TECHNICAL MEMORANDUM
Compliance Averaging Period for Chloride Threshold Guidelines in Avocado

REVISED DRAFT

Prepared for

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Los Angeles Regional Water Quality Control Board;
Technical Working Group for the Santa Clara River Chloride TMDL Collaborative Process

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1 INTRODUCTION

1.1 BACKGROUND

On May 6, 2004, the Los Angeles Regional Water Quality Control Board (Board) adopted an amendment to the Water Quality Control Plan for the Los Angeles Region to revise the interim waste-load allocation and Implementation Plan of the Upper Santa Clara River (SCR) Total Maximum Daily Load. The Implementation Plan included an evaluation of the appropriate chloride (Cl) threshold for the reasonable protection of salt-sensitive agriculture. The Sanitation District of Los Angeles County (District) and the Board are working jointly on this study. The evaluation process was guided by a stakeholders' working group, the Agricultural Technical Working Group (AGTWG), and the Agricultural Technical Advisory Panel (AGTAP), a panel of salinity and agronomy experts.

A Literature Review Evaluation (LRE) was conducted by CH2M HILL in 2005 to determine if scientific literature could be used to develop a Cl threshold or range of thresholds for salt-sensitive crops in Reaches 4 and 5 of the Santa Clara River. Literature was not sufficient to determine Cl thresholds for strawberries or nursery crops; however, a hazard range of 100 to 120 mg/L was determined for avocado.

The Board and District submitted a supplemental request of questions to the co-chairs of the AGTAP for guidance on how long the compliance averaging period should be, i.e., a rolling average period of a number of days, weeks or months. The co-chairs' responses to the supplemental request included guidance on how long the compliance averaging period should be in relation to the variability of Cl measurements in surface water used for irrigation. The Board and District then conducted independent analyses of Cl variability.

The Project Team now requires an evaluation of the co-chairs' responses, the Cl variability analyses, and other literature with additional information on what the Cl compliance averaging period should be for avocados in the Upper SCR.

1.2 PURPOSE

The purpose of this technical memorandum is to provide information from the LRE and other literature that would help determine an appropriate compliance averaging period for Cl. This memorandum includes the following sections:

- Relevant Information from the LRE
- Additional Literature Review of applicable articles published since the LRE
- Review of Project Team Questions
- Review of Project Team Analysis
- Feasibility of Establishing a Compliance Averaging Period
- Determination of Compliance Averaging Period for Cl
- Recommendations
- Works Cited

1.3 SUMMARY

Relevant information from the scientific literature in the LRE and the AGTAP responses in the supplemental request were reviewed to determine what factors should influence a compliance averaging period for Cl. The review of these articles found that Cl toxicity symptoms on avocado appear 4 to 8 weeks after exposure to Cl excess begins when high rates of Cl are appied. In addition, stress caused by Cl excess can affect avocado growth even after the stress has been removed. Chloride uptake is highest near the beginning of the exposure period.

According to the AGTAP responses to the Supplemental Request, the compliance averaging period should be as short as possible, but that the degree of variability in Cl concentration could be considered in determining the averaging period length. The compliance averaging periods of 12 months and 2 days proposed by the District and Board respectively are likely too long or too short, in light of agronomic considerations specific to avocado.

One specific critical growth stage or time of year was not determined because 1) the stress of Cl excess is carried over after the stress is removed; 2) there are too many "critical periods" during the year, considering plant-specific and environmental critical periods; 3) duration of exposure is likely more important than growth stage or critical period at which exposure occurs.

A residual analysis was conducted to determine at what point the averaging period did not represent the fluctuations in Cl concentration. This analysis was combined with the previous review on avocado growth and Cl injury to determine a recommended compliance averaging period of 3 months.

2 RELEVANT INFORMATION FROM THE LRE

2.1 APPROACH

The LRE methodology consisted of a document management and ranking system that served to organize and scored literature according to its scope, applicability and study quality. This ranking system is summarized Table 1.

TABLE 1 SUMMARY OF LRE EVALUATION METHODOLOGY

CHLORIDE COMPLIANCE AVERAGING PERIOD RECOMMENDATIONS

Evaluation/Characterization Criteria	Scoring System
Study Scope Criteria	
1. Type of Study	Recorded
2. Crop	Recorded
3. Growth Stage	0 or 1 (present or not present)
4. Yield Impact	0 or 1 (present or not present)
5. Source of Cl	0 or 1 (present or not present)
6. Cl-specific Ion Toxic Effect	0 or 1 (present or not present)
7. Irrigation Water Requirement	0 to 3 (degree of applicability)
8. Osmotic Effect	0 or 1 (present or not present)
9. Physical Mechanism of Cl Toxicity	0 or 1 (present or not present)
10. Fruit Quality	0 or 1 (present or not present)
11. Seasonal Cl Variation	0 to 3 (degree of applicability)
Study Applicability Criteria	
1. Location	0 to 3 (degree of applicability)
2. Climate	0 to 3 (degree of applicability)
3. Irrigation Method	0 to 3 (degree of applicability)
4. Soil Type	0 to 3 (degree of applicability)
5. Rootstock, Variety, Species, and Genotype	0 to 3 (degree of applicability)
6. Cultural Practices	0 to 3 (degree of applicability)
7. Irrigation Management	0 to 3 (degree of applicability)
8. Routes of Exposure	0 to 3 (degree of applicability)
9. Rate of Exposure	0 to 3 (degree of applicability)
Study Quality Criteria	
1. Experimental Design	0 to 3 (presence of essential components)
2. Strength of Analysis	0 to 3 (presence of appropriate statistical methods)
3. Strength of Interpretation	0 to 3
4. Strength of Conclusion	0 to 3
5. Strength of Implementation	0 to 3
6. Study Duration Appropriate for Study Objectives	0 to 3
7. Level of Review	0 to 3 (categories of sources of literature)

The approach to finding relevant studies for this purpose involved finding studies, by their scores, which documented growth stage, rate of exposure, and duration of the experiment. These parameters were chosen for the following reasons:

- Growth stage is an on-going concern expressed by the project team in the Supplemental Request to AGTAP (see Section 4, Review of Project Team Questions)
- Rate of exposure is a required study detail that helps determine how the plants in the study were exposed and at what Cl concentration. For example, some studies sufficiently indicate the concentration of Cl that was applied, while others only indicate that treatments of increasing Cl were applied. Also, some researchers apply the treatments in a phased manner (called "ramping up" the Cl concentration), while others start exposing the plants to Cl without this phasing-in period.
- Some experimenters documented the duration of the experiment, while others did not. Without knowing the duration, and when sampling took place, it is impossible to gather information about exposure period and its affects on the subject plants. Short-term studies are useful for determining the minimum exposure period that results in Cl injury. Long-term studies are useful for determining the long-term effects of short exposure periods.

The applicability scores were also considered, and further narrowed down to a group of studies that were then reviewed for information relevant to developing compliance averaging periods. In some cases, one scoring parameter might have been documented (such as growth stage), while another scoring parameter was not (such as study duration). This narrowed the list of relevant studies even further. Studies that used short sampling periods, such as days or weeks, were of particular interest. The original list of selected studies and their scores are provided in Table 2. The studies that were evaluated as being highly relevant are discussed in the following sections.

TABLE 2 LIST OF RELEVANT STUDIES FROM LRE

Study Name	LRE Score	Comments on Relevancy
Studies that Considered Growth Stage		
Bernstein et al., 2001	1	Low applicability. Used West Indian rootstock; monitored at end of 2-year period of salt stress.
Bingham et al., 1968	1	High. Results of minimum time of Cl excess exposure to produce injury.
Shalhevet, 1994	1	High. Information on salinity and growth stage.
Studies that Considered Rate of Exposure		
Amrhein, 1999 (review)	3	Moderate (see Montgomery-Watson). Review of Montgomery-Watson's study.
Arpaia et al., 1996	3	Low. No information on timing of exposure and injury or yield results.
Ayers, 1950	2	High. Results of minimum time of Cl excess exposure to produce injury.
Bar et al., 1997	3	Low. Leaf samples were taken at 26 days, but results are not given.
Ben Ya'acov et al., 1992	3	Low. Measured yield only.
Bingham and Fenn, 1966	3	High. Results of minimum time of Cl excess exposure to produce injury.
Bingham et al., 1968	3	High. Results of minimum time of Cl excess exposure to produce injury.
Crowley et al., 1999	3	Low. Ramped up Cl/salt treatments over period of two months.
Downton et al., 1978	3	High. Results of minimum time of Cl excess exposure to produce injury. Sampled plants after sodium chloride (NaCl) stress was removed for a period of time.
Ehlig and Bernstein, 1968	3	Low. Sprinkler application.
Faber et al., 1995	3	Low. Sampled once per year.
Faber, 2004 (review)	3	Moderate. Not reviewed. Information on delayed effects of Cl stress; information on Cl stress and root rot.
Dr. Grattan and Oster, 2002 (review)	2	Low. No specific exposure time related to injury.
Gustafson et al., 1973	2	Low. Irrigation study.
Gustafson, 1962	3	Moderate. Anecdotal information on soil Cl, tipburn, and timing of Cl exposure.
Haas and Brusca, 1955	2	Low. Sampling interval and experiment duration not given.
Haas, 1950	3	Low. Study duration and sampling times were not given.
Kadman and Ben Ya'acov, 1969	2	Low. Sampling done at end of multi-year experiment.
Kadman, 1963	3	High. Results of minimum time of Cl excess exposure to produce injury.
Lahav et al., 1990	2	Low. Results did not include duration of exposure.

Meiri et al., 1999	2	Low. Study on irrigation interval.
Montgomery-Watson, 1997	3	High. Results of minimum time of Cl excess exposure to produce injury.
Oster and Arpaia, 2002	3	Low. No specific sampling. Production function.
Partida, 2002 (review)	2	Low. No specific results.
Patel et al., 1976	3	Moderate. Glasshouse study.

2.2 RELEVANT RESULTS AND CONCLUSIONS OF LRE STUDIES

2.2.1 REVIEW OF AVOCADO PRODUCTION AND CHLORIDE INJURY BASICS FROM LRE

The following pertinent basics of avocado growth and production were discussed in the LRE and should be considered during the development of a compliance averaging period.

- Natural environmental variability (temperature, humidity, wind) affects avocado growth differently every year.
- Management practices, including irrigation frequency and duration, have a considerable effect on the level of stress avocado tress experience from a particular yield factor and how much stress avocado trees can experience before exhibiting injury or decreasing production.
- Natural variability in population accounts for much of the wide variation in avocado production from year to year and site to site.
- Avocados are alternate bearing (yields are large in “on” years and small in “off” years) and have a cyclical growth pattern (plants grow in surges, or shoot flushes rather than at a constant rate).
- Cl uptake increases when transpiration increases.
- Cl excess affects roots earlier and to a greater extent than it affects shoots in avocado.
- Cl toxicity is affected by interactions with other ions that directly and indirectly impact the physiological functions of Cl in plants, and the overall health of the plant.
- Salinity and the specific ion toxicity of sodium are directly linked with the extent of Cl injury, and tend to exacerbate its effects.

2.2.2 Summary of Relevant Information in Articles From LRE

Ayers, 1950

Ayers (1950) treated avocado trees with increasingly concentrated solutions of sodium chloride (NaCl), calcium chloride (CaCl), and sodium sulfate. Within one month, all treated trees showed growth stunting, except for the control treatments and the lowest treatment of CaCl. Leaf injury was also observed. Unfortunately, the study does not document when the leaf injury was observed. Leaves showing slight tipburn were sampled and had 0.6% Cl content. Haas (1928) observed that normal, mature avocado leaves contained between 0.09 and 0.33 percent Cl, and tip-burned leaves contained between 0.54 and 1.21 percent Cl. Embleton et al. (1962) found that leaf Cl levels in the range of 0.25 to 0.5 percent were harmful in avocados.

Bingham and Fenn, 1966

Bingham and Fenn (1966) presented preliminary results to their study on Cl injury in avocado. The study was completely documented in Bingham et al. (1968), which was discussed extensively in the LRE. They observed that Cl uptake was rapid and reached a maximum value within two to three weeks after avocado trees were first subjected to Cl treatments. Further additions of Cl to the substrate resulted in an additional rapid increase in uptake. They concluded, "salt build up in the root zone even for short periods of time, say two to three weeks, would result in injurious quantities of Cl moving into the plant."

The authors also suggest that avocado trees likely tolerate some degree of leaf burn without registering reduction in production, though these limits were unknown at the time this study was published. In light of Haas (1950b) and other more recent studies (Berstein et al., 1994; Weisman, 2005) that demonstrate the effect of Cl on roots before leaf injury appears, the authors' suggestion is likely not valid.

Bingham et al., 1968

Bingham et al. (1968) conducted the most extensive study on Cl toxicity in avocado to date. Their study was conducted on grafted (Haas on Mexican root stock) avocado trees that were maintained in optimal nutrient solutions in outdoor sand tanks for two years. Treatments were imposed for four additional years.

The authors noted that wide fluctuations in soil salinity (and Cl concentration) in the root zone can occur during the irrigation season between irrigations. The significance of this pattern is shown by the results from leaf Cl analysis. In trees under the 10 meq/l Cl treatment, leaf Cl content increased from 0.02% to 0.7% during the first 6 weeks of treatment. Another rapid increase in Cl uptake was observed after the Cl concentration was increased to 15 meq/l. The authors suggested that "Under field conditions, relatively short periods of exposure to Cl within the root zone could conceivably lead to significant accumulation of Cl in the foliage and possibly to a level detrimental to the trees." Bingham et al. (1968) also observed that blossom set appeared to be reduced by excessive Cl; however, no data were provided in the article.

Downton, 1978

The study Downton (1978) conducted is unique in the literature because Cl treatments were applied to avocado trees for a period after which the trees were returned to less or non-saline conditions. Various measures of tree growth were monitored during the application period of the salinity treatments, as well as after the saline treatments were

stopped. This study, therefore, provides some information on the deferred effects of salt stress.

The study was conducted in a glasshouse on 1-year old avocado trees (1 year from graft.) The plants were treated with increasing treatments of NaCl for nine weeks, and then returned to less or non-saline (depending on the treatment) conditions for a period of 20 weeks. Stem diameter, shoot weight, flowering, and leaf tissue content were monitored. Flowering occurred two months after the treatment period ended.

The main results from this study for Fuerte scions grafted on Mexican rootstock were as follows:

- Growth as measured by stem diameter and dry weight was increasingly inhibited with increasing salinity. Even after the treatment period ended, slowed growth was observed, compared to the control treatment.
- Cl uptake occurred most rapidly in the first 16 days of treatment.
- Leaf Cl measured at harvest (following the 20-week non-saline period) reflected the pattern that was found in tissue samples taken after the 9-week treatment period. Leaf symptoms of Cl toxicity were evident in all trees receiving salt treatment.
- Flowering increased with salinity up to 10 mM NaCl, but was severely inhibited by 20 mM NaCl. No conclusions could be drawn about fertilization and fruit set, even though the study demonstrated that physiological stress promoted flowering to a certain extent.

The authors' main conclusion was that none of the salt-stressed plants showed a tendency to recover during the period of low-salt conditions, which indicates that injury to the trees was not immediately reversed.

GUSTAFSON, 1962

Gustafson (1962) conducted an experiment to find out if changing a conventional 2-3 week irrigation interval would reduce or eliminate tipburn on avocado trees. The author noted, as did Bingham and Fenn (1966), that Cl tends to by highest in the root zones of irrigated soils in Southern California from September to November, after which they are leached by winter rains. It follows, then, that Cl content is highest in leaf tissue in the fall as well. Gustafson also notes that fall is a critical time for injury because weather conditions are hot, dry and windy. The combination of these conditions with high soil Cl places stress on avocado trees. Therefore, fall irrigation is very important.

Gustafson (1962) also noted, by way of anecdote, the following:

> There have been cases where trees suffering extreme tipburn have been put on an excellent irrigation program, and the accumulation of salt in the soil has been reduced, and yet in the following year tipburn is still evident on the leaves. This might indicate the possibility of a carryover of Cl in the tree.

KADMAN, 1963

Kadman (1963) demonstrated that the rate of transpiration influences the rate of Cl uptake. Transpiration of trees in this experiment increased during hot, dry weather. The author observed that when trees were irrigated with high concentrations of NaCl in irrigation water, no injury symptoms were noticeable during the first month of treatment. During the

second month, tipburn started to appear. During the third month of treatment, symptoms of Cl toxicity were severe and culminated in leaf necrosis (death).

MONTGOMERY-WATSON, 1997

Montgomery-Watson (1997) conducted a field study that compared the effects of reclaimed water and potable water on growth, fruit quality, and yield of mature avocados. The four-year study used four irrigation treatments as follows:

1. 100% potable water (76 ppm Cl)
2. 50% potable water and 50% reclaimed water (169 ppm Cl)
3. 100% reclaimed water (262 ppm Cl)
4. 100% reclaimed water applied at 140% ET (262 ppm)

The most relevant results from this study are those from leaf tissue sampling. Leaves were sampled for Cl content in July and September of all years (1992 through 1995). In 1995, the last year of the study, leaf Cl content increased from 0.13 to 0.70 percent from July to September. This pattern was similar in other years. The authors observed that this increase occurred during this time period (July to September) in all treatments. They also noted that in all of the reclaimed water treatments, unacceptable levels of tipburn occurred in the trees. Embleton et al. (1962) advised that leaf Cl content from 0.3 to 0.5 percent is indicative of injury. Amrhein (1999) noted that leaf Cl content in this two-month period escalated from non-hazardous levels to above hazardous levels in this study.

The authors also noted that yield is a result of a 13 to 16-month growth cycle, and that many factors throughout that time period could affect yield.

PATEL ET AL.,1976

Though this study intended to study salt and, in particular, sodium effects on avocado growth, leaf tipburn that is distinctive and typical of Cl injury was observable after the first four weeks of treatment. The authors confirmed that Cl was 25 times higher than sodium in severely tipburned leaves.

2.2.3 SUMMARY OF RELEVANT CONCEPTS IN LRE STUDIES

Table 3 summarizes the studies that observed short-term and in some cases, long-term effects of Cl and/or salt stress on avocado growth. Cl treatment concentrations were high (i.e., well over the 100-120 guideline range determined by the LRE) because most of the studies were conducted in controlled environments where there are few other stresses on growth. Under these circumstances, higher Cl treatments were utilized in order for effects from Cl to be observable. The Montgomery-Watson (1997) study was conducted in the field, and injury was observed in treatments at a lower Cl concentration (169 mg/L) due to the presence of other stresses on growth.

TABLE 3 MINIMUM AMOUNT OF TIME CHLORIDE INJURY APPEARED AFTER EXPOSURE WAS INITIATED

Study	Minimum amount of time, after chloride stress was initiated, when injury occurred	Lowest chloride content in treatment that caused injury (mg/l)
Ayers, 1950	4 to 8 weeks	247.5 (408 ppm as NaCl)
Bingham and Fenn, 1966	2 to 3 weeks	356 (10 meq/l)[a]
Bingham et al., 1968	6 weeks	356 (10 meq/l Cl as NaCl)
Downton, 1978	9 weeks or under	178 (5 meq NaCl)
Kadman, 1963	4 to 8 weeks	303 (500 ppm NaCl)
Montgomery-Watson, 1997	8 weeks	169
Patel	4 weeks	215 (10 meq NaCl)

The authors only provided data for the 10 meq/l treatment; however, they also noted that similar relations were observed for more dilute Cl concentrations.

The relevant information from the LRE studies is summarized by the following points:

- Cl treatments from the relevant LRE studies were at levels higher than the recommended LRE guideline range of 100-120 mg/L.
- Cl toxicity symptoms from these relevant LRE studies appeared relatively soon (on the order of weeks) after exposure to Cl excess began.
- Stress caused by Cl excess can affect avocado growth even after the stress has been removed.
- Cl uptake is highest near the beginning of the exposure period.

3 ADDITIONAL LITERATURE REVIEW

The following sources were consulted for information on avocado growth and physiological functions. They did not give specific information on Cl sensitivity during particular periods of growth, nor did they make recommendations on how long a compliance averaging period should be. Therefore, these studies were not ranked in the scoring system (See Table 1).

- Arpaia, M.L. (University of California), Fetscher, A.E. (University of California) and R. Hofshi (del Rey). Undated. Avocado Flowering Basics http://www.ucavo.ucr.edu/AvocadoWebSite%20folder/AvocadoWebSite/Flowering/FloweringBasics.html
- Arpaia, M.L. General Introduction to Avocados http://www.ucavo.ucr.edu/AvocadoWebSite%20folder/AvocadoWebSite/General/Introduction.html
- Bergh, B.O. 1973. Adapted from The Remarkable Avocado Flower California Avocado Society Yearbook. 57:40–41 http://ucavo.ucr.edu/avocadowebsite%20folder/avocadowebsite/Flowering/RemarkableFlower.html
- Martin, G. and G. Witney. 1995. Avocado field grafting anew. Proceedings of The World Avocado Congress III, 1995 pp. 217 – 222.
- Robinson, P.W., M.V. Mickelbart, X. Liu, C. Adams, G. Witney, and M.L. Arpaia. 2002 Development of a Phenological Model of Avocado Tree Growth in California. ISHS Acta Horticulturae 575: 859-864. International Symposium on Tropical and Subtropical Fruits http://www.actahort.org/books/575/575_102.htm
- University of California, Agriculture and Natural Resources. 2007. UC Pest Management Guidelines. http://www.ipm.ucdavis.edu/PMG/r8100111.html

The following sources were cited but not reviewed because they were secondary sources in the two sources above by Arpaia. These sources neither made recommendations on compliance averaging periods, nor provided specific information on Cl exposure and injury.

- Chandler, W.H. 1958. Evergreen Orchards. Lea & Febiger, Philadelphia.
- Inoue, H., and B. Takahashi. 1989. "Differentiation and Development of Avocado Flower Buds in Japan." Journal of the Japanese Society for Horticultural Science 58(1): 105-111.
- McGregor, S. E. 1976. Insect Pollination of Cultivated Crop Plants. Agric. Handbook. No. 496) USDA.
- Sedgley M., C. M. Annells. 1981. Flowering and fruit-set response to temperature in the avocado cultivar 'Hass'. Sci. Hortis. 14:27-33.
- Thorp, T.G. and M. Sedgley. 1992. Shoot growth and tree architecture in a range of avocado cultivars. Proc. Second Wold Avocado Congr. 1:237-240.
- Whiley, A.W. and B. Schaffer. 1994. Avocado. In: Handbook of Environmental Physiology of Fruit Crops, Volume II. Subtropical and Tropical. B. Schaffer and P.C. Andersen (eds.). CRC Press, Inc., Boca Raton, Florida, pp. 3-35.

- Wolstenholme, B.N., and A. W. Whiley. 1992. Requirements for improved fruiting efficiency in the avocado tree. Proceedings of Second World Avocado Congress 1992 pp 161-167.

4 REVIEW OF PROJECT TEAM QUESTIONS

In September 2006, the Project Team submitted questions to the co-chairs of the AGTAP, Dr. Ben Faber and Dr. Stephen Grattan, to acquire more information about an appropriate compliance averaging period for the LRE Cl guidelines. These questions, the responses from Dr. Faber and Dr. Grattan, and a review of these responses are provided in the following section.

1. Should the LRE guidelines be applied as a chronic threshold (i.e., an average over some specified period of time) or an acute threshold (a single sample never to be exceeded)?

Response from Dr. Grattan: It seems appropriate to me that the LRE guidelines be applied as a chronic threshold. The 110 to 120 mg/L range for the upper limit of Cl for the irrigation of avocado assumes long-term use under steady state conditions assuming the more Cl sensitive rootstock and that rainfall is not considered significant as an annual means of leaching or partially leaching Cl from the root zone. However, this assumes that the variation in irrigation Cl concentration is not large.

Response from Dr. Faber: I would think it should be set as a chronic threshold, since you never know when hot, dry winds might kick up. I've seen avocado trees show leaf burn symptoms a week after a Santa Ana condition.

Review: The literature from the LRE indicates that the guidelines should be applied as a chronic threshold. Though studies from the LRE were both short- and long-term, studies were conducted to test for chronic exposure, not acute exposure.

The response from Dr. Faber speaks to the concept that there might not be a "critical period"; every period is critical because every stress affects growth, regardless of when it occurs.

2. If the LRE guidelines are to be applied as a chronic threshold, what is the appropriate averaging period (e.g., 12-month average, 6-month average, 1-month average, etc.)?

Response from Dr. Grattan: Because avocados are so sensitive to salinity and Cl and that they represent a long-term investment, I would tend to error on the safe side. As indicated by Ben Dr. Faber, trees may be particularly susceptible should an additional stress present itself such as Santa Ana winds. Therefore I would suggest that a shorter time interval be used (one month seems appropriate but is somewhat dependent on the extent by which Cl deviate from the mean) (see #3).

Response from Dr. Faber: I would think the averaging period would be the shortest period possible, since the weather is quite variable along the coast – hot in January and cold in June some years.

Review: The appropriate averaging period should consider the minimum time for exposure to Cl excess to cause injury. As Dr. Grattan points out, a shorter time interval is appropriate, and is only somewhat dependent on the extent by which Cl deviates from the mean. Dr. Faber's response indicates that an averaging period that spanned more than one season (i.e. 6 months) would be too long.

Dr. Grattan also points out that avocados are a long term investment. This is significant, especially because "annual production in California and elsewhere suffers fluctuations

caused by periodic freezes, droughts, winds, or other factors including the alternate bearing habit of the crop" (Wolstenholme and Whiley, 1992).

3. Is the averaging period dependent upon the magnitude by which the Cl concentration deviates from the average?

Response from Dr. Grattan: I do believe that the extent by which Cl deviates from the mean should affect the averaging period. If deviations are in the 10-20% range, perhaps 6 month averages or longer is more appropriate. If Cl concentrations double over a short period of time, then shorter periods may be appropriate. Hopefully this is not the case because a doubling in Cl (eg 120 to 240mg/L), even for a short period of time, may be extremely detrimental to this salt-sensitive tree. Perhaps a dual chronic/acute interim limit is appropriate at this point in time. More research is needed to get a better idea on plants response averages and deviations. Such a study could readily be conducted.

Response from Dr. Faber: Not sure what the question is? If the concentration average varies slightly, then the averaging period can be longer. If there are sharp spikes, it should probably be shorter, such as a month.

Review: As Dr. Grattan pointed out in the response to Question 2, the averaging period is only somewhat dependent on the magnitude by which the Cl concentration deviates from the mean. Dr. Grattan (2007) qualified that the suggested range of deviation of 10 to 20 percent was a best guess, based on personal experience and professional judgment. In fact, that suitable range of deviation may be higher or lower depending on the sensitivity of the plant. Furthermore, the effect of deviations in Cl concentration from the mean depend on how frequently they occur (Dr. Grattan, 2007). Therefore, while the averaging period will level out the fluctuations in Cl concentration, it should still represent the nature of the pattern of Cl concentration changes.

4. Are there growth stages for avocado, strawberry, and nursery plants that are especially susceptible to Cl hazard, i.e., if the crop is exposed to Cl at that stage, the Cl hazard will be more than if exposed at other growth stages? If yes, how long is the sensitivity period?

Response from Dr. Grattan: This is a really good question and I don't think the research is adequate enough to adequately address this issue. We know that tolerance in most plants varies with stage of development. Many annual crops are generally sensitive during early growth and development. Tree crops can be sensitive to specific ion toxicities, particularly over long periods of time. I would defer this question to Ben since he has had more practical experience than me. This too is a researchable topic.

Response from Dr. Faber: Typically flowering and fruiting are the most sensitive periods for avocado and strawberry. For nursery plants, as well, but often they are sold for the foliage condition.

Review: Literature from the LRE indicates that most crops are more susceptible to salinity and other stresses during early growth stages; however, the duration of exposure may be more important in determining overall effect than any particular period of exposure (Shalhevet, 1999). In fact, Shalhevet (1999) maintains that growth stage is difficult to isolate and study and calls into question those studies that have produced results concerning growth stage as a dependent factor in injury. Dr. Faber's response is indicative of the all-season sensitivity of nursery crops to any kind of injury. This is largely because nursery crops are sold for their appearance, not for their level of production. (See section 6 for a more detailed explanation of critical growth periods.)

5. Is it possible for the Cl hazard to occur at a short period of time, but the symptoms (such as leaf injury and yield) will be shown at much later time? If it is possible, how long would the period of time that causes Cl hazard be?

Response from Dr. Grattan: I am aware of some research that describes no ill effects of a crop until a hot, dry day comes about. Researchers describe injury at that time as being instantaneous. If the plants are sensitive at flowering, then the damage that occurs during flowering may be subtle, yet such subtle damages could translate into large yield losses later on (ie harvest).

Response from Dr. Faber: It's possible to have damage and not see it until a stress, such as a Santa Ana comes along. Not sure how long the hazard needs to be in place.

Review: There are few studies that specifically address how long a Cl hazard has to be in place for it to have lasting effects. It is clear that at high concentrations of Cl, stress over a period of 4 to 8 weeks produces symptoms of Cl injury; however, it is unclear how long exposure must be before the effects of Cl stress will carry over. In addition, the frequency of applied stress has not been addressed. It is likely that three components of Cl hazard affect the overall effects of Cl toxicity: 1) duration of exposure; 2) intensity of exposure; 3) frequency of exposure.

The literature from the LRE indicates that the answer to the first part of this question is yes (see Downton, 1978; Gustafson, 1962). In Downton's study (1978), the period of exposure that caused a delayed injurious effect the plants was 9 weeks. However, injury was observed during the period of exposure at 9 weeks (or possibly sooner). There are no other studies that applied Cl excess for a shorter period than 9 weeks and then removed the stress.

6. Are the terms "acute" and "chronic" suitable to describe Cl hazard to plants?

Response from Dr. Grattan: I think for salt or Cl sensitive crops, such terms are suitable.

Response from Dr. Faber: Again not sure what length of time it takes to impact plant growth and yield.

Review: Though these terms may be suitable in some instances, there is not information available to determine an acute Cl hazard to avocado trees, as determined by the LRE.

5 REVIEW OF PROJECT TEAM ANALYSES

5.1 INTRODUCTION

The responses given by Drs. Faber and Grattan in the above section indicated that the length of the compliance averaging period is related to the variability of the Cl content in the waters of concern. The District and the Board then conducted separate analyses of the Cl variability, to help determine the relative length of the compliance averaging period. A review of those analyses is provided in the following section.

5.2 REVIEW OF CHLORIDE VARIABILITY ANALYSIS – SANTA CLARITA VALLEY SANITATION DISTRICT

5.2.1 METHODOLOGY

Water quality data for the Santa Clara River at the Camulos Ranch Diversion is available from January 2000 to December 2006. The District analyzed the Cl data by comparing monthly grab samples of surface water with the preceding 12-month and 6-month rolling averages of the monthly grab samples (Guerrero, 2007).

Usually, deviation from the mean is determined by comparing each datum to the mean calculated for the whole period of record. Choosing a particular averaging period against which to compare data to determine the range of deviation is questionable, because of the random nature by which the averaging period is chosen. This methodology might be appropriate if the averaging periods were similar, i.e., each year had similar data, which is not the case. Cl data from any given year is different from any other year because of changes in yearly precipitation. For example, 2003 had low annual precipitation and high Cl measurements resulted. Averaging monthly Cl measurements against 12-rolling averages during that year would not necessarily show there was greater deviation, and would mask the higher overall Cl level.

The methodology might also be appropriate if avocado had a high capacity to adapt to saline environments. If that were the case, it would seem appropriate to compare any given Cl concentration to the concentrations that came immediately before it. However, it is unlikely that avocado has this ability to adapt to saline environments to any significant degree, because of its high sensitivity to salt and Cl.

Given that 6- or 12-month periods in the period of record are not particularly similar (See Section 7), and that avocado likely has little ability to increase its tolerance to excess salinity exposures, a more accurate method of determining how much Cl variation deviates from the mean would be to compare deviations from mean conditions over the entire period of record.

5.2.2 RESULTS

The District determined that most of the historic ratios of monthly to 6-month and 12-month averages were within 20 percent of the mean. The District further suggested that this analysis and guidance from the AGTAP co-chairs indicates that a 12-month average compliance period is appropriate for Cl.

In Dr. Grattan's responses to Question 2 and 3 of the Supplemental Request to AGTAP on Averaging Periods (Section 4), he stated that the averaging period is somewhat dependent

(and not entirely dependent) on the extent by which Cl deviates from the mean. The determination of an appropriate averaging period needs to also take into account the duration of exposure to excess Cl that causes injury. Hence, both the deviation from mean conditions and the time it takes excess Cl to cause injury should be considered together. For example, variability outside of the 20 percent range might not occur until the averaging period was increased by several more months beyond 12, but that should not imply that the averaging period should be that long.

5.3 Review of Chloride Variability Analysis – Regional Water Quality Control Board

5.3.1 Methodology

The Board determined deviation from the mean by comparing each monthly datum to the mean of the entire period of record (Chu, 2007). As previously stated, this method is the conventional way to determine how much data varies.

5.3.2 Results

The Board had similar results to those of the District, even though different methodologies were used. Both determined that the majority of the time, Cl varied within 20 percent of the mean. However, because the mean represented the whole period of record, spikes in Cl were more apparent in their analysis. (The difference between the amount of exceedances of the 20 percent range found by the District and by the Board is unknown because the Board did not provide the results of their analysis in tabular form.) For example, during 2003, Cl varied above the 20 percent range in several months. In 2005, a wet year, Cl varied below the 20 percent range. The Board thus concluded that an averaging period of 6 months or longer is not appropriate because of the deviations that can occur in wet and dry years. The Board also determined that variance was outside of the 10 percent range in most years, and this should further support the need for a shorter averaging period.

Further to these findings, the Board suggested that the averaging period should be no longer than two days because "the flowering stage for avocado generally lasts for two days" (Chu, 2007). However, it should be noted that the avocado tree functions such that each avocado flower opens during a two-day period, but there are over one million flowers on each tree, opening and closing on different days over a period of several weeks (Arpaia, undated; Arpaia et al., undated; Bergh, 1973). Even under ideal conditions, only a very small fraction of these flowers result in an actual avocado being produced. The flowering stage lasts for several weeks, up to approximately three months. (See Section 6 for more explanation of avocado flowering.) Therefore, the averaging period can reasonably be much longer than two days, even if critical growth stages are considered.

6 FEASIBILITY OF ESTABLISHING A RANGE OF COMPLIANCE AVERAGING PERIODS

6.1 INTRODUCTION

The feasibility of establishing a range of compliance averaging periods depends on the following factors identified by the Project Team and the review of the LRE:

- Critical growth stages
- Sensitivity during critical growth periods and physiological functions
- Timing of weather conditions that cause stress to avocado trees
- Timing of soil Cl conditions that cause stress to avocado trees

These factors are addressed in the following section.

6.2 CRITICAL GROWTH STAGES

It is generally assumed that young trees are more susceptible to environmental stresses than mature trees. For example, Martin and Witney (1995) note that summer heat soon follows the beginning of graft growth in newly grafted trees. They further explain that summer heat inhibits the growth of young developing grafts, which then have to be strong enough for fall winds and low winter temperatures.

However, Shalhevet (1994) reviewed several studies on salinity and growth stage in different crops, and stated that duration of exposure is even more important than growth stage in determining damage from salinity. The author reasons that it is difficult to isolate growth stages in experiments, and that duration of salinization may be more significant than sensitivity during a critical stage of growth. He concludes that the seedling stage of growth is the most sensitive to higher levels of salinity. However, since soil salinity changes with time are generally gradual, the best way to approximate the exposure to salinity is to weight the average salinity a plant experiences over the duration of its life. No similar studies were found that examined avocado exposure to Cl in particular.

In any case, it would be difficult to determine the maturity of avocado orchards at any point in time, in the study area. At any given time, the age of avocado orchards might range from newly planted to very mature (20 or more years old).

6.3 CRITICAL GROWTH PERIODS AND CRITICAL ENVIRONMENTAL CONDITIONS

6.3.1 CRITICAL GROWTH PERIODS ASSOCIATED WITH PHYSIOLOGICAL FUNCTIONS

FLOWERING AND FRUIT SET

Avocado flowering behavior is unique in that each flower has functional male and female parts. Each flower opens at different times as either male or female over a period of two days. “A” type avocado varieties have flowers that open as female in the morning of the first day (for a few hours), close and then open as male and shed pollen on the afternoon of the second day. “B” type varieties open as female on the afternoon of the first day, close, and then open in the male phase shedding pollen on the morning of the second day. In both

cases, once the flower closes after the male phase, it does not open again. This flowering behavior is known as synchronous dichogamy, and promotes cross-pollination.

Each avocado tree can produce in excess of a million flowers (Bergh, 1973). Though each flower is only functional for a few hours over a period of two days, there are hundreds of flowers opening in both stages, day after day, for the entire flowering period. According to the calendar in the Avocado Handbook, (Ventura County Cooperative Extension, 2007), flowering typically occurs in Haas avocados in March, April and May. However, the flowering period can be shortened or extended depending on environmental conditions. MacGregor (1976) explains that "Avocado flowering may extend from one to several months depending upon conditions affecting fruit setting. A sufficient supply of pollinating agents will tend to shorten the period of flowering."

MacGregor (1976) suggested that only a small fraction of 1 percent of flowers actually produce fruit. Whiley and Schaffer (1994) found that usually, less than 0.1% of the flowers set fruit and most of these fruit abscise within 6 weeks from full bloom. Timing and conditions have to be right for pollination, fertilization, and fruit set to be successful on each flower and produce an avocado fruit. The three climatic factors that influence flowering and fruit set are as follows (Arpaia, undated):

1. Frost in winter
2. Low temperatures during flowering and fruit set
3. High temperatures during fruit set

Low temperatures (< 10C) during bloom can negatively affect flowering and fruit set. Temperatures exceeding 35C has also been shown to negatively influence flowering, fruit set and fruit retention for Hass (Sedgely and Annells, 1981). Flowering behavior is surprisingly regular and exact when the average temperature (night minimum and day maximum) is above 70 degrees F (21.1 C). As temperatures fall, the daily openings become delayed and become irregular, so that a single tree may have flowers in both female and male stages at the same time. As the average temperature falls below about 70 F, the flower parts function less well. Below about 60 F (15.5 C), there may be zero set (Bergh, undated).

Wind can also adversely affect fruit set by blowing flowers off trees (Arpaia et al., undated).

BUD INITIATION

One study demonstrated that at least three varieties of avocado (Zutano, Julna and Fuerte) initiate budding in November (Inoue and Takahashi, 1989). It is likely for this reason that frost during the winter, before flowering has begun, can adversely affect flowering (Arpaia, undated).

CYCLICAL SHOOT GROWTH

Avocado has a cyclical growth pattern. This means that growth does not occur at a constant rate throughout the year. Rather, shoots have growth spurts or shoot flushes. There may be one to six per year (Thorp and Sedgley, 1992). Experiments conducted in this study area have documented two main shoot flushes per year – one in the spring and one in the early summer (Robinson et al., 2002). However, there are no studies that compared that timing of Cl stress in relation to shoot growth, and how that affects production. In other words, shoot flushes may also represent critical growth periods, but it is uncertain how stress during these periods might or might not affect production overall.

6.3.2 Critical Environmental Conditions

Santa Ana Winds

Santa Ana winds are hot, dry winds that usually occur in the autumn and early winter in Southern California. However, Faber (2007) notes that recently they have started occurring as late as March. Hot, dry conditions strain avocado growth, likely because the avocado evolved in a humid, temperate environment, and functions best in temperate and slightly humid conditions (CH2M HILL, 2005). Wind increases transpiration gradient by drying the leaf, and increased transpiration results in increased Cl uptake (CH2M HILL, 2005).

Temperature and Humidity

As explained above, temperature is critical during the flowering period, and temperature extremes during the non-flowering period can also affect flowering and fruit set. Temperature and humidity also affect the rate that avocado trees take up Cl. Cl uptake increases as transpiration increases. Conditions that increase transpiration are high heat, humidity and windy conditions. These are all typical conditions during the summer months.

Soil Chloride

Soil Cl typically builds up during the summer irrigation season and reaches a peak during the fall, when irrigation declines or stops, and before winter rains can leach them below the root zone. This pattern was recognized by Bingham and Fenn (1966) and Gustafson (1962).

Faber (2004) noted that during dry years, avocado orchards had leaf burn in the spring from the accumulation of salts that occurred during winter irrigation. During the spring of 2004, avocados dropped salt-burned leaves when flowering began (Faber, 2004).

Figure 1 is a calendar that shows when critical physiological functions and critical environmental conditions for avocados occur. During some months, more than one critical condition may occur. For example, in the autumn months, soil Cl is at a peak while Santa Ana winds are likely to occur.

6.4 Critical/Non-Critical Compliance Averaging Period vs. Overall Compliance Averaging Period

Flowering is considered a critical time in the seasonal growth and production of avocado trees, because it determines fruit set, and therefore yields. The review literature indicates that stresses before and during the flowering period influence flowering and the ability of avocado trees to set fruit. The stresses that are referred to in these review documents are associated with weather, such as extreme heat, cold, or wind (Arpaia, undated). There is no literature stating that Cl or salt stress during flowering affects or does not affect fruit set.

As described in Section 2, Downton (1978) demonstrated that applied Cl stress (at levels of >178 mg/L) affect avocado growth even after the stress has been removed, and salt stress decreased tree growth, but stimulated flowering when it was applied previous to the flowering period. As the author of this study noted, physiological stress is known to promote flowering in many species. How this increased flowering is related to fruit set, and how this physiological stress affected other aspects of tree growth, was not explored by this author or by any others, as found in this literature review.

The autumn months (September and October) are considered critical environmental periods in avocado production because of multiple stresses that result from weather, and

potentially high Cl soil conditions that result from irrigation. Experts believe that multiple stresses can seriously affect avocado tree growth and production (Gustafson, 1962; Bingham and Fenn, 1966; Faber's response to Questions 1 and 5 above). This period may also be the time when earlier stresses reveal themselves, even though they were not apparent at the time (Faber's response to Questions 1 and 5 above.)

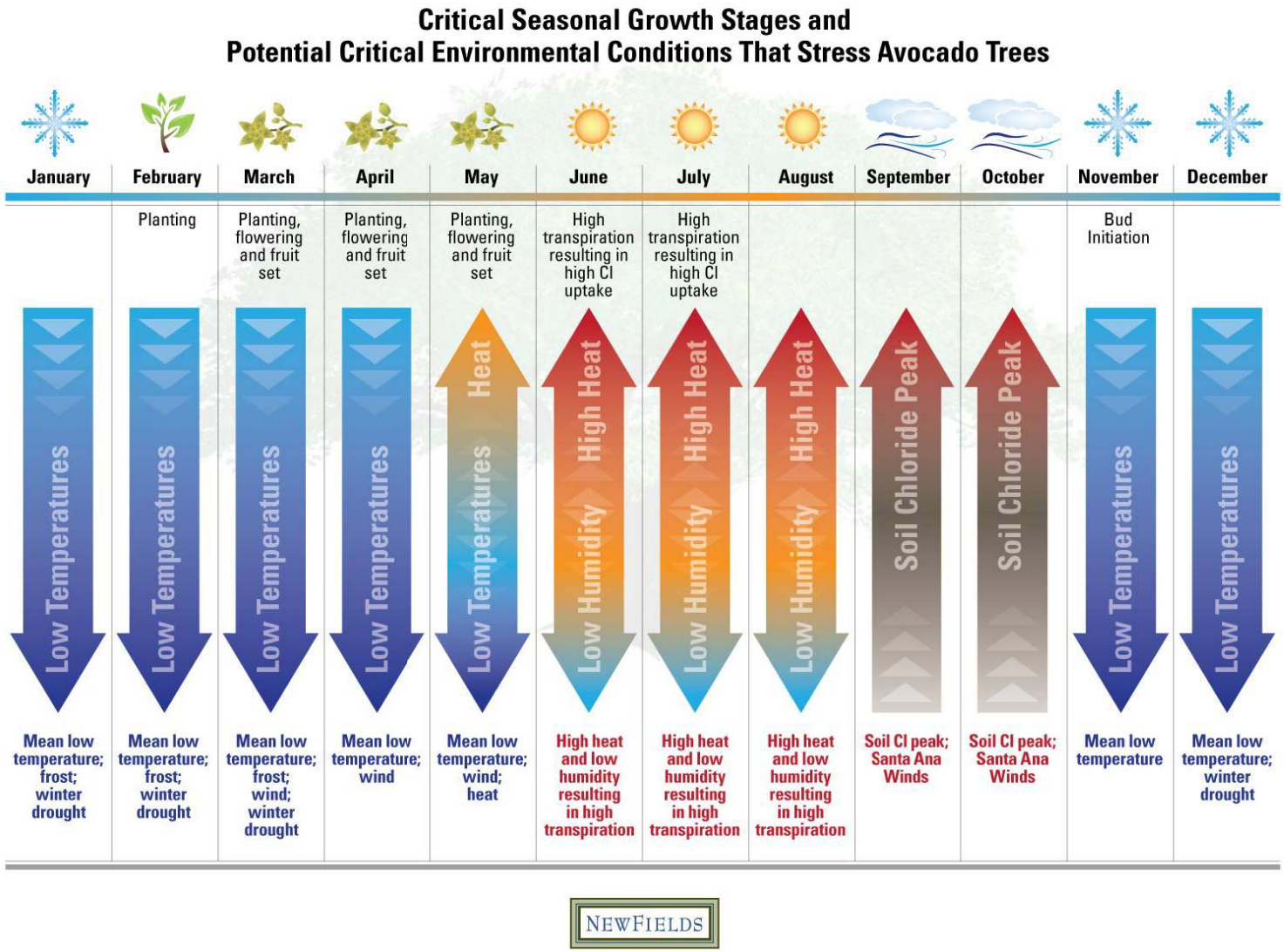
Another consideration is root rot, caused by the pathogen *Phytophthora cinnamomi.* Root rot is the most serious avocado disease (University of California, 2007) because it is prevalent and very difficult to remove once it infects soil. Cl stress induces conditions for root rot infection (Faber, 2004; University of California, 2007) regardless of time of year; however, wet soil conditions that usually occur during the winter months are ideal for root rot infection.

Therefore, there are at least three reasons why it may be difficult to determine a critical and non-critical compliance averaging period by considering physiological functions and environmental conditions, as follows:

1. **The stress of Cl excess is carried over after the stress is removed.** In other words, even if the period in which Cl excess occurs is not "critical," the Cl excess may have a critical effect on avocado growth and production. In particular, stress that occurs during the non-flowering and non-fruit set period can be carried over to affect those physiological functions during those times. These functions are critical to yield. Though only climatic stress has been indicated as such stress, it is likely that Cl excess would create additional stress and may negatively affect avocado production. This scenario would be similar to the multiple stresses described below.
2. **There are too many "critical periods" during the year, considering plant-specific and environmental critical periods.** Multiple stresses on avocado trees during the fall months resulting from high soil Cl and hot, dry conditions; flowering and fruit set during the spring; heat during summer months; and perhaps bud initiation in the early winter are critical times that account for much of the year, even without considering the carry over of Cl stress from other non-critical times.
3. **Duration of exposure is likely more important than growth stage or critical period at which exposure occurs.** The studies cited from the LRE did not specifically investigate particular growth stages or critical periods of physiological function, yet they all produced results within a relatively small range: visible leaf injury from Cl appeared between 2 and 9 weeks after exposure. Furthermore, they all used different rates of Cl. In addition, Shalhevet (1999) reviewed several studies and found that duration, not critical period, was the important factor in determining injury from salinity, though Cl was not specifically reviewed.

Another approach would be to determine if there were seasonal patterns of Cl in the irrigation water quality data. This memorandum did not evaluate seasonal patterns in depth, but based on a cursory review of the data, it does appear that chloride concentrations increase in dry years and decrease in wet years, as it relates to precipitation. This effect could be studied in further detail to assess whether a compliance period could be different based on certain rainfall conditions.

FIGURE 1



NEWFIELDS

7 DETERMINATION OF A COMPLIANCE AVERAGING PERIOD FOR CHLORIDE

The following analysis using the monthly data at LACSD station RF was performed to determine at what point the averaging period becomes too long. This data was used with the assumption that there is relatively little intra-month variability, as indicated by the limited hourly sampling data provided by the District (Guerrero, 2007). Rolling averages were calculated for 12-month, 6-month, 3-month, 2-month and 1-month periods. These averages are provided in Table 4. The rolling averages were calculated by averaging the current month with the number of preceding months needed to provide the average. For example, the 2-month average for August 2000, is an average of the July and August 2000 monthly samples.

TABLE 4 ROLLING AVERAGES FOR 2, 3, 4, 5, 6, AND 12 MONTH PERIODS

		Averaging Periods					
Month-Year	Cl (mg/L)	2-month	3-month	4-month	5-month	6-month	12-month
Jun-00	123	--	--	--	--	--	--
Jul-00	122	122.50	--	--	--	--	--
Aug-00	128	125.00	124.33		--	--	--
Sep-00	122	125.00	124.00	123.75	--	--	--
Oct-00	ND	122.00	125.00	124.00	123.75	--	--
Nov-00	110	110.00	116.00	120.00	120.50	121.00	--
Dec-00	117	113.50	113.50	116.33	119.25	119.80	--
Jan-01	122	119.50	116.33	116.33	117.75	119.80	--
Feb-01	110	116.00	116.33	114.75	114.75	116.20	--
Mar-01	98.4	104.20	110.13	111.85	111.48	111.48	--
Apr-01	ND	98.40	104.20	110.13	111.85	111.48	--
May-01	119.5	119.50	108.95	109.30	112.48	113.38	117.19
Jun-01	ND	119.50	119.50	108.95	109.30	112.48	116.54
Jul-01	120	120.00	119.75	119.75	112.63	111.98	116.32
Aug-01	130	125.00	125.00	123.17	123.17	116.98	116.54
Sep-01	133	131.50	127.67	127.67	125.63	125.63	117.77
Oct-01	112	122.50	125.00	123.75	123.75	122.90	117.19
Nov-01	129	120.50	124.67	126.00	124.80	124.80	119.09
Dec-01	128	128.50	123.00	125.50	126.40	125.33	120.19
Jan-02	125	126.50	127.33	123.50	125.40	126.17	120.49
Feb-02	127	126.00	126.67	127.25	124.20	125.67	122.19
Mar-02	125	126.00	125.67	126.25	126.80	124.33	124.85

Apr-02	133	129.00	128.33	127.50	127.60	127.83	125.59
May-02	136	134.50	131.33	130.25	129.20	129.00	127.09
Jun-02	138	137.00	135.67	133.00	131.80	130.67	128.00
Jul-02	141	139.50	138.33	137.00	134.60	133.33	129.75
Aug-02	142	141.50	140.33	139.25	138.00	135.83	130.75
Sep-02	152	147.00	145.00	143.25	141.80	140.33	132.33
Oct-02	154	153.00	149.33	147.25	145.40	143.83	135.83
Nov-02	142	148.00	149.33	147.50	146.20	144.83	136.92
Dec-02	140	141.00	145.33	147.00	146.00	145.17	137.92
Jan-03	149	144.50	143.67	146.25	147.40	146.50	139.92
Feb-03	129	139.00	139.33	140.00	142.80	144.33	140.08
Mar-03	145	137.00	141.00	140.75	141.00	143.17	141.75
Apr-03	130	137.50	134.67	138.25	138.60	139.17	141.50
May-03	144	137.00	139.67	137.00	139.40	139.50	142.17
Jun-03	163	153.50	145.67	145.50	142.20	143.33	144.25
Jul-03	145	154.00	150.67	145.50	145.40	142.67	144.58
Aug-03	151	148.00	153.00	150.75	146.60	146.33	145.33
Sep-03	133	142.00	143.00	148.00	147.20	144.33	143.75
Oct-03	138.9	135.95	140.97	141.98	146.18	145.82	142.49
Nov-03	124	131.45	131.97	136.73	138.38	142.48	140.99
Dec-03	130	127.00	130.97	131.48	135.38	136.98	140.16
Jan-04	ND	130.00	127.00	130.97	131.48	135.38	139.35
Feb-04	132	132.00	131.00	128.67	131.23	131.58	139.63
Mar-04	142	137.00	137.00	134.67	132.00	133.38	139.35
Apr-04	142	142.00	138.67	138.67	136.50	134.00	140.45
May-04	138	140.00	140.67	138.50	138.50	136.80	139.90
Jun-04	138	138.00	139.33	140.00	138.40	138.40	137.63
Jul-04	141	139.50	139.00	139.75	140.20	138.83	137.26
Aug-04	141	141.00	140.00	139.50	140.00	140.33	136.35
Sep-04	137	139.00	139.67	139.25	139.00	139.50	136.72
Oct-04	138	137.50	138.67	139.25	139.00	138.83	136.64
Nov-04	138	138.00	137.67	138.50	139.00	138.83	137.91
Dec-04	139	138.50	138.33	138.00	138.60	139.00	138.73
Jan-05	ND	139.00	138.50	138.33	138.00	138.60	138.73

Feb-05	103.3	103.30	121.15	126.77	129.58	131.06	136.12
Mar-05	59.6	81.45	81.45	100.63	109.98	115.58	128.63
Apr-05	104	81.80	88.97	88.97	101.48	108.78	125.17
May-05	93.7	98.85	85.77	90.15	90.15	99.92	121.15
Jun-05	111	102.35	102.90	92.08	94.32	94.32	118.69
Jul-05	102	106.50	102.23	102.68	94.06	95.60	115.15
Aug-05	120	111.00	111.00	106.68	106.14	98.38	113.24
Sep-05	119	119.50	113.67	113.00	109.14	108.28	111.60
Oct-05	125	122.00	121.33	116.50	115.40	111.78	110.42
Nov-05	109	117.00	117.67	118.25	115.00	114.33	107.78
Dec-05	104	106.50	112.67	114.25	115.40	113.17	104.60
Jan-06	95.1	99.55	102.70	108.28	110.42	112.02	103.81
Feb-06	90.4	92.75	96.50	99.63	104.70	107.08	102.73
Mar-06	115	102.70	100.17	101.13	102.70	106.42	107.35
Apr-06	90	102.50	98.47	97.63	98.90	100.58	106.18
May-06	135	112.50	113.33	107.60	105.10	104.92	109.63
Jun-06	110	122.50	111.67	112.50	108.08	105.92	109.54
Jul-06	121.5	115.75	122.17	114.13	114.30	110.32	111.17
Aug-06	120	120.75	117.17	121.63	115.30	115.25	111.17
Sep-06	123	121.50	121.50	118.63	121.90	116.58	111.50
Oct-06	120	121.50	121.00	121.13	118.90	121.58	111.08
Nov-06	112	116.00	118.33	118.75	119.30	117.75	111.33
Dec-06	130	121.00	120.67	121.25	121.00	121.08	113.50
Average	125.67						

NOTE: ND = NO DATA

The mean of the Cl data for the entire period of record was 125.67 mg/l. The difference between each rolling average and this mean was calculated as a residual. These residuals are provided in Table 5.

TABLE 5 RESIDUALS FOR 1, 2, 3, 4, 5, 6, AND 12 MONTH ROLLING AVERAGE PERIODS

		Residuals						
Month-Year	Cl (mg/L)	1-month	2-month	3-month	4-month	5-month	6-month	12-month
Jun-00	123	--	--	--	--	--	--	--
Jul-00	122	--	-3.17	--	--	--	--	--
Aug-00	128	2.33	-0.67	-1.33	--	--	--	--
Sep-00	122	-3.67	-0.67	-1.67	-1.92	--	--	--
Oct-00	ND	NR	-3.67	-0.67	-1.67	-1.92	--	--
Nov-00	110	-15.67	-15.67	-9.67	-5.67	-5.17	-4.67	--
Dec-00	117	-8.67	-12.17	-12.17	-9.33	-6.42	-5.87	--
Jan-01	122	-3.67	-6.17	-9.33	-9.33	-7.92	-5.87	--
Feb-01	110	-15.67	-9.67	-9.33	-10.92	-10.92	-9.47	--
Mar-01	98.4	-27.27	-21.47	-15.53	-13.82	-14.19	-14.19	--
Apr-01	ND	NR	-27.27	-21.47	-15.53	-13.82	-14.19	--
May-01	119.5	-6.17	-6.17	-16.72	-16.37	-13.19	-12.29	-8.48
Jun-01	ND	NR	-6.17	-6.17	-16.72	-16.37	-13.19	-9.12
Jul-01	120	-5.67	-5.67	-5.92	-5.92	-13.03	-13.69	-9.35
Aug-01	130	4.33	-0.67	-0.67	-2.50	-2.50	-8.69	-9.12
Sep-01	133	7.33	5.83	2.00	2.00	-0.04	-0.04	-7.90
Oct-01	112	-13.67	-3.17	-0.67	-1.92	-1.92	-2.77	-8.48
Nov-01	129	3.33	-5.17	-1.00	0.33	-0.87	-0.87	-6.58
Dec-01	128	2.33	2.83	-2.67	-0.17	0.73	-0.33	-5.48
Jan-02	125	-0.67	0.83	1.67	-2.17	-0.27	0.50	-5.18
Feb-02	127	1.33	0.33	1.00	1.58	-1.47	0.00	-3.48
Mar-02	125	-0.67	0.33	0.00	0.58	1.13	-1.33	-0.82
Apr-02	133	7.33	3.33	2.67	1.83	1.93	2.17	-0.08
May-02	136	10.33	8.83	5.67	4.58	3.53	3.33	1.42
Jun-02	138	12.33	11.33	10.00	7.33	6.13	5.00	2.33
Jul-02	141	15.33	13.83	12.67	11.33	8.93	7.67	4.08
Aug-02	142	16.33	15.83	14.67	13.58	12.33	10.17	5.08
Sep-02	152	26.33	21.33	19.33	17.58	16.13	14.67	6.67
Oct-02	154	28.33	27.33	23.67	21.58	19.73	18.17	10.17
Nov-02	142	16.33	22.33	23.67	21.83	20.53	19.17	11.25
Dec-02	140	14.33	15.33	19.67	21.33	20.33	19.50	12.25

Jan-03	149	23.33	18.83	18.00	20.58	21.73	20.83	14.25
Feb-03	129	3.33	13.33	13.67	14.33	17.13	18.67	14.42
Mar-03	145	19.33	11.33	15.33	15.08	15.33	17.50	16.08
Apr-03	130	4.33	11.83	9.00	12.58	12.93	13.50	15.83
May-03	144	18.33	11.33	14.00	11.33	13.73	13.83	16.50
Jun-03	163	37.33	27.83	20.00	19.83	16.53	17.67	18.58
Jul-03	145	19.33	28.33	25.00	19.83	19.73	17.00	18.92
Aug-03	151	25.33	22.33	27.33	25.08	20.93	20.67	19.67
Sep-03	133	7.33	16.33	17.33	22.33	21.53	18.67	18.08
Oct-03	138.9	13.23	10.28	15.30	16.31	20.51	20.15	16.82
Nov-03	124	-1.67	5.78	6.30	11.06	12.71	16.82	15.32
Dec-03	130	4.33	1.33	5.30	5.81	9.71	11.32	14.49
Jan-04	ND	NR	4.33	1.33	5.30	5.81	9.71	13.69
Feb-04	132	6.33	6.33	5.33	3.00	5.56	5.91	13.96
Mar-04	142	16.33	11.33	11.33	9.00	6.33	7.71	13.69
Apr-04	142	16.33	16.33	13.00	13.00	10.83	8.33	14.78
May-04	138	12.33	14.33	15.00	12.83	12.83	11.13	14.23
Jun-04	138	12.33	12.33	13.67	14.33	12.73	12.73	11.96
Jul-04	141	15.33	13.83	13.33	14.08	14.53	13.17	11.60
Aug-04	141	15.33	15.33	14.33	13.83	14.33	14.67	10.69
Sep-04	137	11.33	13.33	14.00	13.58	13.33	13.83	11.05
Oct-04	138	12.33	11.83	13.00	13.58	13.33	13.17	10.97
Nov-04	138	12.33	12.33	12.00	12.83	13.33	13.17	12.24
Dec-04	139	13.33	12.83	12.67	12.33	12.93	13.33	13.06
Jan-05	ND	NR	13.33	12.83	12.67	12.33	12.93	13.06
Feb-05	103.3	-22.37	-22.37	-4.52	1.10	3.91	5.39	10.45
Mar-05	59.6	-66.07	-44.22	-44.22	-25.03	-15.69	-10.09	2.96
Apr-05	104	-21.67	-43.87	-36.70	-36.70	-24.19	-16.89	-0.49
May-05	93.7	-31.97	-26.82	-39.90	-35.52	-35.52	-25.75	-4.52
Jun-05	111	-14.67	-23.32	-22.77	-33.59	-31.35	-31.35	-6.98
Jul-05	102	-23.67	-19.17	-23.43	-22.99	-31.61	-30.07	-10.52
Aug-05	120	-5.67	-14.67	-14.67	-18.99	-19.53	-27.28	-12.43
Sep-05	119	-6.67	-6.17	-12.00	-12.67	-16.53	-17.38	-14.07
Oct-05	125	-0.67	-3.67	-4.33	-9.17	-10.27	-13.88	-15.25

Nov-05	109	-16.67	-8.67	-8.00	-7.42	-10.67	-11.33	-17.89
Dec-05	104	-21.67	-19.17	-13.00	-11.42	-10.27	-12.50	-21.07
Jan-06	95.1	-30.57	-26.12	-22.97	-17.39	-15.25	-13.65	-21.86
Feb-06	90.4	-35.27	-32.92	-29.17	-26.04	-20.97	-18.58	-22.93
Mar-06	115	-10.67	-22.97	-25.50	-24.54	-22.97	-19.25	-18.32
Apr-06	90	-35.67	-23.17	-27.20	-28.04	-26.77	-25.08	-19.48
May-06	135	9.33	-13.17	-12.33	-18.07	-20.57	-20.75	-16.04
Jun-06	110	-15.67	-3.17	-14.00	-13.17	-17.59	-19.75	-16.13
Jul-06	121.5	-4.17	-9.92	-3.50	-11.54	-11.37	-15.35	-14.50
Aug-06	120	-5.67	-4.92	-8.50	-4.04	-10.37	-10.42	-14.50
Sep-06	123	-2.67	-4.17	-4.17	-7.04	-3.77	-9.08	-14.17
Oct-06	120	-5.67	-4.17	-4.67	-4.54	-6.77	-4.08	-14.58
Nov-06	112	-13.67	-9.67	-7.33	-6.92	-6.37	-7.92	-14.33
Dec-06	130	4.33	-4.67	-5.00	-4.42	-4.67	-4.58	-12.17
Average	125.7							

Note: ND = no data; NR = no residual

The residuals were then plotted and simple linear regression was used to determine which averaging period best represented the pattern of Cl data. Figures 2 and 3 illustrate these selected plots, their regression equations, and the coefficient of determination (R^2) for each regression.

FIGURE 2 PLOT OF 1-MONTH AND 12-MONTH RESIDUALS

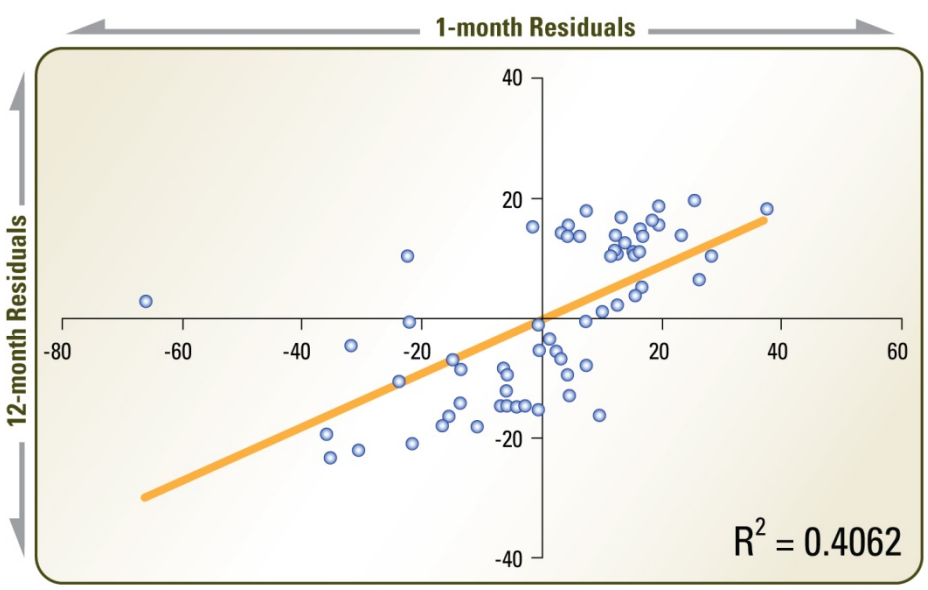
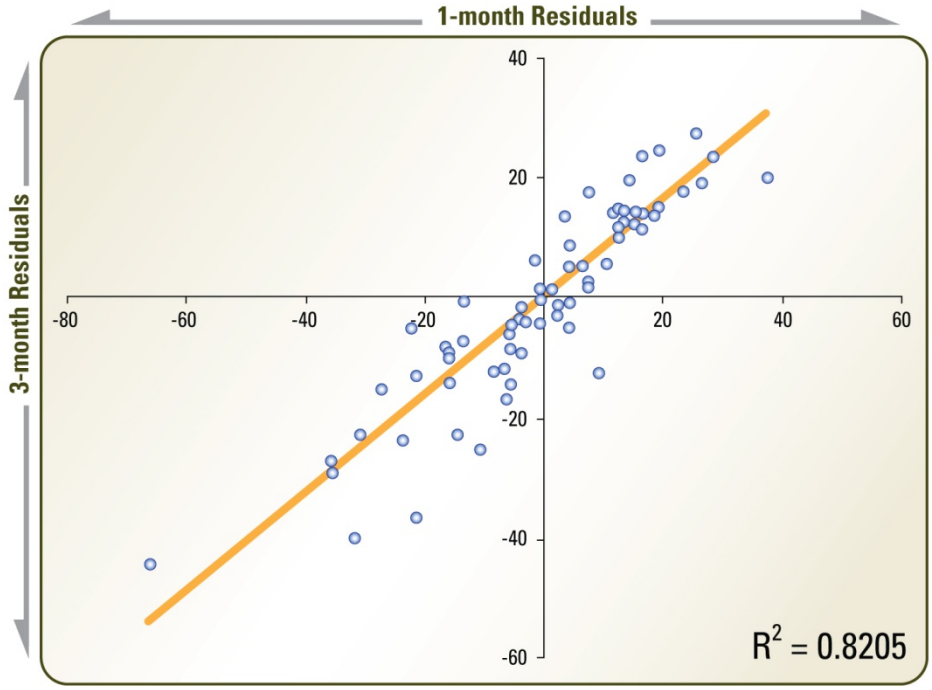


FIGURE 3 PLOT OF 1-MONTH AND 3-MONTH RESIDUALS



A summary of the residual regressions is provided in Table 6. Clearly, the shorter the averaging period is, the closer the fit between the residual data. Both the residuals for the 6-month and 12-month averaging periods had low coefficients of determination (0.40 and 0.56 respectively). However, the fit increased greatly only when the averaging period was decreased to a certain point. In this case, the increase in fit from the 6-month averaging period to the 3-month averaging period was significant (0.56 to 0.82), whereas the improvement in fit from the 3-month averaging period to the 2-month averaging period was slight (0.82 to 0.85). In other words, the increased benefit from decreasing the averaging period from 3 to 2 months would be small.

TABLE 6 SUMMARY OF RESIDUAL REGRESSIONS

Averaging Period	R^2 of residuals	Comments
2-month	0.847	Represents likely minimum period of exposure in which injury occurs, considering research treatment levels that are significantly greater than LRE guidelines of 100-120 mg/L. But may not represent duration of exposure that causes lasting injury. Represents nature of Cl fluctuating pattern. Data fit is good.
3-month	0.821	Approaches likely minimum period of exposure in which injury from Cl stress occurs, considering research treatment levels that are greater than LRE guidelines of 100-120 mg/L. Represents likely duration of exposure which may cause lasting injury. Represents nature of Cl fluctuating pattern. Data fit is good.
4-month	0.698	Spans two seasons; longer then minimum period in which injury from Cl excess is likely to occur. Does not represent fluctuations in Cl. Data fit is fair.
5-month	0.629	Spans two seasons; longer then minimum period in which injury from Cl excess is likely to occur. Does not represent fluctuations in Cl. Data fit is fair.
6-month	0.563	Spans slightly under half of the growing cycle for 1 year's yield; spans two seasons; significantly longer then minimum period in which injury from Cl excess is likely to occur. Does not represent fluctuations in Cl. Data fit is poor.
12-month	0.406	Represents almost entire growing cycle for 1 year's yield; spans four seasons; significantly longer then minimum period in which injury from Cl stress is likely to occur and have lasting effects. Does not represent fluctuations in Cl. Data fit is poor.

The 3-month averaging period appears to meet the following important criteria:

- It represents the fluctuating pattern of Cl and does not entirely average out the fluctuations. Therefore, the effect of frequency of these fluctuations will be negligible.
- It allows for equilibrating soil and water processes to occur; therefore, it is not too short.
- It approaches the minimum time it takes for Cl excess to cause injury; therefore, it is not too long. Though 3 months is longer than the 4- to 8-week minimum period that resulted in injury, this averaging period allows for the fact that higher rates of Cl were used in the LRE studies.

8 RECOMMENDATIONS

The following considerations were used to determine a recommended compliance averaging period for Cl:

- There are many sensitive physiological functions in avocado growth, stressors, and environmental conditions that combine to create numerous critical periods during the growing season. It would be difficult to determine one particular critical period during the growing season. Therefore, one compliance averaging period that allows for critical periods in avocado growth, physiological function, environmental stress, and all growth stages should be developed.
- Though the compliance averaging period somewhat depends on the magnitude of the fluctuations in Cl concentration, it does not entirely depend on this measure, largely because the long-term effect of the frequency of these fluctuations is unknown, and because of the relatively short period in which Cl injury symptoms occur after exposure to Cl excess begins.
- The time it takes for Cl to accumulate in the soil and affect avocado trees should influence the compliance averaging period because it has been shown that uptake occurs consistently if an increased level of Cl intercepts the root system (CH2M HILL, 2005). Studies indicate that the minimum time between the beginning of exposure to Cl stress and signs of visible leaf Cl injury is between 2 and 9 weeks when high Cl concentrations are applied (at least 170 mg/L), and usually between 4 and 8 weeks. It can be assumed that this is the amount of time it takes for equilibrating processes between soil and water to take place in the root zone, resulting in Cl accumulation that causes injury. The compliance averaging period is too short when it does not allow for these processes to occur. Therefore, the compliance averaging period should be at least 8 weeks (2 months).
- The compliance averaging period is too long when the resulting averages do not represent the fluctuating nature of Cl concentrations in the waters of concern. These fluctuations should not be averaged out since short, intense periods of stress have been shown to affect avocado growth, indicated by the LRE studies in Table 2. Though the magnitude of those fluctuations will be somewhat minimized from the averaging process, the averaging period should not totally eliminate the fluctuations in Cl.
- A 3-month compliance averaging period is recommended for the following reasons:
  - It represents the fluctuating pattern of Cl and does not entirely average out the fluctuations. Therefore, the effect of frequency of these fluctuations will be negligible.
  - It allows for equilibrating soil and water processes to occur.
  - It approaches or approximates the minimum time it takes for Cl excess to cause visible leaf injury.

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