flow is a hysteretic process, meaning that it is different when the initial soil moisture is low than when the initial soil moisture is high. Many early formulae to estimate capillary rise did not consider initial soil moisture. While texture is relatively easy to measure, and does not vary in space and time, structure is difficult to quantify and does vary greatly in space and time; hence, it is difficult to estimate and extrapolate capillary rise predictions.

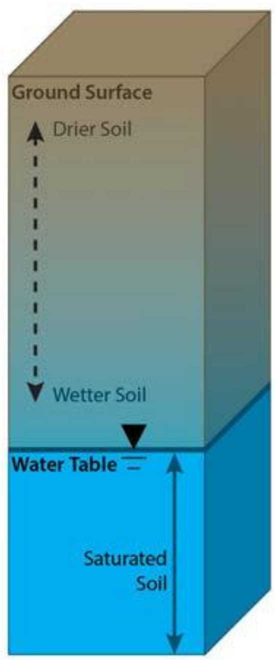
Tanji and Keilen (2002) also state that "*In the presence of high water table, shallow groundwater and its salts may move up into the rootzone (recharge) and down out of the rootzone (discharge) depending on the hydraulic head. Deficit irrigation under high water table may induce rootwater extraction of the shallow groundwater. The salinity level of the shallow groundwater is of some concern under such conditions. However, there does not appear to be a simple conceptual model of capillary rise of water and solutes."*

Ronen et al. 2000 found that the capillary fringe they measured was compact (i.e., there was an abrupt change in soil water content that clearly defined its upper limit). In their study, all soil moisture profiles exhibited an abrupt change in water content at some height above the water table. They also noted that saturated conditions were detected in some regions of the capillary fringe, indicating that the whole region of capillary fringe was not saturated. Over a horizontal distance of 4 m, the height of the capillary fringe varied (Figure A-2). Their data showed that the height of top surface of the capillary fringe changes seasonally, but its shape does not. In other words, the upper limit of the capillary fringe changed in elevation with the seasons, but the “peaks and valleys” were preserved regardless of its elevation.

These results indicate that the capillary fringe, including both saturated and less than saturated regions, including saturated and unsaturated zones, is not accurately represented by a diffuse continuum of soil moisture that decreases gradually as it approaches the soil surface as illustrated in Figure A-1 (from SMP Appendix H). Rather, the capillary fringe is represented more accurately by the illustration shown in Figure A-2 (Ronen et al. 2000). A simplified version of this understanding of the capillary fringe is corroborated by other sources and presented in Figures A-3 and A-4.

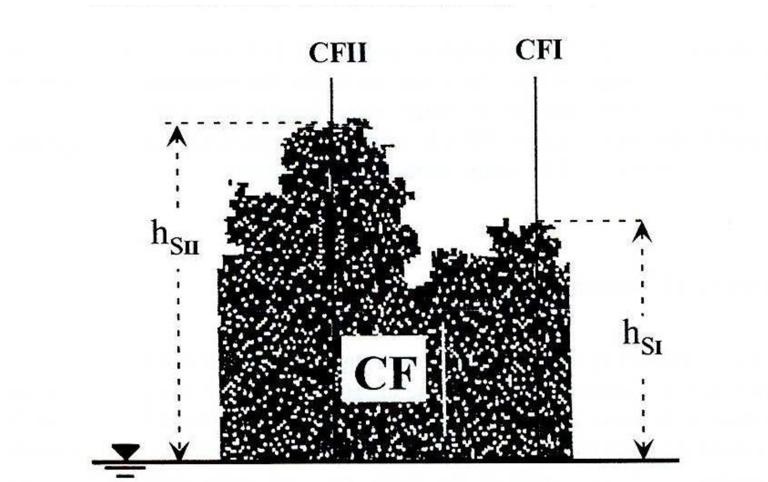
Summary

The height, spatial variation and temporal variation of capillary rise are dependent on several factors. The upper limit of the capillary fringe, even though it may not be saturated by some definitions, is likely better represented by an abrupt change in soil moisture rather than as a point in a diffuse continuum of soil moisture that extends from the water table to the upper limit of the vadose zone.



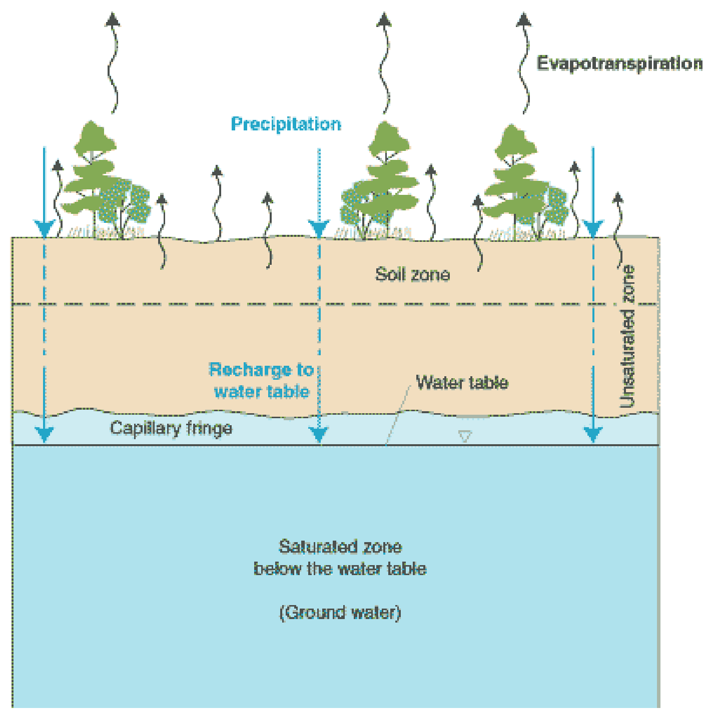
(adapted from Sands 2001)

Figure A-1.
Conceptual Diagram Near the Water Table



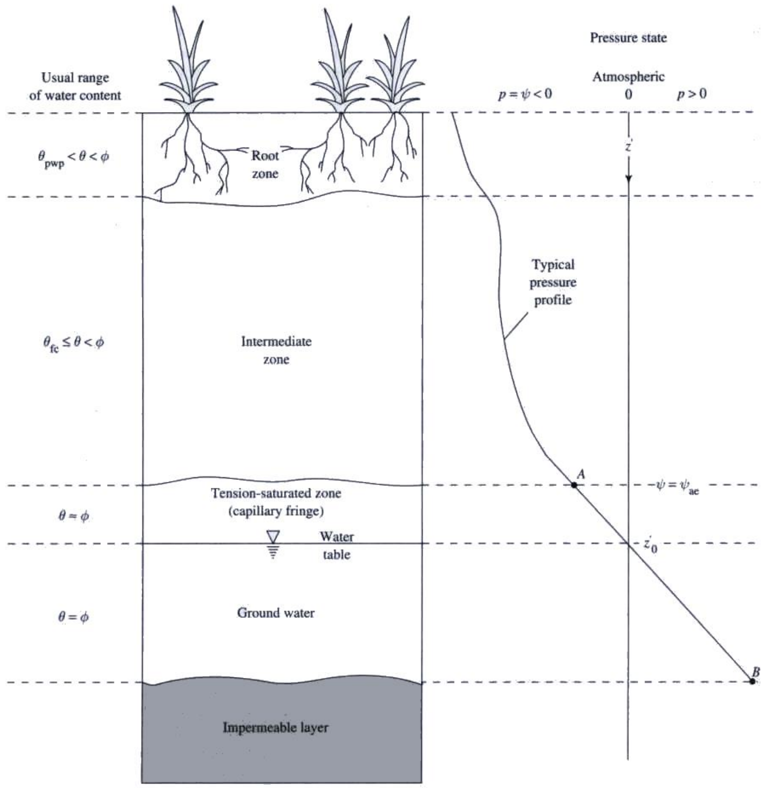
CF=Capillary Fringe (I and II); H=Height; S=Saturation

Figure A-2.
Vertical Section of 3D Capillary Fringe Simulation.



(Source: Alley et al. 1999)

Figure A-3.
The Unsaturated Zone, Capillary Fringe, Water Table, and Saturated Zone.



(Source: Dingman (2002). From University of Colorado Boulder, undated)

Figure A-4.
Soil profile and idealized hydrologic horizons

A.3.3 Typical Height of Capillary Fringe in Fine Soils

Given the inconsistency in the definition of capillary fringe and the disparity between modelled, laboratory, and field estimates, predictions of capillary rise should be considered with caution. For each estimate of capillary rise, it should be understood whether it is derived from models, formulae, lab tests, or field observations. It should also be understood what definition of capillary rise is being applied, the depth of the water table, what time of year the measurements were taken, etc. In many cases this information is not available. Therefore, the estimates of capillary rise from different sources cannot be meaningfully compared in some cases.

For example, the Roscoe Moss Company in their *Handbook of Groundwater Development* (1990) includes their definition of capillary fringe in their estimate but does not specify if it refers to materials observed in the field or to laboratory conditions. "*Unbound water continues downward until it reaches the lower boundary of the vadose zone, known as the "capillary fringe". Here pore spaces are completely filled with water. The thickness of the capillary fringe varies from a few inches to several tens of feet, depending upon the nature of materials forming the zone. Material composed primarily of fine particles have a large surface area to volume ratio and may have capillary fringes of 50 ft or more."* These estimates may refer to disturbed, lab-derived soil measurements and/or very specific sub-surface conditions.

However, Salem and Hampton (2012) noted the wide range of conflicting data in literature estimating capillary rise in different soils. They submit that the equation that is generally used works reasonably well for coarse-textured soils but greatly over-estimates in fine-textured soils. In fact, they call into question values of 100 cm and above in any soils coarser than a fine sand.

Sumner (1999) provides a table of different soil textures and associated capillary rise, which only extends to several inches (at three to four ft) and therefore is likely referring to agricultural field conditions and not laboratory tests. This source implies that the definition of capillary fringe applied here is only the tension saturated zone.

Burt and Freeman (2010) investigated capillary rise in an agricultural field adjacent to Reach 4A of the San Joaquin River. They measured volumetric soil moisture at 3-inch vertical intervals in a pit 8 feet deep. In this case, the water table was around eight ft. The measurements were taken in October when there was no crop planted and no irrigation. A TDR portable instrument was used that produced results with significant variation. Their results showed that the capillary fringe extended approximately 4.5 feet above the water table. They defined capillary fringe as the saturated zone above the water table, but interpreted the capillary fringe as the depth at which the soil moisture content increased noticeably (rather than determining saturation). They cite Brouwer et al. (1985) for guideline estimates of capillary rise extending up to several meters in fine soils. These estimates, however, are not explained in detail.

Summary

"Typical" heights of capillary fringe published in reference sources should be interpreted with caution if they do not include information that clarifies and defines the estimate. Researchers are investigating new ways of improving calculated predictions of capillary fringe estimates. Calculated, modeled, lab-run and field-observed capillary fringe measurements can vary widely and should not be compared unless they are derived from the same method. Because of the wide range in capillary fringe estimates, site-specific measurements with reliable instrumentation is the best way to determine capillary fringe.

A.3.4 Spatial and Temporal Variability of Capillary Fringe

As described previously, Ronen et al. (2000) found that over a relatively small horizontal distance of 4 m in a medium soil they studied, the height of the capillary fringe varied. This variation, though changing in elevation seasonally, preserved its shape. Cloke et al. (2006) in their study of capillary-fringe "groundwater ridging" investigated the relationship between capillary fringe height, water table response, and hydraulic conductivity in a hillslope-riparian context. Though catchment hydrology is beyond the scope of this effort, it is noted that the authors acknowledged the complicated hydrological systems of riparian zones and their influence on capillary fringe.

Summary

The upper limit of the capillary fringe is spatially and temporally variable. Measurements of capillary fringe should be reported with information indicating time of year, and the spatial resolution at which measurements were made.

A.3.5 Field Methodologies to Measure Capillary Fringe

Field methods of studying capillary fringe range from cumbersome in-situ measurements in actively growing crops over several years (Webster and Topp, 1983) to using micro-injections of deuterium-enriched solution into unsaturated soil (Grönberger et al. 2011). Portable soil moisture instruments have been used as in Burt and Freeman (2010), but the variability of their results is a concern in some soil types. Ronen et al. (2000) used hydraulic probe coring to extract soil samples to 7 m deep. They measured gravimetric water content, bulk density, particle density, saturation percent, pore volume and porosity to determine the extent of saturation throughout the profile. They were able to accomplish 37 cores per day, each about 1.2 m long. This method seems the most practical and feasible, did not require specialized materials or equipment, was time-efficient, did not pose any obvious safety hazards to field staff, and relied on standard soil laboratory tests. Their methods and sample handling were well described and are repeatable.

Summary

Capillary fringe can be measured in the field with standard sampling and analysis methods. Using such a method would likely result in variation of results depending on the spatial resolution of the sampling protocol.

A.4 Recommendations

The field data on soil observations that has already been collected in the project area can be used to develop more refined estimates of capillary fringe. The field data can also be analyzed to determine where there are data gaps, i.e., soils that are underrepresented by existing data. These data gaps can be addressed by incorporating field and/or bench scale investigation of capillary fringe independently or in coordination with almond root zone study field work. With refined assessment of capillary fringe data and the addition of field data, a broader spectrum of capillary fringe estimates can be generated to serve the objectives of the SMP.

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Appendix B
Log of Conversations with Experts

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Expert	Meeting Notes	
Dr. Jan Hopmans, UC Davis, Associate Dean International Programs Office Soil Physicist Professor of Vadose Zone Hydrology	• It is difficult to predict the extent of capillary rise in future field conditions • Recommend speaking with Hutmacher, O'Geen and Grismer • We don't know what level of oxygen affects almond roots in particular. The harmful level could be and probably is less than saturation. So, the problem is not measuring capillary fringe, however you want to define it using soil moisture contents, but interpreting that measurement. • If almond production experts say that they are most worried about saturation, especially if that saturation is going to be transient in nature, then the tension-saturated zone should be considered the capillary fringe. • A bench-scale study could be used to observe wetting front/saturated zone if all you are looking for is saturation vs. non-saturation. • Published values for various soils are a good starting point, because measuring cap fringe in the field is highly variable and very difficult. Values for coarse soils are probably pretty accurate. Values for fine soils may be less accurate. • Doing field investigation might not refine/validate these values because of variability. The best we could do would be to find a reasonable range based on published values – these could likely not be improved upon with field study. • The depth of drains installed in other parts of the state to protect almond roots (such as Westlands) should be considered, and would provide an example of drainage needed to protect almond roots.	In-person meeting, May 4, 2016

Expert	Meeting Notes	
Dr. Robert Hutmacher UCCE Specialist And Center Director West Side REC	• These kinds of measurements will always be approximations because of variability • Agrees that published values are a good place to start and may not get much refinement from field study. • The best way to get volumetric water content across various site conditions is still a neutron probe. There hasn't been a better way developed from various capacitance probes, etc. Advantages include: measure a large volume of soil, not affected by gap between tube and surrounding soil. Would have to be used with piezometer data. • Water front type sensors deliver more data but are inconvenient. • There would probably be a way with suction lysimeters but would be easier in the lab than field. • Observing capillary fringe in the field is difficult especially in riparian soils because there are soil textural changes that make it difficult to see what is going on. With precipitation/irrigation it's difficult to tell. In some sites it may be easy to tell and in others it may be more difficult • Using soil property data (saturation percentage) from soil cores along with neutron probe data and MW groundwater level data seems like a good approach. • Not sure if there are drained areas where almonds are grown. In Westlands, drainage is used for salinity as well as water table control, and because almonds are sensitive, they were not planted there. There may be some at the S end of Hwy 33, S of Mendota, near Three Rocks, W of SJR and W of Tranquility. • Suggested talking to Jim Ayers	Telephone conversation, May 9, 2016

Expert	Meeting Notes	
Dr. Charles Burt Cal Poly	Hysteresis in soil water content contributes to the variability and difficulty in measuring capillary fringe consistently. The height of the capillary fringe (CF) might be different in the same soil with the same groundwater level because of ET, therefore it is important to do field observations in the winter. This is because CF depends on saturated hydraulic conductivity and the gradient that's pulling the water up; it can only move up so fast, and ET might take up all of that gradient/water. In the Cal Poly work they were mainly concerned about salinity and the upward movement of salt. TDR probes don't necessarily have to be calibrated because their accuracy isn't that important – it is the relative change in moisture content that is important. For this reason, you don't need to know saturation percentage either. You can use any kind of device that measures water content, but you have to be aware of the resolution of the instrument. For example, a neutron probe measures the water content in a relatively large volume of soil (about the size of a football) and you might want finer resolution than that. Not sure if TDR probes can be used in cores, but you could try and validate it using measurements from a pit. The other potential problems with soil moisture probes is that when you disturb soil to get a sample, you might preferential flow, which would reflect in the reading. The two important messages from this conversation are: 1) don't spend any time calibrating an instrument; 2) make sure you do measurements in the winter when there is no ET.	Telephone conversation, May 10, 2016.

<table>
<tr><th>Expert</th><th>Meeting Notes</th><th></th></tr>
<tr><td>Dr. Mark Grismer
UC Davis</td><td>
Capillary fringe can be a meter or more in fine soils
Important thing in draining is how fast you can lower the water and how much aeration you can get
Agrees that pulsing (duration and frequency) will affect this and is an important consideration.
Worked in Imperial Valley on clay soils (down to 2 m) underlain by fine sand; ended up draining the sandy layer, not the clay, because the saturation seemed to be controlled by sandy soils that were conducting the water, and by cracking in clay soils that conducted water downward quickly. Sandy soils underlain by clay soils are less common in his experience and not as much of a problem.
Crops will adjust to changing water and salt layers, but unknown how/how fast for each crop
If we take cores in the field to sample, we should segregate soil types by as small increments as necessary (or 6 inches or so) so we know what kinds of soils we are dealing with – soil survey isn’t enough information because it only goes down to 5 feet, and soils beneath that will influence capillary fringe and drainage
Could do drainage test on intact cores; hysteresis would not be a major concern because initial water content is below saturation so the drainage rate would be the conservative rate
Experience near Gridley on fine soils in orchard. River levels were rising and trees in some parts of the field were showing impacts but not in others. No salinity. Couldn’t see flooding on top of field, but sub-surface flooding/saturation was happening in parts of field where trees were showing impacts. Had to do observation cores down to 15 feet on transects to figure out what was going on.
Cautions that it is difficult to find specific thresholds to generally apply because of site-specific conditions
General guidelines can be used, but must be refined with site-specific field investigation.
</td><td>Telephone conversation May 19, 2016.</td></tr>
</table>

Expert	Meeting Notes	
Jim Ayars UDSA Parlier	• Agrees with Mark Grismer that soil layering/stratification at depth is really important • Fine-textured soils would limit capillary rise in some cases because CR can't keep up with ET • The fine-coarse soil interface is an important factor in determining rate/extent of CR • To know CR of saturated zone, need to figure out upper limit of CR through all layers • Getting more information about stratification at depth (at more refined scale/grid than existing boring logs/wells) would be useful for modelers; boring/drilling mixes up soil so soil sampling is more representative. • On pulsing water into river – agrees that the timing (season), duration and frequency matters, but the only way to figure out how differences in those parameters would affect seepage (before it occurs) would be through modeling • Agrees with others in that literature values are a good place to start; they are probably correct for each type of soil, but in the field with the soil types are layered then it is difficult to figure out the overall effect/CR of that layering. • You can spend a lot of money observing/gathering data for different types of soils or soil conditions in the field, but if you did a sensitivity analysis with a model you might find that changing some soil types out for others wouldn't make that much difference • On bench-scale study –probably should wet from the bottom. • Measuring relative water content using neutron probe is a good idea – should do it over time so you can see how CF varies with time. • Agrees that field studies should be done in winter when there is no ET in orchards	Telephone conversation June 14, 2016.

Table B-1. Soil Water Parameters of Saturated Soils

Table Header	Saturated Hydraulic Conductivity (cm/hr)	Total Porosity (cm^3/ cm^3)	Air-entry Matric Head (cm)	Estimated Capillary Rise (inches)	Microscopic Capillary Length (cm)	Microscopic Capillary Length (cm)
Sand	21.00	0.437	-16.0	6.4	2.83 x 10-2	2.83 x 10-2
Loamy sand	6.11	0.437	-20.6	8.24	2.06 x 10-2	2.06 x 10-2
Sandy loam	2.59	0.453	-30.2	12.08	9.92 x 10-3	9.92 x 10-3
Sandy clay loam	0.43	0.398	-59.4	23.76	4.63 x 10-3	4.63 x 10-3
Loam	1.32	0.463	-40.1	16.04	1.11 x 10-3	1.11 x 10-3
Silt loam	0.68	0.501	-50.9	20.36	5.83 x 10-3	5.83 x 10-3
Clay loam	0.23	0.464	-56.4	22.56	4.50 x 10-3	4.50 x 10-3
Sandy clay	0.12	0.430	-79.5	31.8	3.84 x 10-3	3.84 x 10-3
Silty clay loam	0.15	0.471	-70.3	28.12	3.31 x 10-3	3.31 x 10-3
Silty clay	0.09	0.479	-76.5	30.6	3.02 x 10-3	3.02 x 10-3
Clay	0.06	0.475	-85.6	34.24	2.77 x 10-3	2.77 x 10-3

Source:Handbook of Soil Science. Ed. Sumner. 2000. CRC Press LLC, Boca Raton, FL. Adapted from Rawls et al. (1982) and Brakensiek and Rawls (1992).