August 22, 2014

Mr. Matthias St. John, Executive Officer
California North Coast Regional Water Quality Control Board
5550 Skylane Boulevard, Suite A
Santa Rosa, CA 95403
VIA EMAIL: NorthCoast@waterboards.ca.gov

Dear Mr. Matthias St. John:

On behalf of Wine Institute, I would like to register my strong concern with the California Regional Water Quality Control Board, North Coast Region (CRWQCB) proposed Draft General Waste Discharge Requirements for Discharges of Wine, Beverage, and Food Processor Waste to Land (Draft WDRs).

Wine Institute serves as the voice for the California wine industry, representing over 1,000 California wineries and affiliated members. Our members uphold a strong commitment to protecting the environment, and many of our members are active in Wine Institute's Environmental Working Group (EWG). The EWG is research based and science driven, focusing on the most relevant environmental issues within the wine industry.

Enclosed in this letter and attached to this packet are the EWG's written responses to the North Coast Region CRWQCB proposed Draft WDRs to supplement the discussion between staff and representatives of the wine industry in your office on August 19th, 2014.

A summarization of our concerns about the Draft WDR is as follows.

- Draft WDR, Section II C. (CEQA) on page 3 – The Draft WDR currently requires the discharger to provide CEQA documents. Generally, the RWQCB is the lead agency and completes the CEQA analysis on the General Permit so that the discharges do not need to undergo a CEQA review. In Attachment 2, we request that this section should be re-written.

- Draft WDR, Section III (Application Process) on page 7 – Wineries currently enrolled under the existing General WDR will need to submit an NOI within 6 months. Many of these currently permitted facilities may not meet the specifications and limitation (or prove that they meet the specifications) listed in this draft order. If facilities cannot meet the terms of the General WDR, they can apply for an Individual WDR and negotiate directly with RWQCB. If the Draft WDR as currently written goes forward, wineries will not seek enrollment under the Draft WDR and the sought for efficiencies for the protection of Groundwater will not be achieved. Efficiency in design of this WDR and compliance requires changes; otherwise facilities seeking efficiency to compliance will increasingly request coverage under an individual WDR.

- Draft WDR, Section II (Findings) vs. Section VI (Groundwater Limitation) – The draft WDR says some degradation of groundwater is allowed per CWC (Section II. Findings on p. 5). However, Section VI (Groundwater Limitations on p. 9) contradicts this findings and says that "no statistically significant degradation of groundwater quality occur due to a discharge." The wine industry does not support a "no degradation" position.

- Draft WDR, Section XI (Compliance Determination) – When calculating the biochemical oxygen demand (BOD) effluent limitation, we recommend that cycle loading that accounts for application and resting cycles be used. The formula currently in the draft WDR has to be changed as it does not reflect the capacity of the soil or vegetation to process BOD. Please see attached document Land Treatment of Municipal Wastewater Effluents, Chapter 2, EPA/625/R-06/016 September 2006.

- Draft MRP – The requirement in the draft for quarterly reporting isn't consistent with operational cycles. Activities such as solids reporting, chemical use reporting, and land application reporting are good examples of processes that are best done on an annual basis, as the activity is only done once a year. Winery waste water profile is basically uniform in character during crush season and then during non crush. Repetitive testing of waste streams will not yield actionable information. We recommend semi-annual monitoring of winery waste water.

- Draft Order, Section V.B. (Effluent Limitations Table 4) – TDS discharge limitation of 450 mg/l is very low and is not a level that can be or need to be achieved by the wine industry. The Draft demonstrates confusion between effluent levels and water quality objectives. Taking into consideration additional hydraulic loading from rainfall and additional irrigation, the potential TDS levels will not lead to degradation of ground water. Please see Attachment 1, Technical Comments #1 for explanation as to why TDS shouldn't be a consideration as a monitored constituent.

- Draft MRP, Section VII A (Irrigation Area Monitoring) – If NCRWQCB is going to consider annual TDS applied as a concentration, NCRWQCB should add a calculation of effective TDS concentration in process water + supplemental irrigation + rainfall should be included in the MRP (see Attachment 1, Technical Comments #1). Also in the Antideg salinity section (II.D.2 on page 5 of the WDRs), Regional Board staff takes credit for the soil removing the volatile solids component of TDS. This information should be taken into account for establishment of TDS limits.

- Draft MRP Section V.B. (Effluent Limitations Table 4) – Please see the attached document Process Design Manual for Land Treatment of Municipal Wastewater Effluents, EPA/625/R-06/016 September 2006, Section 2.9 which addresses the impact of potassium in wastewater. The PFD titled Potassium. It is a technical document explaining the potassium consumption per acre for vineyards.

- Draft FSNMP – Attachment 1 discusses issues with Nitrogen Monitoring (Technical Comment #3). The nitrogen loading calculation is from the influence of dairy permitting and CVSALTs. The wine industry requests a reasonable alternative where total nitrogen is measured and is kept less than the agronomic rate during irrigation.

- At the August 14th Board meeting where an update of the WDR was presented, staff stated that "the FSNMP is only for those facilities that don't comply with the effluent limits in the WDR." If this is correct, that WDR compliance will be tiered based on risk, this needs to be clearly written in the WDR. Specific language needs to be added stating a tiered risk program and what level of risk trigger the tiers. In a tiered program, impact of TDS/FDS still needs to be defined with consideration of dilution impacts from rain and irrigation. Also, under a tier program, the inability of meeting 60 mg/l BOD needs to be addressed.

- Should CRWQCB revise the Draft WDR and attachments based on these (and other) comments, the EWG respectfully asks for another opportunity to review those proposed changes.

Attached are four documents that, together, represent Wine Institute EWG's technical review of the North Coast Region CRWQCB proposed Draft DWR.

- Attachment 1 – This document contains an overview of our top technical concerns with the Draft General WDRs and the attachments.
- Attachment 2 – This document provides a detailed list of our concerns with the Draft General WDR. Often, it references back to the Technical Comments provided in Attachment 1.
- Attachment 3 – This document gives specific concerns with the proposed Facility Specific Salt and Nutrient Management Plan.
- Attachment 4 – This document summarizes issues with the Draft Monitoring and Reporting Program concerns with the Draft General WDR.

Other resources:
- Land Application of Winery Stillage and Non Stillage Process Water, Wine Institute, 2004
- Manual of Good Practice for Land Application of Food Processing/Rinse Water, California League of Food Processors, 2007. http://clfp.com/documents/Manualofgoodpractice/CLFP%20Manual_COMPLETE_FINAL_3-14-07%20(2).pdf
- Land Treatment of Municipal Wastewater Effluents, , EPA/625/R-06/016 September 2006.
- Potassium: Technical document on Potassium in vineyards.

Thank you for your serious consideration of the concerns outlined by Wine Institute's EWG. If you need additional information from the EWG, please contact Tim Schmelzer, Director of Legislative & Regulatory Affairs, at tschmelzer@wineinstitute.org.

Sincerely,

Robert P. Koch
President and CEO

Attachment 1: Comments on Draft General Waste Discharge Requirements for Discharges of Wine, Beverage, and Food Processor Waste to Land

Below are our top technical concerns with the Draft General WDR for Wineries, Beverage and Food Processors (Draft WDRs). In addition to the list below, the attached tables detail specific concerns and, when appropriate, make suggestions for improvements. The table references back to these over-arching technical concerns.

Technical Comment #1 – Effluent Limits for Land Application

a) Technical justification for the limits is needed in the findings.

b) The Draft WDR inappropriately applies groundwater limits to effluent:

   i. The effluent quality limits do not account for land application treatment of applied process water, including crop uptake.

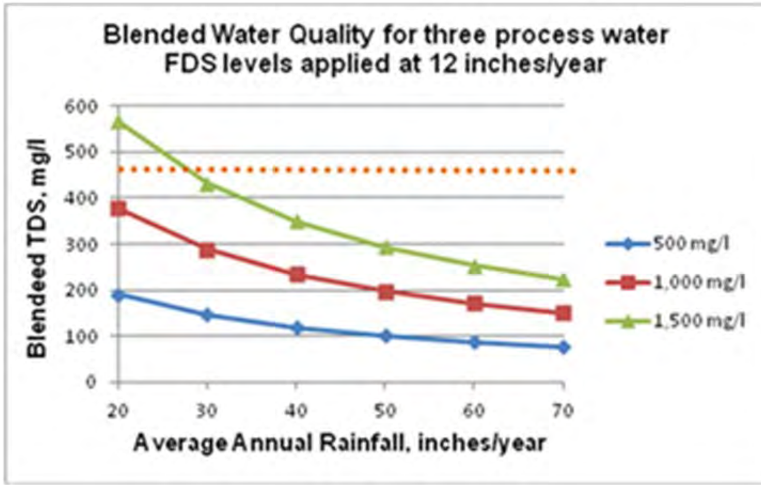
      - Soil adsorption is referenced as the limiting factor for nutrient application when nutrient management in soil-crop systems is largely accomplished by crop uptake.
      - The proposed biochemical oxygen demand (BOD) loading limit of 60 pounds per acre per day (lb/Ac/day) is much lower than the rates that are known to occur near the ground surface due to the favorable temperature and aeration conditions of the summer cropping season. Use of a single loading rate designed for the worst application conditions prevents dischargers from developing sustainable management practices. This restrictive limit for BOD is, in effect, the opposite of the FSNMP approach because it does not allow the discharger to develop practices that protect groundwater and are cost efficient. This limit will have far-reaching impact on most dischargers by significantly and unnecessarily increasing the required land application acreage.

        Common practices that are used to increase BOD oxidation and to support higher loadings without impact to soil and groundwater include a) use of sprinkler irrigation, b) application of higher loadings during summer months when biological processes are most active, and c) application of frequent light hydraulic loadings when higher strength process water is applied.

   ii. The calculating formula for BOD loading required in the WDRs does not account for the resting part of the application cycle. This has to be corrected because almost all land application programs apply more than the daily rate and then cease application for a period of time while the BOD is consumed.

   iii. The draft effluent concentration limits do not account for the blending of process water, supplemental irrigation water, and rainfall. There's enough rain to maintain salinity in percolating water to levels below much of the groundwater in the North Coast and below the water quality objectives the draft WDRs uses. Thus, the low process water TDS, Cl and Na effluent limits are inappropriate.

      The chart below shows how blended TDS looks for the North Coast at 3 process water FDS levels. The calculations go down to 20 inches of rainfall per year, but the lowest average rainfall across 20 different weather stations throughout Region 1 was 31 inches/year. The orange dotted line represents the proposed 450 mg/l effluent discharge limit.



iv. The proposed effluent limits for sodium (Na), Chloride (Cl), and TDS appear to be groundwater quality standards for the agricultural beneficial use. They are not related to health-based standards and the values proposed may be based on crop growth concentration ranges that are used to quantify narrative standards for water quality objectives. The underlying research findings for these values (see Ayers and Westcot, 1985) are not precisely defined.

- The proposed sodium effluent limit is apparently derived from a damage threshold that sprinkler irrigated crops can sometimes have when sodium is deposited directly on leaves. This isn't an appropriate limitation for a general permit since it is only addresses sprinkler irrigation in arid conditions. The technical basis for this standard is not well documented in Ayers and Westcot. These factors make the proposed effluent limitation inappropriate for the North Coast.
- In the case of the proposed Cl limitation of 106 mg/l, sometimes used as a groundwater quality objective, the technical basis for the limitation is based on laboratory studies made using measurements of chloride on a charge basis: millequivalents per liter (Ayers and Westcot, 1985). Laboratory studies conducted by other researchers using a variety of experimental and analytical methods were combined to develop a rule of thumb, not a rigorous technical standard. It should be noted that, in the Central Valley of California, it is common to use groundwater quality objectives at values higher than the value proposed here.

c) The draft Monitoring and Reporting Plan (MRP) requires dischargers to calculate the total hydraulic loading on land application fields.

i. This lends support to Technical Comment No. 1 b) ii, above.

ii. Salt and nutrient management need to be based on loading rate restrictions, not concentrations.

iii. Groundwater quality effects occur on a scale that is most appropriately measured on an annual basis.

Technical Comment #2 – Fixed Dissolved Solids/Total Dissolved Solids

TDS is not an appropriate measure of salinity in food and beverage process water because these effluents have significant concentrations of organic acids that are immediately consumed when applied to land application areas. The inorganic, or salts, component of the process water discharge is quantified by the parameter fixed dissolved solids (FDS) which uses higher sample drying temperatures to remove the volatile solids, leaving the mineral fraction, the salt ions. FDS represents the inorganic fraction of the Total Dissolved Solids (TDS). It is common practice in food and beverage permits in most of California to address process water salinity effects using FDS limits.

Technical Comment #3 – Draft Facility Specific Salt and Nutrient Management Plan Nitrogen Monitoring Issues

The FSNMP attachment to the draft WDRs appears to use the nitrogen management strategy used in dairy permits:

Allowable loading = agronomic application of <u>available</u> nitrogen – nitrogen stored in the soil

This requires soil testing but not necessarily crop tissue testing. We could suggest that if calculations show that the total nitrogen applied (process wastewater, fertilizer, supplemental irrigation, etc.) is less than that taken up by the crop, there is a de minimis risk and no further action needed. However, if the calculations show that the available nitrogen is applied is greater than that needed by crops, the facility needs to make certain management choices including use of soil monitoring. These choices need to be flexible

Technical Comment #4 – Non-Degradation of Existing Groundwater

The Draft WDR currently requires non-degradation of existing groundwater rather than some allowance for degradation above existing groundwater quality but below the water quality objectives. This appears to be a mistake. Neither the state Antidegradation Policy nor the common SNMP plan guidance for other industry sectors (dairy and municipal reuse) requires nondegradation.

The Draft WDRs include an Antidegradation Policy finding and constitute the proposed demonstration that the requirements of these WDRs will limit degradation of groundwater. However, there is no technical support to demonstrate that they will be successful. The WDR would be a better document if the conditions and requirements were supported by technical and policy justifications. These technical and policy justifications could be put into a separate finding or group of findings.

Technical Comment #5 – Reporting Period

Both the Draft MRP and the Draft WDRs mention both semi-annual and quarterly reporting. Semi-annual reporting is more appropriate.

Attachment 2: Comments on Draft General Waste Discharge Requirements for Discharges of Wine, Beverage, and Food Processor Waste to Land

Section / Page Number	Concern	Suggestion
Section II Findings		
Page 3. **II.A. Basis and Rationale for Requirements**.	This section states that requirements were developed based on review of data submitted by dischargers under past WDRs.	The WDR would be a better document if the conditions and requirements were supported by technical and policy justifications. These technical and policy justifications could be put into a separate finding or group of findings.
Page 3 **C. CEQA**	Discharges from new or expanded facilities seeking coverage under this draft Order, are required to provide CEQA documents	For general WDRs, the RB is the lead agency
Page 5 & 6. **II.D.1 to II.D.3**.	These three paragraphs are part of the Antidegradation Policy finding and constitute the proposed demonstration that the requirements of these WDRs will limit degradation of groundwater. However, there is no technical support to demonstrate that they will be successful or may be unnecessarily restrictive.	See Technical Comment #4 , attachment XXX
Page 5 & 6. **II.D.1 to II.D.3**.	The paragraph above II.D.1 notes that effluent limits and groundwater limitations will be established. The groundwater limitations in the permit are set at the Water Quality Objectives based on Title 22 (see Section VI.C and VI.D) along with specific limits for total coliform and pH. These last two items are provided without justification.	Total coliform is typically a proxy for fecal coliform is not a concern with processing waste and because neither domestic nor animal waste is covered by this permit. Provide justification for including total coliform and pH is needed.

Attachment 2: Comments on Draft General Waste Discharge Requirements for Discharges of Wine, Beverage, and Food Processor Waste to Land

Section / Page Number	Concern	Suggestion
Page 5 & 6. **II.D.1 Salinity**	"Salinity is a measure of dissolved solids in water. " The support given for Total Dissolved Solids (TDS) nondegradation includes volatile solids reduction in land application areas, and a requirement for a source control in the FSNMP. This seems inadequate.	This first sentence should be reversed: Total Dissolved Solids (actually Fixed Dissolved Solids) is a measure of salinity in water. See Technical Comment #2 - This section should more fully address nondegradation and address the issue of TDS versus Fixed Dissolved Solids (FDS).
Page 5 & 6. **II.D.2. Nitrogen**.	The antidegradation approach for nitrogen relies entirely on the FSNMP and one other sentence: *"Nutrient application rates shall not approach a site's maximum ability to contain one or more nutrients through soil adsorption"*. There are no specifics regarding this and no mention why soil adsorption is the limiting factor (nutrient management in soil-crop systems is largely accomplished by crop uptake).	See Technical Comment #1 - Incorporate crop-uptake into the basis and requirements.
Page 5 & 6. **II.D.2. Nitrogen**.	This second idea and the following sentences in the paragraph do not address the antidegradation policy, do not mention the fundamental mechanisms for land application treatment, and are too vague to be of use.	This portion of the Nitrogen paragraph should be rewritten.
Page 6. **II.D.3 BOD**	This paragraph establishes a BOD loading limit of 60 pounds per acre per day (lb/Ac/day) with no justification, analysis, or technical references. See Technical Comment #1.	The finding must be developed in much more detail with justification, analysis, and references. See Technical Comment #1.
Page 6. **Paragraph following II.D.2.**	The sentence: "*groundwater quality will improve once these WDRs are adopted"*	This sentence should be deleted because it is entirely speculative.
Page 6. **Paragraph following II.D.2.**	The remainder of this paragraph states that, because there are new conditions in these WDRs, the results will be better.	This is not a satisfactory demonstration that these draft WDRs meet the Antidegradation Policy.

Attachment 2: Comments on Draft General Waste Discharge Requirements for Discharges of Wine, Beverage, and Food Processor Waste to Land

Section / Page Number	Concern	Suggestion
III. Application Process		
Page 7. III. A	Indicates that the information required <u>with</u> the NOI is equivalent to a ROWD.	This is not clear. This can be read in two separate ways: (1) the information requested in the NOI is equivalent to a ROWD or (2) the discharger needs to provide information in addition to the NOI form that is equivalent to a ROWD. If the more information is expected than requested in the NOI, additional guidance should be provided.
IV. Discharge Prohibitions		
Page 8. **IV.H. No irrigation during rain events**	This prohibition occurs in older permits that seek to prevent runoff from land application areas by establishing a moratorium on land application before and after rainfall events. In the draft prohibition, a rainfall event of 0.01 inches would result in no irrigation for as much as 5 days. This prohibition unnecessarily limits flexibility for the discharger who may have dry soils with sufficient storage capacity for both a small rain and some necessary irrigation.	This should be rewritten so that the discharger has flexibility to irrigate to meet crop water uptake needs (that are needed to drive nutrient and salt removal) when sufficient soil water storage capacity is available. The WDRs should regulate the key issue – saturated soils – not be prescriptive about mandatory no-application periods
V. Effluent Limitations		
Page 8. **V.A. Comply with FSNMP**	This condition adds an example to the requirement to comply with the FSNMP.	The limitation should simply say “Comply with all terms of the FSNMP”. There is no need to single out one part of the FSNMP for special mention.
Page 9. **V.B.Effluent limitations table.** Biochemical Oxygen Demand (BOD)	This limitation has not been adequately justified in the findings and will limit the ability of the discharger to manage land application programs to protect groundwater.	See Technical Comment #1.

Attachment 2: Comments on Draft General Waste Discharge Requirements for Discharges of Wine, Beverage, and Food Processor Waste to Land

Section / Page Number	Concern	Suggestion
Page 9. **V.B.Effluent limitations table.** Ammonia	No justification has been provided for the 1.5 mg/l limit and there are not groundwater limitations for ammonia-N. In discharge to land, ammonia is simply a component of plant available nitrogen and will undergo conversions in the soil and be taken up by plants.	In food and beverage process water discharge to land, ammonia is not a constituent of concern (CLFP, 2007). As a suggestion, the Draft WDR could briefly note that plant available N is ammonia plus nitrate. For groundwater protection, ammonia is a useful form because it is easy for plants to remove and is less mobile in soils than nitrate which leaches readily.
Page 9. **V.B.Effluent limitations table.** Nitrate-N	This limit is reasonable.	
Page 9. **V.B.Effluent limitations table.** Nitrite	In other states and regions, nitrite-N and nitrate-N are often combined because nitrite is unstable in soil environments	Combine nitrite-N and nitrate-N.
Page 9. **V.B.Effluent limitations table.** Total Dissolved Solids (TDS)	The proposed limit, 450 mg/l, is a groundwater quality objective sometimes used for AGR uses, and almost always in areas where rainfall is low. Use of this value is inappropriate as described in Technical Comment #1 a. Additionally, use of this low process water effluent limitation may also prevent dischargers from using water conservation practices in processing facilities so this arbitrary limit concentration limit can be met. IT is the loading rate, not the concentration that is of most concern	See Technical Comment #1.

Attachment 2: Comments on Draft General Waste Discharge Requirements for Discharges of Wine, Beverage, and Food Processor Waste to Land

Section / Page Number	Concern	Suggestion
Page 9. **V.B.Effluent limitations table.** Sodium	This effluent limit requires justification.	See Technical Comment #1.
Page 9. **V.B.Effluent limitations table.** Choride	In the case of the chloride limitation of 106 mg/l, is based on Ayers and Westcot, 1985. Laboratory studies conducted by other researchers developed a rule of thumb instead of using more rigorous analytical methods. See Technical Comment #1	See Technical Comment #1.
VI. Groundwater Limitations		
Page 9. **VI.A.1**. Total Coliform	See comments on Page 5 & 6. **II.D.1 to II.D.3**.	A rationale and justification for the total coliform value proposed must be provided, especially for process water discharges. And/or, clearly indicate that this specific applies to subsurface discharges only.
Page 9. **VI.A.1**. Total Coliform	The proposed requirement specifies that groundwater levels be evaluated as a 7-day median value for measurements. This is inappropriate for ground water monitoring and suggests that this limitation may have been taken from another intended monitoring application without necessary modifications.	This requirement should be removed.
Page 9. **VI.B**.	This limitation requires that no statistically significant degradation of groundwater quality occur due to a discharge. This directly contradicts the Antidegradation Policy finding of this Order: Section II.D. The Antidegradation Policy finding allows degradation of groundwater quality with appropriate justification as long as the Water Quality Objectives required for the groundwater beneficial uses are not exceeded. This concept is also clearly stated in the Salt and Nutrient Management Planning requirements for municipal recycled water programs in California.	Remove this limitation or change “to prevent exceedances of groundwater quality objectives., not exceedances of background groundwater quality”

Section / Page Number	Concern	Suggestion
VII. Discharge Specifications		
Page 10. A through C	These three items seem unnecessary: A. The mean daily flow of process wastewater shall not exceed the designed treatment and disposal capacity stated in the NOI, in gpd, averaged over a calendar month except as provided for in VII.B. B. The mean daily process wastewater flow shall not exceed the designed peak capacity of the treatment and disposal system stated in the NOI, in gpd, as averaged over the crush or peak production period of the facility. C. The maximum daily process wastewater flow shall not exceed the maximum design capacity of the treatment and disposal system as stated in the application.	Rather than being prescriptive with these three points, simply have the discharger justify the design basis for their system
VIII. Design Specifications		
Page 11. **VIII.H. Requirements for Subsurface Disposal Systems – *bullet #1***	1. "*The system shall be designed for the specific process water characteristics and <u>should</u> consider screening, detention time, effluent filters, and use of dual disposal fields for loading and resting.*"	This is acceptable advice but seems out of place in the design specifications section. It is this sort of advice given using "should consider" that adds ideas that may become dated and may guide dischargers to not consider other important ideas and factors. It also makes the design specifications longer and involved instead of straightforward and to the point.
Page 11. **VIII.H. Requirements for Subsurface Disposal Systems – *bullet #3***	3. "*Infiltration surface sizing should be based on the more conservative of organic loading and hydraulic loading*".	These may not be the limiting constituents in all cases. This specification uses 'should' and ignores salt and nutrients in the design. This condition seems like a possibly out of date domestic wastewater leach field requirements

Section / Page Number	Concern	Suggestion
Page 11. **VIII.H. Requirements for Subsurface Disposal Systems –** *bullet #5*	5. *"No part of the disposal system shall extend to a depth where waste may pollute groundwater"*. Not clear what this specification is trying to address and it may be redundant with specification H.2 that sets 5 feet separation between the adsorption trench bottom and groundwater.	Can be eliminated without compromising subsurface system design.
Page 11. **VIII.H. Requirements for Subsurface Disposal Systems –** *bullet #7*	Solids accumulation in septic tanks. This specification sets several depths for sludge buildup, scum layers, and percentage filling of tank capacity.	This seems too prescriptive and may clash with other management practices a discharger implements.
Page 11. **VIII.H. Requirements for Subsurface Disposal Systems –** *bullet #8*	8. "*Dual disposal fields shall be operated in a regular rotating sequence. With rotation frequency no less than semi-annually*".	Please clarify if this means that the fields should be rotated a) semi-annually or more frequently or b) no more frequently than twice per year (semi-annually).
IX. Solids Discharge Specifications		
	Throughout this section, the terms solids and sludge are used. In Specification IX.F, the term sludge is used for the solids land application program plan.	The term sludge should be changed to solids here and elsewhere in this section.

Section / Page Number	Concern	Suggestion
Page 12. **IX.F. Proposal for Solids Land Application –** *bullet #2*	2. Chemical characterization of solids for land application specifies cadmium, chromium, copper, lead, nickel, zinc, and total N. This list doesn't seem appropriate for winery solids as well as some other food processing solids.	The basis for use of this list for all situations should be justified. An alternative would be to put this list in the MRP so it can be modified on a case by case basis. This paragraph also refers to stockpiled sludge; the term stockpiled should be deleted to allow solids sampling from storage ponds.
Page 12. **IX.F. Proposal for Solids Land Application –** *bullet #5*	5. This specifies that sludge loading to land be applied at agronomic rates based on nutrient uptake of the crop.	This should be revised to specify that loading rate be established in the FSNMP. This will avoid having two potentially different calculation procedures in the facility's permit.
Page 12. **IX.F. Proposal for Solids Land Application –** *bullet #6*	6. This paragraph specifies a fixed date range for solids land application.	Because the appropriate climatic conditions may occur outside of this range, the Proposal for Solids Land Application should provide dates and mitigation procedures for erosion, runoff, and nuisance conditions to be reviewed and approved by the Regional Board.
X. General Provisions		
Page 13. **X.D. Operation and Maintenance**	This section has a paragraphs describing operations of wastewater systems followed by a list of 4 items that are, apparently, a list of items to include in an O&M Plan.	Commenting on this provision will likely result in the addition of a requirement for preparing an O&M Plan.

Section / Page Number	Concern	Suggestion
XI. Compliance Determination		
Page 17. **XI.E. BOD Effluent Limitation**.	This section provides the formula that must be used to determine compliance with the BOD effluent limitation. The formula calculates a daily loading rate in pounds per acre per day. The formula is not appropriate because it does not account for BOD oxidation during the “rest” days between applications. This is likely an error but land applications can’t function using this one-day loading formula (let alone the 60 lb/Ac/day effluent limitation).	We recommend that cycle loading that accounts for application and resting cycles be used.

Attachment 3: Comments on Attachment D. Facility-Specific Salt and Nutrient Management Plan

Section / Page Number	Concern	Suggestion
Section A. FSNMP Purpose and Implementation		
Section A. Paragraph 2	This paragraph recommends periodic updating of the FSNMP. In other locations in this attachment, update frequencies of 30, 90, and annual are proposed.	The most reasonable frequency since the information required to develop an update are generally gathered on an annual basis and the effort to prepare an update, submit it, and receive Regional Board approval.
Section A Paragraph 3	The SNMP must be developed with the assistance of specialists.	It is not clear if the Regional Board has coordinated with some of the recommended specialists to determine if they have staff to provide assistance. Has the Regional Board estimated the cost for this assistance?
Section A Paragraph 4	This paragraph addresses the timing of preparation of a FSNMP. It has a different schedule than the one provided in the WDRs at Section III.C Application Process which says that the Plan is part of the application process.	These two schedules need to be coordinated.
Section A Paragraphs 6 and 7 Page 2	The first sentence suggests that the FSNMP must be revised within 30 days when discharges exceed water quality objectives. In the next sentence, 90 day periods for updating the FSNMP are required for other situations. In the following paragraph, an annual review of the FSNMP is required.	As mentioned above, an annual review and update of the FSNMP is more practical. For the conditions triggering a 90 day revision, the plan can be revised but the new conditions are not likely to be addressed in such a short period. It may well be better to complete the annual cycle to collect additional data for use in updating the FSNMP. The need for revising the FSNMP when water quality objectives are exceeded is more serious but it is likely that the impending exceedance will have been noted previously and planning should already be underway.

Attachment 3: Comments on Attachment D. Facility-Specific Salt and Nutrient Management Plan

Section / Page Number	Concern	Suggestion
Section A Paragraphs 6 and 7 Page 2	An additional concern regarding exceedance of water quality objectives: we assume that use of the term ‘water quality objectives’ is in the standard regulatory sense where water quality objectives are the water quality values above which beneficial uses are impaired. During our review, it occurred to us that the term water quality objectives may be used in some other sense.	If this is the case, the language must be clarified. If the use of the term is indeed for the water quality associated with beneficial use requirements, then, for this discharge to land permit, there must be some form of groundwater monitoring in place.
Section C. Contents of FSNMP		
Section C.2 Specific Dates Page 3	This section requires that dates of anticipated reviews and revisions to the FSNMP be proposed.	This information does not seem to be necessary, especially if the review requirement is established as an annual task.
Section C.5. Salt and Pollutant Minimization Page 3.	The examples of source minimization methods are not comprehensive. Use of a partial list adds some confusion to the scope of the analysis and shouldn’t be included in this document which will be adopted as a part of the WDRs.	The use of examples of source minimization methods should be deleted unless the list is comprehensive.
Section C.6. Nutrient Budget Calculations. Page 3&4	The information in this paragraph on Nutrient Budget Calculations is largely in Section D which is also titled ‘Nutrient Budget Calculations’.	For clarity, this paragraph should be deleted and any important issues not currently in Section D should be added.
Section C.8. Sampling and Analysis Program Page 4	The sampling and analysis program requirement is acceptable but the requirement to identify the analytical laboratory seems unnecessary. The need for soil sampling and petiole sampling is unnecessary.	The requirement that the laboratory have California certification should be sufficient. Suggest delete this requirement unless appropriate justification can be provided for including it.

Attachment 3: Comments on Attachment D. Facility-Specific Salt and Nutrient Management Plan

Section / Page Number	Concern	Suggestion
Section D. Nutrient Budget Calculations		
Section D Four numbered paragraphs	The four numbered paragraphs in this section are clear.	No changes recommended
Section D The paragraph following the fourth numbered paragraph	The paragraph following section 4 starts with the following sentence: *"Nutrient application rates shall not approach a site's maximum ability to contain one or more nutrients through soil adsorption"*. There are no specifics regarding this and no mention why soil adsorption is used as the key factor when nutrient management in soil-crop systems is largely accomplished by crop uptake. The remaining sentences in the paragraph address other topics and could be incorporated into the first paragraph of Section D.	This first sentence should be deleted or its' relevance clearly explained. The remaining sentences in the paragraph should be incorporated into the opening paragraph of Section D.
Section D Paragraph Starting with "Nitrogen" Page 5	The MRP adds monthly measurement of process water nitrate-N along with ammonia and Total N. This is of value because measurement of both ammonia-N and nitrate-N allows calculation of plant available nitrogen (PAN) which is used to determine nitrogen available from process water for each crop in the land application area.	This information should be incorporated into the discussion of nitrogen on page 5.
Section D Paragraph Starting with "Nitrogen" Page 5	After the first sentence of the 'Nitrogen:' paragraph, the remaining information deals with detailed calculations to compare actual application rates with initial estimates for each crop and field. This information is not clearly written and should be improved. Since this information is primarily targeted for the technical person preparing the FSNMP for the discharger, this information may not be appropriate in this WDR attachment.	Replacement of these details with a reference to nutrient management planning calculations (UCCE or NRCS references) would streamline the WDRs while providing access to more complete information than can be included in this attachment.

Attachment 4 – Comments on Attachment B. Monitoring and Reporting Plan

Section / Page Number	Concern	Suggestion
Section III.B **Chemical Use Reporting** Page 3	This requirement is for an annual report that should occur in the first quarterly monitoring report and on/or before May 1.	There is no apparent reason for two date specifications.
Section IV.A. **Septic Tank Monitoring** Page 3	This condition specifies that annual monitoring be conducted before July 1 each year.	What is the purpose of this date?
Section IV.B. **Septic Tank Maintenance** Page 3.	This section directs the discharger to pump the tank when one of three measured conditions occurs.	This requirement is addressed in the draft WDRs in Section VII.H.7.and should be deleted here.
Section V.C. **Effluent Monitoring**. Page 5.	This section specifies water quality monitoring. • Regarding the effluent limitations, no testing is required for nitrite-N and chloride, sodium, and FOG monitoring may be optional. • This section also says that no monitoring except for DO is required in months when there will be no land application discharge.	Clarify if the discharger is expected to sample for all constituents listed in the effluent limitations in the Draft General WDR, or not
Page 5. **Section VI.A, Table 5 Groundwater Monitoring**	Based on the Title 22 citation is it correct to assume that groundwater limits will be 500 mg/l for TDS and 250 mg/l for chloride (these are both higher than the effluent limits in the Draft WDR).	Clarify what limits are applicable for the discharger. The sample type for groundwater elevation should be “calculation”, not “measurement”.
Section VI.B **Groundwater Reporting** Page 5.	The reporting frequency is quarterly.	Suggest that the reporting should be semi-annual or annual to address potential groundwater impacts: while one summer or fall quarter may have higher TDS concentration, the winter quarter will have low blended TDS. Technical Comment #5

Attachment 4 – Comments on Attachment B. Monitoring and Reporting Plan

Section / Page Number	Concern	Suggestion
Section VII.A. Irrigation Area Monitoring. Page 6.	There items to address in the table in this section: 1. The item "Crop Planting" is unclear. It may be that this is supposed to be the crop planting date? 2. Footnotes 4 and 5 refer to the semi-annual reporting frequency. This is a good idea for land application programs because annual management is all that can be accomplished.	Need to address FDS vs. TDS, see Technical Comment #2. Suggest that the MRP be semi-annual reports rather than quarterly reports. Technical Comment #5.
Section VIII. **FSNMP**. Item VIII.A Page 7.	This section repeats the general requirements to have a FSNMP in place.	This is inappropriate in the MRP and should be deleted or just retain the first two sentences. The rest of the information is a partial synopsis of the FSNMP requirement and can only cause confusion.
Section VIII. **FSNMP**. Item VIII.B Page 7.	Addresses revisions to the plan	Plan revisions should be submitted no more than once per year.
Section IX.B. Solids Monitoring Reporting Page 7.	The entire contents of the solids monitoring program (Section IX.A.) involves annual calculations. The current time schedule calls for reporting during the quarter that individual measurements are made.	This will only cause confusion – it is better to have an annual solids reporting program that puts all the information in one place without duplication.
Section X.A. **Monitoring Reporting Schedule**. Page 7.	In this section quarterly and semi-annual are used in the same sentence.	Clarity is needed and recommend semi-annual reports.

Land Application of Winery Stillage and Non-Stillage Process Water

Study Results and Proposed Guidelines

WINE INSTITUTE
THE VOICE FOR CALIFORNIA WINE

August 2004
K/J 020112.01

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Land Application of Winery Stillage and Non-Stillage Process Water: Study Results and Proposed Guidelines

6 August 2004

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K/J Project No. 020112*01

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Glossary of Terms

Acidity – The measure of the capacity of a water to neutralize strong base. In most natural waters this is attributable to the sum of the concentrations of bicarbonate (HCO_3^-), carbonic acid (H_2CO_3), and hydrogen ion (H^+); in winery process waters acidity is affected by the organic acids originating from grapes.

Aerobic – In the presence of oxygen; usually referring to biological processes.

Agronomic Rates – The amount of nitrogen fertilizer (customarily ammonia-N plus nitrate-N) required for optimum crop yield. These values are specific for individual crops but do not account for other soil and environmental factors.

Alkalinity – The measure of the capacity of a water to neutralize strong acid. In most natural waters this is attributed to the sum of the concentrations of bicarbonate (HCO_3^-), carbonate (CO_3^{2-}) and hydroxide (OH^-); in winery process waters alkalinity is affected by the conjugate base salts of the weak organic acids originating from grapes.

Annamox – Abbreviation for anaerobic ammonia oxidation, a microbial mediated reaction where ammonia is oxidized to nitrogen gas under anaerobic conditions where nitrite is the terminal electron acceptor.

Application Cycle – A complete application cycle consists of: application of process water, a resting period for soil drainage and re-aeration, and maintenance to the spreading basin prior to the commencement of the next application cycle.

Application Rate or Loading Rate (gal/acre; lb/acre; and lb/acre/day) – The volume of process water or the mass of a process water constituent applied onto a spreading basin. As process water is applied in a relatively short amount of time (< 1 day) followed by a resting period, application rates are presented in two ways: 1) as volume or mass per area of spreading basin (i.e., either gal/acre or lb/acre), or 2) as mass per area of spreading basin divided by the number of days in the entire application cycle (lb/acre/day). This latter method expresses the average daily constituent load for the length of the cycle. It is important to note that instantaneous hydraulic application rate (i.e., gal/acre) can be determined at the time of application; the instantaneous constituent application rate (i.e. lb/acre) can be determined from the hydraulic application rate and the constituent concentration in the applied water; and the cycle application rate (i.e., lb/acre/day) can be calculated only when the cycle has been completed.

Anaerobic – In the relative absence of oxygen; usually referring to biological processes. For the purposes of this report, anaerobic refers to either anoxic or anaerobic conditions.

Available Water Storage Capacity – The amount of water that can be stored in the soil without draining. This amount is used as the maximum application volume for a spreading basin loading cycle under the proposed guidelines.

Biodegradable Dissolved Organic Carbon (BDOC) – The change in dissolved organic carbon over a five-day incubation period.

Five-Day Biochemical Oxygen Demand (BOD_5) – The quantity of biologically degradable organic matter in a process water in terms of the amount of oxygen required by microorganisms to oxidize it during a five-day test.

Deep Ripping – Rupturing of and the aeration of soils in a spreading basin to depths five feet below the ground surface. Ripping is used to loosen subsoil and break up any restrictive layers caused by machinery or process water chemical processes such as salt deposition.

Denitrification – Biological conversion of nitrate into nitrogen gases under anaerobic conditions, resulting in loss of nitrogen from ecosystems.

Disking/Tilling – Shallow mixing and aeration (i.e., 2 to 8 inches below the ground surface) of soils in a spreading basin. These techniques can be used to break the mat of particulate and biological matter that can accumulate at the soil surface of spreading basins. Disking/Tilling is a common technique to reestablish infiltration rates at the end of a cycle prior to the start of the next cycle.

Exchangeable Sodium Percentage (ESP) – The percentage of soil cation exchange capacity occupied by sodium ions. This measure is closely related to the SAR.

Inorganic Dissolved Solids (IDS) – Analytically determined as the Total Dissolved Solids (TDS) minus the Volatile Dissolved Solids (VDS). IDS approximates the sum of the inorganic ions in the water analyzed (e.g., Ca^{2+}, Mg^{2+}, etc.).

Leveling – The process of evening the ground surface of a spreading basin to assure the most even application of process water practically possible.

Nitrification – The biological conversion of ammonium to nitrite then to nitrate.

Process Water – Water generated by various operations in the non-stillage and stillage winery industry, usually characterized by high BOD_5 and organic nitrogen.

Redox – Abbreviation for oxidation-reduction. Redox, in this report, refers to the oxidation-reduction potential of a subsurface environment that can affect whether certain water quality constituents are present in their reduced or oxidized forms.

Resting period – The time after process water application until the beginning of the next application cycle. During this period, the applied water partially evaporates and the remainder moves downward into the soil column, allowing the upper reaches of the soil horizon to dry and reaerate.

Salinity – "The term salinity refers to the presence of the major dissolved inorganic solutes, essentially Na^+, Mg^{2+}, Ca^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^-, and CO_3^{2-} in aqueous samples. In soil it refers to the soluble plus readily dissolvable salts in soil." (Rhoades, 1996).

Although there is a large range, EC greater than 4 dS/m generally indicates that salinity will affect crop growth. The value of salinity where adverse effects occur is a function of SAR (see below).

Salt – Salt is the reaction product of an inorganic acid and an inorganic base. The term can refer to table salt (sodium chloride). For the purposes of this report, the term refers to the sum of the major inorganic ions in soil and groundwater: calcium, magnesium, potassium, sodium, chloride, sulfate, bicarbonate and carbonate.

Sodium Adsorption Ratio (SAR) – The SAR equals the sodium concentration expressed in moles of charge per liter divided by the square root of half the sum of calcium and magnesium expressed in moles of charge per liter. The SAR along with EC impacts the ability of water to infiltrate into soil. At a low EC, <0.2 dS/m, an SAR of 0 to 3 can impede infiltration while at a higher EC, > 5 dS/m, a SAR of less than 20 will not impede infiltration. (Ayers and Westcot, 1985)

Spreading Basin – The parcel of land used for the even application of process water for treatment and discharge. Spreading basins can be various sizes, including long, thin furrows; long and slightly wider surface irrigation checks, and larger infiltration ponds.

Total Dissolved Solids (TDS) – The amount of organic and inorganic residue after a filtered liquid sample has been evaporated to dryness. In most waters, this approximately corresponds to the sum of the inorganic ions. In winery process waters, this analysis can be greatly affected by the organic content of the water.

Total Nitrogen (TN) – The sum of ammonia/ammonium-nitrogen (ammonia-N), organic-nitrogen (organic-N), and nitrate-nitrogen (nitrate-N). Although there are other nitrogen species (e.g., nitrite) that occur during the chemical and biological processes during land application, these three are the dominant nitrogen species. All species concentrations are normalized to mg-N/l allowing the direct comparison between species and mass balance calculations with all dominant nitrogen species.

Vadose Zone – The unsaturated portion of soil between the soil surface and saturated soil associated with the water table. Synonymous with unsaturated zone.

Volatile Dissolved Solids (VDS) – The portion of Total Dissolved Solids that are volatilized at 550° C. This fraction of dissolved salts equals the organic acids, sugars, and other organic components removed during the TDS analysis.

Abstract

Two years of field study investigating the land application of winery process waters has been conducted at two different wineries in the San Joaquin Valley, California. One winery conducts distillation and one winery does not. Hydraulic loading rates, application and resting periods, and water quality constituent loading rates were varied at both well-instrumented sites. The results of the study indicate that land application is a viable natural process in regards to treatment of water quality constituents:

- pH is buffered to neutral values
- Near complete BOD_5 removal occurred at five feet
- Total nitrogen treatment is effective
- Inorganic Dissolved Solids applied load was similar to that measured at five feet

These results indicate that the efficacy of land application of winery process waters is comparable to treatment by engineered aerated biological reactors.

Guidelines have been established that significantly increase the management of land application of winery process waters and address both nuisance conditions and groundwater protection. The guidelines are comprised of the following:

- Site Characterization – to assure proper soil conditions
- Limiting Constituent Analysis – to assure process water quality is appropriate for land application
- Process Water Application Management – to assure that application is performed to maximize beneficial treatment, and
- Program Management – to assure that the winery conducts practices that coincide with good land application practices

Executive Summary

The Wine Institute of California (Wine Institute) has worked with several of the California Regional Water Quality Control Boards (Board) for over 20 years to address environmental issues associated with discharge of winery process water to land. Recently, the Wine Institute and the California Association of Winegrape Growers (CAWG) developed a *Code of Sustainable Winegrowing Practices*. These guidelines are part of a program to educate vintners and growers on how to conserve natural resources, protect the environment and enhance community relationships. In a related effort, the Wine Institute has developed a technical basis for operating procedures and guidelines for winery process water land application using spreading basins. This report is the primary technical document that presents and summarizes the results of 2002 and 2003 field experiments to assess the treatment capability of spreading basins and to establish guidelines for management of a spreading basin process water treatment system.

Previous Work. In the early 1980s, the Wine Institute membership funded a study of process water land application and provided guidelines that have been used by the Board as part of winery process water discharge permits (Metcalf and Eddy, 1980). These guidelines were developed for wineries that have Stillage operations but they have been applied in Non-Stillage discharge permits as well. Recently, both the Board and the Wine Institute have noted that the 1980 guidelines should be re-evaluated. The Board has made some use of other available information from other industries and municipalities (e.g., Environmental Protection Agency (EPA), 1984, 1981, 1977). The Wine Institute retained Kennedy/Jenks Consultants (Kennedy/Jenks) to design and conduct a field study to address key technical, scientific, and operational issues associated with minimizing environmental impacts of process water land application. The project work plan was reviewed both by staff of the Board and researchers at Fresno State University. The results of the Phase I Study (Final Draft Land Application of Winery Stillage and Non-Stillage Process Water Study Results and Proposed Guidelines, 2 May 2003, prepared by Kennedy/Jenks Consultants for the Wine Institute) were reviewed and commented on by the Board (see Appendix D) and Fresno State University.

Basic Technical Understanding. The premise of the 1980-era work was that Stillage process water land application to spreading basins should be managed on the basis of a) hydraulic loading amount per application, b) number of days “rest” between application events, and c) monitoring to assure that excessive odor generation does not occur. In the 2004 update, a more complex conceptual model of process water land application management is used. The three factors mentioned above are still of importance. In addition, the potential impacts of several chemical constituents of winery process water are addressed. This addition provides a mechanism to incorporate site specific factors that will represent a significant advance in site management and environmental protection.

The metrics included in the field studies are:

- pH: Process water acidity could have an impact on soil and microbial processes that contribute to treatment of the process water in spreading basins.

- Biochemical oxygen demand (BOD_5): This parameter is a measure of biodegradable organic matter content and affects spreading basin soils by contributing to the development of anaerobic conditions under certain circumstances.

- Nitrogen (total N, organic-N, ammonia-N, nitrate-N): Because nitrate-N is an important groundwater quality indicator, the process water nitrogen content and chemical form are important in determining appropriate spreading basin loading rates.

- "Salts": Groundwater quality goals for salt (typically measured as total dissolved solids (TDS)) are of importance in land application regions. The concentration of inorganic ions in process water is therefore of importance in determining how spreading basin applications should be made.

- Soluble iron (Fe) and manganese (Mn): Although they are not generally found in significant concentrations in process water, these constituents are measured in soil water and groundwater to assess the redox environment. In spreading basins, they are commonly found after extended duration of anoxic conditions. Iron and manganese are common constituents of soil that are present in a solid phase under aerobic conditions.

Study Objectives and Approach. This study addresses use of spreading basins for treatment and discharge of winery process water for both Stillage and Non-Stillage production facilities. The project objective is to provide basic data for use in a) revising Stillage winery process water land application guidelines and b) developing Non-Stillage process water land application guidelines.

Kennedy/Jenks Consultants and the Wine Institute designed and equipped two field study plots at existing spreading basin land application sites in Ceres (Non-Stillage) and Fresno (Stillage), California. The plots were instrumented with process water flow meters, soil moisture monitoring devices, soil gas sampling ports, and pan lysimeters designed to collect soil water at depths of one (2002 only) and five feet below ground surface. Measurements included process water chemical constituents, lysimeter sample chemical constituents, soil chemistry sampling, actual application rate, soil moisture and volume of lysimeter samples. During the 2002 and 2003 crush seasons, the study plots were loaded at different process water application rates and sampled to determine the degree of process water treatment as a function of loading rate. The experimental dataset is presented in this document.

Study Results. Field experiments were conducted between September 2002 and January 2003 and between August and December 2003 according to the protocols outlined in the project work plan (Appendix A). Twenty two loading cycles were completed; ten at the Non-Stillage Test Site and twelve at the Stillage Test Site. Hydraulic application amounts were varied in order to establish a range in BOD, nitrogen, and inorganic dissolved solids (IDS) constituent loadings. Application amounts were above and below both the 1980 guideline limits and the revised limits proposed here. The basic results of the 2002 crush season study are summarized as follows:

- **pH.** Neither stillage nor non-stillage process water applications result in a permanent decrease in soil or soil-water pH. Therefore, *pH is naturally controlled and does not constitute an important management factor for these spreading basins. However, pH should be monitored periodically to assess soil conditions.*

- **BOD_5.** Removal of BOD_5 is above 89 percent at the five food depth for each site in both years. This calculation is based on comparing the total process water BOD_5 load (lb/acre) for each season with the total percolate BOD_5 content (lb/acre) measured in the lysimeters. *BOD_5 treatment is very effective in spreading basins over the entire range of loading rates used in the study.*
- **Iron (Fe) and Manganese (Mn).** Soluble iron and manganese are produced in the soil profile under anaerobic conditions. The production of these reduced forms is highly correlated with nitrate removal via denitrification. This effect is the basis for BOD_5 loading limits proposed in the draft spreading basin management guidelines. Non-Stillage process water applications resulted in lower soluble iron and manganese production than the Stillage Site applications in both study seasons.
- **Nitrogen.** Total Nitrogen was efficiently removed when constituent and hydraulic loading were properly managed. If sufficient anaerobic conditions are not established (as indicated by soluble iron and manganese production), nitrate-N may not be effectively denitrified. If high process water loadings and insufficient (short) resting periods do not allow the spreading basin to drain and establish aerobic conditions, organic-N and ammonia-N are not effectively nitrified. At the stillage site, overall total nitrogen removal was approximately 70% at the five foot depth. In 2002, total removal was 68% at the five foot depth and was limited by the nitrification rate for ammonia-N. In 2003, nitrification of ammonia was satisfactory but denitrification was incomplete. The Non-Stillage study site percentage removal was 34% and 23% at the five foot depth for the 2002 and 2003 field seasons. In both years, there was incomplete denitrification. *Proper aerobic/anaerobic cycling is critical for high total nitrogen removal.* In particular, prior to process water application in 2003 for the Non-Stillage Test Site, the test basin had been ripped. This deep ripping may have increased hydraulic conductivity (and increased re-aeration rates), and allowed rapid water flow past the depth of the lysimeters. These effects, therefore, may not have allowed the establishment of anaerobic conditions needed for denitrification (Refer to Section 3.5.1 Non-Stillage Test Site for discussion of Nitrogen Transformations and Removal). Proper basin management is necessary not only to assure that ponding does not occur for extended periods of time, but also so that water remains in an anaerobic zone long enough for denitrification to occur.
- **IDS.** TDS is a poor indicator of inorganic ions in winery process waters as organic acids contribute to TDS levels. Inorganic Dissolved Solids (IDS) is a better indicator. The IDS process water load was approximately the same as the amount measured in the percolate for both sites and years. Calcium and alkalinity in applied process water were lower than at the five foot depth values observed in five-foot lysimeter samples and potassium generally decreased. Sodium was higher in the percolate than in process water at the Stillage site. *Although the ionic proportions changed, IDS was measured to be approximately the same for the load and percolation.*
- **Per-Application Loading Rate.** Loading rates were generally lower than the soil water storage capacity. Therefore, applied process water had a residence time in the soil and did not immediately pass through the soil profile*. Hydraulic application amount should match site soil/subsurface characteristics.*
- **Duration of Resting Cycle.** Resting time was lengthened during the 2002 and 2003 field studies because saturated soil profile conditions limited treatment of process water for both Stillage and Non-Stillage flows. *Resting time must be established based on site hydraulic*

characteristics so that aerobic and anaerobic conditions alternate in the soil to maximize nitrogen removal and control iron and manganese concentrations.

- **Draft Guidelines.** The proposed guidelines expand consideration of spreading basin process water management from the 1980 guidelines (application rate and duration of the resting cycle) to address additional process water constituents including: **pH** control within the surface soil; **BOD_5** management (oxidation, odor control, appropriate iron and manganese dissolution); **Nitrogen** transformation and removal; **IDS** management; and **hydraulic loading** (per-application rate and resting time between loading events)

The guidelines proposed here for spreading basin process water treatment are separated into the four topic areas:

- **Site selection** involves evaluation of process water quality, and spreading basin soil and groundwater conditions. Guidelines are for suitable sites using conventional management. For sites that do not meet this guideline, other management procedures may be employed to achieve proper operation and environmental protection.
- **Identification of the application rate-limiting constituent** (usually hydraulic, nitrogen, or BOD_5 load).
- **Management of individual application events** to address infiltration rates, resting cycle duration, verification of treatment, and basin maintenance.
- **Planning for the overall process water management program** including determination of acreage required, annual maintenance, cropping to remove additional soil nitrogen, and evaluation of salt management.

Conclusions. The Wine Institute and Kennedy/Jenks conducted a successful study of process water land application using spreading basins. The study updates the 1980 guidelines to address additional factors important for design and operation of spreading basins for winery process water treatment: pH, BOD_5, nitrogen, inorganic salts, and iron and manganese. Important results of the field study include:

- pH is buffered and is not a critical process water factor for either the Stillage or Non-Stillage sites,

- Near complete BOD_5 removal (95%) occurred in the surface soils

- Nitrogen treatment in the spreading basins was approximately 70% for the Stillage Site and approximately 30% at the Non-Stillage Site

- IDS load in the percolate was the same as that of process water but the ionic composition was different with calcium, magnesium, and bicarbonate higher in the percolate.

- Anaerobic conditions necessary for denitrification were indicated by iron and manganese dissolution.

In this study, it was found that on a load basis land application treatment of winery process waters within the upper five feet of soil is comparable to treatment obtained during typical engineered biological treatment (e.g., aerated sequencing batch reactors).

Additional treatment in the subsurface below five feet will reduce the concentrations measured at 5 feet depth. A review of available literature for deep vadose zone treatment (Section 4) indicates that treatment is well documented and will likely reduce percolate concentrations during subsurface flow.

The technical conclusions of the field study (Section 3) were used to develop proposed guidelines for spreading basin management (Section 5). The guidelines address site characterization; quantification of spreading basin loading rates based on site-specific measurements; management needs during application events; and overall planning requirements for a spreading basin program.

Section 1: Introduction

The Wine Institute and its member wineries have a long history of cooperating with the Regional Water Quality Control Boards to develop methods to manage winery process water. The technical studies discussed in this report were undertaken to update past information, develop a scientific basis for changing management practices, and continue to work with the regulatory community.

1.1 Regulatory Environment

Land application of winery stillage has been practiced for over 50 years in California. In 1947, Coast Laboratories prepared a report for the Wine Institute with recommendations for land application of stillage in the Central Valley Region of California where soils were favorable for this method of treatment and disposal (Coast Laboratories, 1947). The method recommended was described as intermittent irrigation that is similar to the rapid infiltration (RI) form of land treatment except that lower hydraulic loads are applied.

A maximum loading rate of 100,000 gallons/acre/week (approximately 4 inches/week) was recommended for sandy, well-drained soils. One day of application of process water was followed by six days of resting for draining and drying.

In the 1970s, odor problems were encountered with stillage land application practices and Metcalf and Eddy was retained by the Wine Institute to prepare a survey and report on then-current practices (Metcalf and Eddy, 1980). The survey and report indicated that odor problems were caused by deep ponding of stillage, inadequate removal of solids, failure to cultivate soils prior to the next application, and inadequate resting periods for drying and soil treatment of applied loads. The report identified three categories of operating systems with recommended hydraulic loading rates, drying times and area requirements for each category. The guidelines in the 1980 report were submitted to the Regional Board and approved in 1982 as the basis for waste discharge requirements (WDR).

Recent WDRs have incorporated additional design and monitoring requirements that were not part of the 1980 guidelines or underlying analysis. In addition, the Stillage guidelines have been applied to winemaking facilities that do not have distilling operations.

1.2 Current Scientific Understanding

The basic technique of spreading basin land application involves flood application of process water to uncropped, open, narrow checks. Wastewater solids are filtered out and dried on the surface of the checks. Dissolved organic material percolates into the soil column where biological treatment, stabilization, and pH buffering occurs. After drying, the soil is often scarified or disked before the next application of process water. In some systems, cover crops are planted in either the winter or spring for nutrient (e.g., nitrogen) uptake and the crop is harvested before the next crush season.

The two-year Wine Institute land application field study was developed on the basis of current scientific understanding of soil and subsurface processes that convert, remove, or reuse process water constituents that are potentially pollutants. The field study focuses on treatment processes near the soil surface where biological processes are most active; the treatment potential of deeper layers is also addressed in Chapter 4 of this report (for additional detail, see the 2003 and 2003 Project Work Plans, Appendix A).

The general behavior of common process water constituents in spreading basins is as follows:

- Organic constituents in process water (characterized by 5-day biochemical oxygen demand, BOD_5) are treated primarily by oxidation at the spreading basin surface and in the surface soil horizons.

- BOD_5 also affects the reduction – oxidation status of the soil. When nitrate is present, it is often denitrified if other sources of oxygen are depleted. Manganese and iron oxides may also be reduced to forms that are soluble in the soil solution. Once these oxygen sources are depleted, sulfate may also be reduced (Miller and Donahue, 1990)

- The fate of dominant nitrogen species (organic-N, ammonia-N, and nitrate-N) depends on water/soil conditions: a) organic-N, the dominant form of nitrogen in winery process water, is mineralized to ammonia-N in the surface soil, b) ammonia-N can adsorb to soils and under aerobic conditions is biologically converted to nitrate-N (nitrification), and c) under anaerobic conditions, nitrate-N is biologically reduced to gaseous nitrogen species (denitrification) that are eventually released to the atmosphere. The oxidation/reduction cycle of nitrogen is intricate, but well-managed application and resting periods have proven to be effective in causing substantial nitrogen removal during land application (Environmental Protection Agency (EPA), 1984, 1981).

- The dominant dissolved inorganic ions in process water are calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), chloride (Cl^-), sulfate (SO_4^{2-}), and bicarbonate (HCO_3^-). The alkalinity in these process waters can be significant; however, it is primarily due to organic acids rather than bicarbonate (HCO_3^-). Each of these ions as well as nitrate-N, ammonia-N, and phosphate are plant nutrients. Nitrate-N, ammonia-N, and phosphorus are present in smaller amounts than the other ions. Of the common ions, Ca^{2+}, Mg^{2+}, K^+, and Na^+ can accumulate in the soil or are taken up by crops (Hanson et al., 1993). Cl^- and other anions generally move with applied water through the soil. SO_4^{2-} moves with the soil water but may also be a source of oxygen during anaerobic biological reactions in the soil. Some ions, primarily calcium, also precipitate in soils or dissolve from soil into solution depending on soil conditions. In general, inorganic salts in the soil profile are concentrated by soil surface evaporation or crop water uptake.

- For most waters, Total Dissolved Solids (TDS) is considered a measurement of combined inorganic ion content. In winery process waters, significant concentrations of organic acids contribute to TDS and electrical conductivity (EC) levels. TDS can be separated analytically into Volatile Dissolved Solids (VDS) and Inorganic Dissolved Solids (IDS). VDS consists largely of the organic acid component of TDS. Therefore, it is more appropriate to monitor combined inorganic ion levels by analyzing samples either for IDS or the sum of individual major ion concentrations.

- Alkalinity measurements (by titration) for winery process water at neutral pH ranges do not necessarily measure bicarbonate ion. The volatile solids / biodegradable organic acids in process waters can add to the alkalinity. In soil pore water samples, the majority of the organics have been consumed during treatment in the soil profile or soil surface and the alkalinity measurement more truly reflects bicarbonate ion levels. Bicarbonate production is often associated with dissolution of precipitated calcium compounds in soil, a cyclical process that occurs in arid-land soils (Bohn et al., 1979).

The general water treatment process in a spreading basin is as follows:

- Before the first application for a season, basin soils are dry due to drainage, evaporation, or plant water use. As a result, the soil profile is well aerated. Inorganic nitrogen in the soil is present primarily as nitrate-N unless cropping has removed the inorganic nitrogen supplies.

- Process water is applied to spreading basins in amounts that are based on estimates of acceptable hydraulic and constituent loading amounts. The 1980 Stillage guidelines give hydraulic application guidelines and other references give constituent limits based on other considerations (e.g., EPA 1977 provides more general BOD loading limits for food processing water).

- When process water is first applied to a spreading basin, process water organics, measured by BOD_5, are oxidized by soil bacteria utilizing free oxygen as well as oxygen gained from nitrate-N and other compounds.

  - In this process, nitrate-N in the soil profile is reduced to gaseous nitrogen species and is ultimately lost to the atmosphere. This process, denitrification, occurs when process water is applied and bacteria consume localized dissolved oxygen causing anaerobic conditions.
  - Under conditions of significant loading, some of the soil iron and manganese can be reduced and become soluble.
  - As the biodegradable organic acids are consumed, the ionized fraction is replaced by bicarbonate ions produced during oxidation. Since other soil processes occur simultaneously (BOD_5 oxidation, nitrogen-N transformations, salt ion exchange and precipitation), the effect on soil solution ion concentrations is variable.

- Process water pH can be low when it is applied but total acidity is generally not high (in comparison to soil buffering capacity). In addition, oxidation processes consume the organic acids in the process water. As a result, there is generally no effect on soil pH for properly managed systems.

- Changes in IDS occur in the soil profile. There is limited removal of salt ions (except for potassium, which is a plant macronutrient). Because salts are concentrated during the process of evaporation and plant water use, IDS concentrations are likely to increase in the soil. In addition, the ion mixture in the soil changes in relation to the composition of the soil water and as bicarbonate ion replaces degraded, ionized organic acids. Additional carbon dioxide produced during oxidation can dissolve calcium carbonate in the soil, increasing both calcium and bicarbonate concentrations.

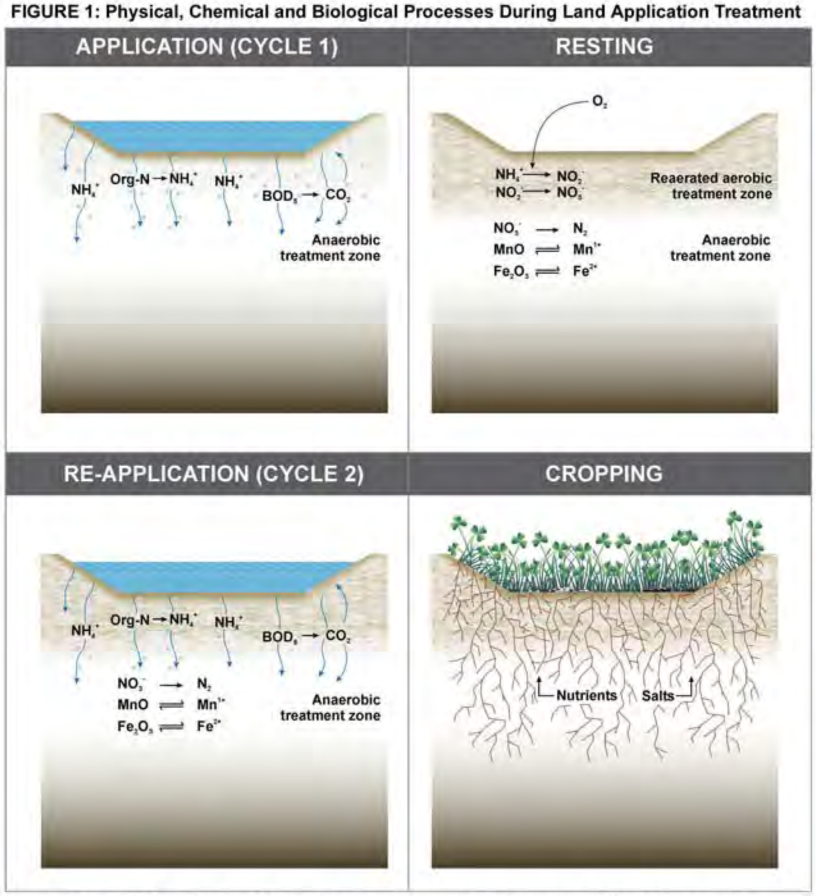
- Applied process water displaces the existing soil water downward. The process water remains in the soil and aerobic processes are initiated as air enters the profile either due to evaporative water loss or soil drainage. Remaining organics are oxidized and ammonia-N is converted to nitrate-N. These conditions occur during the “rest cycle” for a spreading basin.

- Application and rest cycles can be managed so that BOD_5 is attenuated and a significant fraction of the nitrogen present (up to 80 to 95%) is ultimately transformed to gas and lost to the atmosphere (Enfield, 1977; Gilbert et al., 1979). This is primarily achieved by applying oxygen-consuming process water to the basins followed by a period of oxygen introduction.

- The cycling of aerobic and anaeroblc conditions facilitates the discussed removal mechanisms. In addition, hydraulic loading is managed so that these processes occur in the upper layers of the soil. If high loadings are applied, off-season cropping may be employed to achieve greater removal of nitrogen and some salts before the next land application season.

An illustration indicating the various treatment mechanisms can be found on Figure 1. Each mechanism is footnoted and additional biochemical information for these mechanisms can be found in Appendix E.

FIGURE 1: Physical, Chemical and Biological Processes During Land Application Treatment



Note: See Appendix E for Pertinent Chemical Reactions During Land Application of Winery Process Water

1.3 Objectives of Study and Approach

This study addresses use of spreading basins for treatment and discharge of winery process water from both Stillage and Non-Stillage production. Study activities do not address issues related to crop irrigation, or other process water treatment techniques. Section 4.0 addresses treatment that occurs in the vadose zone.

Objective. The objective of the field study is to provide basic data for use in a) revising Stillage winery process water land application guidelines and b) developing Non-Stillage process water land application guidelines. The objective of this report is to summarize those field results, analyze the dataset, and develop draft revised guidelines for winery process water management.

Approach. Kennedy/Jenks Consultants and the Wine Institute of California designed and equipped two field study test basins at existing spreading basin land application sites. Each test basin had lysimeters to collect percolate samples for analysis. These sample results, process water application and water quality information, and periodic soil sampling results comprise the basic dataset for evaluation. These test basin results were used to quantify process water treatment performance as a function of site features, process water characteristics, and management.

The study was conducted during both the 2002 and 2003 crush seasons. The field experiments were conducted by applying loading rates both lower and greater than the rates documented in the 1980 survey. This was done to provide test data for a range of experimental conditions. The complete dataset was then used to develop proposed guidelines for land application of winery Stillage and Non-Stillage process water.

The hypothesis tested during the field studies was that properly managed spreading basin land application is an effective treatment method for Stillage and Non-Stillage winery process water. The following water quality constituents were measured and studied: 1) pH; 2) BOD_5; 3) nitrogen species; 4) common inorganic ions; and 5) soluble iron and manganese. In addition, odor generation and percolation rates were monitored.

Section 2: Experimental Approach

The experimental approach was designed to achieve the objectives of the study. Process water was applied to the test basins in varying hydraulic applications that corresponded to estimated constituent loads. Actual constituent loading was determined by sampling and analysis of applied process water. The range of hydraulic loadings at each test basin spanned the 1980 guidelines loading values (Metcalf & Eddy, 1980). The experimental design is discussed in the documents entitled, "Work Plan for Investigation of Land Application of Stillage and Non-Stillage Process Water" and "2003 Work Plan for Investigation of Land Application of Stillage and Non-Stillage Process Water" (Kennedy/Jenks Consultants, 2002, 2003, see Appendix A).

2.1 Study Locations

Two wineries volunteered to participate in the land application study: 1) the Bronco Winery in Ceres, and 2) the E. & J. Gallo Winery in Fresno. Both wineries are located in California's San Joaquin Valley (Figure 2). The Bronco facility does not conduct stillage operations and produces process water that is representative of winery Non-Stillage process water. The Gallo facility conducts stillage operations and produces water that is representative of winery Stillage process water (stillage wineries generally do not operate stills continuously and produce both Stillage and Non-Stillage process water blended in varying proportions). Throughout this report the Bronco and Gallo Wineries will be referred to as the Non-Stillage and Stillage Test Sites, respectively. In general, the relative strength of constituents of concern (primarily BOD_5 and total nitrogen) is higher in Stillage than in Non-Stillage process water. Historical process water quality and land application management summaries for each facility can be found in Table 1.

Table 1: Field Study Site Summary Characteristics

	Stillage Test Site	Non-Stillage Test Site
Process Water:		
Winery process water type	Stillage	Non-Stillage
Average BOD_5 (min.-max.) mg/l	5,660 (3 – 15,100)	784 (52 – 4,200)
Average total N (min.-max.) mg/l	430 (10 – 1540)	23 (2 – 92)
Average TDS (min.- max.) mg/l	8,845 (272 – 26,400)	1,100 (240 – 3,300)
Application Soil:		
Soil type	Primarily Atwater sandy loam	Dinuba or Hanford sandy loam, Tujunga loamy sand
Available Water Capacity (inches per 5 feet)	10	10
Typical Application Operation:		
Application depth (inches)	3.7 maximum	Variable[a]
Cycle duration	7 day minimum	Variable[a]
Application/Infiltration period	24 hours maximum	Variable[a]
Basin surface treatment	6 inch rototilling between cycles; deep ripping when needed to maintain infiltration	Disking or ripping when needed to maintain infiltration

[a] This facility uses much of its process water for vineyard irrigation. As a result, the spreading basin loading schedule is different than for sites without an irrigation option.

2.2 Test Basins

The experimental approach of the study was to equip the test basins with instrumentation that would allow the collection of soil water at depths of one and five feet below the ground surface. This was performed by installing pan lysimeters (using the design of Gee et al., 2000) connected to four foot long soil cores a foot below the soil surface. Twelve inches of soil above the lysimeter soil core were needed to allow for between-cycle basin management (i.e., roto-tilling, leveling, disking). Twelve-inch diameter undisturbed soil cores were obtained from soils in land application checks near the test basins. New soil cores were collected at the beginning of each crush season. The lysimeters were equipped with 2- or 4-liter plastic bottles to collect percolate samples. Tipping cup rain gauge devices were used as a second measure of flow through the lysimeters. Three deep (i.e., five feet below ground surface (bgs)) lysimeters were placed in each test basin. In 2002, an additional shallow lysimeter (i.e., one foot bgs) was placed in each basin to monitor changes in water quality during transport through the surface layer of the soil.

Field plot locations and instrumentation varied between the 2002 and 2003 study seasons. The experimental layout for each site and each year are shown in Figure 3. The primary difference between years is the presence of the shallow lysimeter in 2002 plots. Field plots were moved to new but adjacent locations at each site to allow re-installation of equipment and to move away from areas where in-plot soil sampling had occurred. 2003 field plots were moved less than 200 yards from the 2002 locations at each site. The Non-Stillage Site plot remained in the same irrigation check but at a different location within the check. The plot was established following harvest of a field corn crop grown during Summer 2003. The 2003 Stillage plot was moved into an adjacent irrigation block at the land application site. The location was selected so the plot could be in a check where a winter grain crop was removed prior to spreading basin use.

2.3 Water and Soil Sampling

Process water was sampled during each application event, which signifies the beginning of a load-rest cycle. The lysimeter sample bottles were sampled at the end of each cycle and, during longer cycles, intermittently within a cycle. Water samples were delivered to local analytical laboratories for water quality analysis immediately after sampling. Soil samples were taken at four to six depths for analysis. In 2002, sampling occurred at the end of each drying cycle; in 2003 sampling was less frequent (see Section 3.7). The analyses performed on the water and soil samples are listed in Table 2.

Table 2: Land Application Study Water and Soil Quality Analyses

Constituent	Water/Soil Quality Parameter/Sampling Details
Water Samples	Process water was grab sampled during each application event. Percolate samples were collected during or at the end of or during the rest cycle from lysimeter sample containers.
pH	pH
Organics	BOD_5, VDS, Alkalinity
Nitrogen	NH_4^+, NO_2^-, NO_3^-, Organic-N, Total N
Salts, salinity	EC, TDS, IDS, VDS, Na^+, Cl^-, Ca^{2+}, Mg^{2+}, SO_4^{2-}, K^+, Alkalinity or Acidity
Reduction – oxidation status	Total Fe, Total Mn
Soil Samples	Samples were collected with a soil auger at 0-1, 1-2, 2-3, 3-4, and 4-5 foot depths. In 2002, sampling occurred at the end of each drying cycle; in 2003 sampling was less frequent (see Section 3.7).
pH	pH
Organics	% Total Carbon
Nitrogen	% Total Nitrogen, NH_4^+-N, NO_3–N
Salts, salinity	EC, TDS, IDS, VDS, ESP, Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, Total P
Reduction – oxidation status	Total Fe, Total Mn

Notes:

VDS = Volatile dissolved solids
IDS = Inorganic dissolved solids
TDS = Total dissolved solids
EC = Electrical conductivity
ESP = Exchangeable Sodium Percentage
Fe = Iron
Mn = Manganese
Ca^{2+} = Calcium
K^+ = Potassium
P = Phosphorus
SO_4^{2-} = Sulfate
NO_3^-N = Nitrate-N
Cl^- = Chloride
Mg^{2+} = Magnesium
BOD_5 = 5-day Biochemical oxygen demand
NH_4^+ -N = Ammonium -N
NO_2^- -N = Nitrite-N

2.4 Instrumentation

Project instrumentation consisted of lysimeter sample collection devices, soil moisture sensors, soil gas probes (2002 only), and flow metering for process water application. Equipment details are briefly described below.

Lysimeters The lysimeters (Gee et al., 2000) are equipped with tipping cups and event loggers (2002: Hobo Event Recorder, Onset Computer Corp., Bourne, MA; 2003: ECH_2O logger, Decagon Devices, Pullman, WA) that allow the tracking of incoming water into the lysimeter sample bottles. Data were recorded and downloaded periodically.

Soil Moisture Sensors and Soil Gas Probes. These sensors were included in the experiments for two purposes: to verify the aeration status of the soil profile and to assess the value of various sensors for future use by spreading basin operators to determine the needed duration of application resting cycles. In 2002, Watermark soil water potential sensors (Irrometer Co., Riverside, CA), were installed at three depths (1, 2.5, and 5 feet bgs) within the test basins to monitor the water content in the top five feet of the soil column. Watermark sensor outputs were recorded in the field using WatchDog Dataloggers (Ag-Water Management, Fresno, California). In 2003, ECH_2O capacitance soil moisture sensors (Decagon Devices, Pullman, WA) were installed at three depths (1, 2, and 5 feet bgs) and output was recorded using ECH_2O loggers. Soil water content measurements for 2003 proved to be more useful than those of 2002 (discussed in Chapter 3). These sensors provided more measurement sensitivity in the near-saturated soil moisture range of the field plots. The moist conditions, moderate electrical conductivity, and varying reduction-oxidation environment affected the durability of the soil moisture sensors, as several sensors needed to be replaced in the 2003 study season.

In 2002, soil gas probes (Geoprobe Systems, Salina, KS) were inserted into each test basin at three depths (1, 2.5 and 5 feet bgs). These probes, in conjunction with tubing and a peristaltic sample pump, allowed the extraction of soil gas at a specific depth to be passed through an oxygen gas monitor to determine the concentration of oxygen in the soil gas.

2.5 Experimental Application and Cycle Design

The field study was conducted to provide a dataset to compare BOD_5, nitrogen, and inorganic ion constituent loadings with resulting percolate concentrations. Field applications were made by estimating hydraulic loads required to apply a given constituent loading. Since process water quality could not be determined before application, hydraulic applications were estimated based on historical process water quality data for each study site. Once laboratory results for applied process water were available, actual constituent loadings were calculated from hydraulic application and measured water quality.

The rest cycle length was determined by one of two methods – either: 1) the recommended seasonal cycle length in the 1980 guidelines was chosen; or 2) a longer cycle based on the infiltration/drainage rate of the basin. Slower infiltration and drainage rates resulted in longer rest cycles to allow the test basins to dry prior to initiating the subsequent cycle.

2.6 Study Schedule

Instrumentation was installed in each of the test basins in late August and early September each year. Experimentation was initiated soon afterward and continued until the end of crush season for both wineries. Between 4 and 7 application cycles were completed at each test site prior to the end of crush in each year.

2.7 Data Analysis and Quality Control Program

The experimental design used for this investigation consists of multiple process water loading events at two sites for two years. Process water was applied and soil water and soil samples were collected to determine the level and quality of treatment that occurs.

The key measurement of treatment success comes from triplicate sets of lysimeters at five-foot depth at each site. Triplicate instrumentation for each test basin provides sufficient data to allow evaluation of variability in results. This can be accomplished in two ways. First, lysimeter water quality results can be averaged to provide a basic assessment of treatment efficiency. These results must, in turn, be used with averaged flow data from the lysimeters to determine potential transport to the deeper vadose zone. This is the method of analysis used for the initial evaluation of the 2002 dataset and is referred to as a “concentration-based” analysis.

A second calculation method is termed a “load-based” analysis. This data analysis method is used in this report to evaluate experimental results because the “load-based” analysis is more representative of actual conditions. Since there is a strong correlation between lysimeter water quality and amount of flow through the lysimeter, each lysimeter can be treated as an accurate representation of the flow and water quality transformations at a point in the test basin. The flow and water quality are combined to calculate constituent loading at that point. In turn, the three lysimeter evaluations of constituent loads can be averaged for the experimental plot.

Quality control. All water and soil samples were analyzed by Dellavalle Laboratory, Inc. or Twining Laboratories, Inc. Analytical variability and analytical methods for water quality analyses performed can be found in Appendix B. The same analysis methods were used for both years except as noted in the tables and appendices. Analytical methods for soil and water samples were standardized during a request-for-bid process to select the analytical laboratory. Bids were reviewed for ability to provide the proper testing, laboratory capacity and timeliness of reporting, availability of electronic data transmittal, shipping/sample management, and cost.

Kennedy/Jenks personnel use standard protocols for evaluating laboratory data when it is received. This allows correction of draft laboratory sheets before final results are presented. With regard to report preparation including data analysis and development of conclusions, Kennedy/Jenks uses a review process that incorporates peer review of analyses, editorial review of reports, and final review by a project Quality Assurance Officer. For this project, the Wine Institute also provided an industry review panel to review the draft manuscript and proposed spreading basin guidelines.

Section 3: Field Results

Two years of results from field experiments are presented in this section. In 2002, field experiments were conducted between September and January 2003 according to the protocols outlined in the previous section. Eleven loading cycles were completed; four at the Non-Stillage Test Site and seven at the Stillage Test Site (Table 3). In 2003, field experiments were conducted between August and December. Eleven loading cycles were also completed in 2003; six at the Non-Stillage Test Site and five at the Stillage Test Site. As discussed in the previous section, hydraulic application loads were varied in 2002 in order to establish a range in BOD_5 constituent loadings. As process water concentration varies at each site, historical average crush season BOD_5 concentrations were used to estimate appropriate hydraulic applications. In 2003, more consistent hydraulic loads were applied to verify optimal treatment conditions observed during the first experimental season. Actual constituent loading rates were determined by analyzing the process water for constituent concentrations in samples taken at the time of application.

The study was designed to assess the effects of chemical constituent loadings on spreading basin treatment. BOD_5 was the primary constituent used to establish loadings. TN, TDS, IDS, pH, iron, manganese, individual inorganic ions, and individual nitrogen species were also monitored.

3.1 Hydraulic Loading, Cycle Length, and Constituent Loading

Figures 4 and 5 show cumulative potential evaporation, rainfall, process water application, and estimated percolation for the period of the field study. During 2002, there was one rain event at both sites in November. At the Non-Stillage Test Site, there were 1.5 inches of precipitation and 8.9 inches of calculated actual evaporation. 25.4 inches of process water were applied. Approximately 18 inches of water was available for soil storage or percolation. At the Stillage Test Site, there were 1.5 inches of precipitation, 10.5 inches of calculated actual evaporation, and 21.7 inches of process water applied. Precipitation plus irrigation exceeded evaporation by 12.7 inches of water.

In 2003, climate and process water loading amounts differed from 2002. Precipitation was less at both sites; November precipitation was 0.43 inches at the Non-Stillage site and the Stillage site received 0.62 inches. At each site, there was a small storm event in early November with intermittent rain later in the month. At the Non-Stillage site, 2003 evaporation was 11.9 inches, applied process water was 67.1 inches, and 53.5 inches of soil water was estimated to percolate after soil treatment. At the Stillage test site, 2003 evaporation was 10 inches, application amount was 20.35 inches and estimated percolation was 11 inches.

The initial study design prescribed consistent resting periods (i.e., percolation and drying times) after application for each cycle. As the study progressed, cycle times were lengthened due to the decrease in infiltration rates, basin and study management operations (e.g., disking, roto-tilling, leveling, sampling), and the need for additional drainage/aeration time between hydraulic loadings.

Constituent loads are presented in two ways: 1) as the load applied per surface area (lbs/acre); and 2) load applied per surface area averaged over the length of the cycle (lbs/acre/day), which is simply the load applied per surface area divided by the number of days in the entire load-rest cycle. Both methods have merit for design and reporting purposes, but confusion between the two should be avoided. This document will focus on method 1) but will also report method 2) to compare between cycles.

3.1.1 Infiltration Rates and Soil Moisture Measurements

Infiltration rates were observed to vary within the timeframe of the study. Test basins were roto-tilled or disked at the end of each cycle just prior to the next application cycle. During the first cycles, the applied process water percolated beyond the soil surface in a short amount of time, less than one hour. In later cycles, percolation rates were observed to be much slower; standing water occasionally remained on the test basins for several days. This behavior was corroborated by lysimeter event data, where immediate response was observed after application during early cycles and a dampened response was observed in later cycles.

The 2002 soil moisture monitoring dataset began after the first loading cycle and documents the rate of soil profile drying during the resting phase and rewetting after applications (Figure 6). The Stillage Test Site showed fairly rapid drainage and drying following cycle 1 application (13 September 2002). Rewetting was almost instantaneous after cycle 2. After this time, soil drying and drainage was slow and did not reach the water potential values achieved after cycle 1.

The rates of wetting and drying were slower at the Non-Stillage Test Site and spreading basin soils generally remained wetter than at the Stillage Test Site. Figure 6 provides data to document that, following application, soils remained saturated for 3 to 8 days before drying/drainage began.

2003 soil water measurements are shown in Figures 7 and 8. These figures show average daily soil water content and the individual application cycles are marked. The accompanying table for each graph provides an initial analysis of soil moisture content change between the “wet end” value that occurs just after application and the values at which soil drying comes to a near-constant value. A recommended rest cycle duration based on soil water content sensors are also listed (the final column lists an evaporation estimate for the cycle).

The Non-Stillage Site dataset (Figure 7) shows expected trends in soil water content for the surface sensors, particularly for the pre-wet and first cycles. The sensors record a high water content value just after application (note that the highest hourly water content is not shown in this presentation of daily averages). Water content decreases due to evaporation and drainage during the resting cycle. In the case of the 12 inch sensor, cycle 2 was initiated before the sensor came to a “steady” value. If this were used to schedule the next application event, the resting cycle would have been slightly longer.

The 60-inch sensor at the Non-Stillage Site shows a slow increase in soil water content throughout most of the application season. The soil water content increases show the effect of the multiple process water applications during the season.

The Stillage Site dataset (Figure 8) shows slower soil water content changes. The 2-foot sensors provide the most useful data for scheduling application cycles. During cycles 2 and 3, the sensors reach a very slow rate of decrease well before significant evaporation has occurred.

3.1.2 Spatial Variability of Application within the Test Basins

During the process water applications, it was observed that unequal application occurred within the test basins. This is corroborated by the 2002 distribution of percolate collected in the three replicate 5-foot lysimeters installed at each site (Figure 9).

The Non-Stillage Test Site process water contains lower BOD_5 levels, which allows higher hydraulic application rates than those used at the Stillage Test Site. At the Stillage Test Site, high process water BOD_5 levels required low hydraulic loadings, at times less than 2.5 inches. It was difficult to apply this low volume of water to the test basin with uniform distribution. It is likely that normal spreading basin applications can be performed with better precision and more uniformity than at the experimental sites. Longer checks can be irrigated with higher flow rates and greater velocity to facilitate spreading. During typical application, however, greater hydraulic loads are realized closer to the point of application.

2003 lysimeter results also showed variability in hydraulic load among lysimeters at each site. In addition, lysimeter sample volumes (Appendix C) were less than the percolation estimates based on process water applications and climate data (see Figure 9).

3.1.3 Non-Stillage Test Site

Four cycles of process water application and resting were performed at the Non-Stillage Test Site during the 2002 crush season. Hydraulic applications ranged from 2,000 to 4,350 gallons in the 780 square foot basin. This corresponds to process water applications of 4.1 to 8.9 inches. BOD_5 loading ranged from 1,770 to 4,120 lb/acre for the individual applications and 142 to 553 lb/acre/day averaged over entire cycles. TN loading ranged from 14 to 86 lb/acre for the individual applications. Cycle duration ranged from 6 to 29 days.

The 2003 crush season was initiated with a pre-wetting spreading basin application in mid-August. This was followed by 6 process water application cycles from 7.8 to 10.1 inches per application. BOD_5 loadings (4,250 to 10,280 lb/acre) were higher than in 2002 as were the total nitrogen applications (74 to 343 lb/acre). The ratio of BOD_5 to total nitrogen ranged from 30 to 77 for the process water applications. This ratio is higher than the levels customarily required to support denitrification (EPA 1984).

3.1.4 Stillage Test Site

Seven cycles of process water application and resting were performed at the Stillage Test Site during the 2002 crush season. The crush season of the stillage operation was longer in duration and allowed for more cycles. Hydraulic application rates ranged from 380 to 1,000 gallons in the 320 square foot test basin. This corresponds to process water applications of 1.9 to 5.0 inches. BOD_5 loading ranged from 54 to 10,200 lb/acre for the individual applications and 3 to 885 lb/acre/day averaged over entire cycles. TN loading ranged from 5 to 233 lb/acre for the individual application. Cycle duration ranged from 7 to 21 days.

One odor event occurred at the Stillage Test Site that lasted approximately 48 hours during cycle 4 of 2002. The odor was sulfurous in nature and typical of odors generated in anaerobic environments. The odor was initially strong near the test basin but no noticeable objectionable odors were detected at the property boundary.

The 2003 field study started with a pre-wetting spreading basin application of 4.7 inches. This was followed by 5 process water application cycles with 3.1 inches of process water per application. BOD_5 loadings were 3,650 to 7,800 lb/acre and total nitrogen applications were 124 to 572 lb/acre. The ratio of BOD_5 to total nitrogen ranged from 16 to 52 for the process water applications. This ratio is higher than the levels customarily required to support denitrification (EPA 1984) and therefore would not be limiting.

3.2 pH effects and Buffer Capacity

All applied process waters and lysimeter samples were measured for pH levels (Table 4). The pH levels were consistently higher in the applied Non-Stillage Test Site process water (median value = 5.4 in 2002 and 6.1 in 2003) than in the applied Stillage Test Site process water (median value = 4.6 in 2002 and 3.7 in 2003). At each site, it is apparent that the soils have sufficient buffering capacity to neutralize the applied water through 5 feet of vertical travel regardless of application loading. In fact, neutralization was observed in the top one foot of the test basins based on results from the 1-foot lysimeters in use in 2002. This is likely related to: a) the buffer contribution of the organic acids in process water as they biodegrade; and b) the buffering capacity of the soil.

The process water pH levels at the Stillage Test Site were generally below the pH endpoint of the alkalinity measurements, suggesting there is little bicarbonate alkalinity present and that the organic acids provide the buffer capacity. The relatively high (1685 to 3300 mg/l) acidity levels measured in 2003 (Appendix C) confirm this observation. On the other hand, the 2003 acidity levels for the process water at the Non-Stillage Test Site were very low (generally < 10 mg/l), indicating that both bicarbonate and organic acids buffer it. In either case, the ionized fraction of the organic acids are converted to bicarbonate and the water at 5-foot depth is predominantly buffered by bicarbonate alkalinity (see Section 3.3.2).

The two sites used in this study have been in operation for a number of years. In that time, there is no evidence that site soil pH buffering capacity has diminished. Soil pH values measured during this study are near neutral to alkaline (see Section 3.7).

Process waters exhibited a wide range in pH during this study, especially during 2002 at the Stillage Test Site. Some variation in process water pH is expected because water generating processes in a facility vary during the day. It is likely that the variation exhibited in the study dataset is larger than is common for operating land application sites. This occurred because the amount of process water required to load the study site basins was relatively small. Applications typically occurred for 15 minutes or less at each site. During such a short time, process water may be influenced by a particular winery operation rendering water with an uncharacteristic pH. Under operational hydraulic applications at a facility, the duration of application would be much longer and pH fluctuations would tend to cancel each other out.

3.3 IDS Movement and Changes in Composition

Detailed information regarding inorganic and organic components of TDS was gathered during the 2002 and 2003 crush season experiments. This dataset was used to assess the relationship of TDS and IDS; site specific changes to IDS concentrations in process water and lysimeter samples; and changes in concentration of individual inorganic ions.

In winery process water, significant concentrations of organic acids can contribute to TDS and EC levels. This is demonstrated for both the Stillage and Non-Stillage process water samples (see Appendix C). VDS concentrations in the applied process water are significant while those in the lysimeter samples are markedly lower indicating that VDS in greatly removed. The good correlation between VDS and BOD_5 levels for all samples (r^2 = 0.85 in 2002 and 0.89 in 2003) also indicates that BOD and VDS reductions are linked.

Evaluation of salt movement and treatment within spreading basin soils was based primarily on IDS concentrations. A key part of dataset quality control, balance between cations and anions in each sample, was based on total dissolved solids for process water and on the inorganic fraction only for lysimeter samples. An assumed distribution of organic acid species in winery process water was used to estimate the charge density of the organic acids. With this estimate, the sum of cations and anions generally matched well for process water samples in the 2002 dataset. This could not be confirmed for the 2003 dataset because alkalinity data were not available.

3.3.1 IDS Concentration Changes During Soil Treatment

Non-Stillage Test Site. At the Non-Stillage Test Site, the five-foot lysimeter samples consistently contained higher levels of IDS than in the process water (Table 5). This was most evident during the first two cycles in 2002, when process water IDS levels were 40% of the average five-foot lysimeter value, and in the pre-wetting cycle in 2003 (about 33%). During the first cycle in 2002, concentrations in the one-foot depth lysimeter were extremely high. This is likely due to the initial flush of salts concentrated at the soil surface by evaporation during the non-application season. The differences between applied and lysimeter constituent levels decreased during subsequent cycles until process water concentration was approximately 70 percent of the lysimeter value in 2002 and about 67% (although with more variability) in 2003. For the season, average process water concentration was 55 percent of average five-foot lysimeter average concentration. Soil solution concentrations at one and five feet were quite similar for all sampling dates after the first one. In addition, the differences in concentration among the replicate samples at five feet depth were quite small after the first date.

The last lysimeter samples in 2002 were collected after a 1.5-inch rain event in early November. Given the size of the rain, it is not likely that rain impacted soil processes significantly. In general, rainfall events that occur during the land application season are not likely to cause major impacts beyond adding to the total hydraulic load and lengthening the resting/drying time required before the next application.

Stillage Test Site. At the Stillage Test Site, the 2002 IDS dataset shows large variability in both process water concentrations and lysimeter concentrations (Table 5). Each of the five-foot lysimeters behaves differently. Lysimeter 1 was consistently low in IDS concentration, lysimeter

2 was quite high, and lysimeter 3 behaved in much the same manner as the lysimeters at the Non-Stillage site. Overall, average lysimeter concentrations were the same at 1 and 5 feet. It is found, however, that, on the dates when both depths were sampled, near-surface concentrations were always higher than those at 5 feet depth. The 2002 season-long average IDS concentration in lysimeter samples is approximately 30 percent higher than the average process water concentration. On a load basis, process water input of IDS approximates that observed in the five-foot lysimeter samples (Table 6).

The 2003 dataset shows less variability for both process water and the five-foot lysimeters after the pre-wetting cycle. IDS loadings were greater in 2003, but the five-foot IDS levels were only 46% of the process water compared with 95% in 2002.

3.3.2 Fate of Inorganic Ions During Land Application

Table 6 summarizes changes in individual ion load (pounds per acre) between process water and five-foot lysimeter samples.

Non-Stillage Test Site. For the Non-Stillage site, process water IDS load was slightly lower than the amount in the five-foot lysimeter samples. Chloride lysimeter levels were 72% of process water in 2002 and 65% in 2003. In contrast, calcium and alkalinity both showed increases in the lysimeter samples, an indication that some dissolution of calcium carbonate may have occurred. Potassium load decreased indicating that soil processes may have lowered potassium concentrations in the soil water. In 2002, sulfate was lower in the Non-Stillage Site lysimeter samples than the load from the process water applied, while in 2003 the sulfate level increased. The 2002 data may have been a result of one outlier result.

Stillage Test Site. For the Stillage Test Site, process water IDS load was approximately equal to the amount in percolate in 2002 but not in 2003. Chloride load also showed the same relationship for the two years. Calcium and sodium both showed significant increases in the 2002 lysimeter samples, an indication that dissolution of calcium carbonate may have occurred in the surface 5 feet. Potassium load decreased indicating that soil processes may have lowered potassium concentrations in the soil water. Sulfate was elevated in the percolate from the Stillage site lysimeter samples in 2002, but decreased in 2003. The constituents that are affected by anaerobic conditions (loss of nitrate, increase in soluble iron and manganese, and loss of sulfate) did not all occur at the Stillage Site in either 2002 or 2003.

Role of Alkalinity. Where increases or no change in IDS loads between the soil surface and 5 feet at both test sites were observed, individual ion analysis indicates that the majority of this increase is due to alkalinity and calcium increases. For lysimeter samples, alkalinity is primarily due to the bicarbonate ion. Potential sources and sinks of alkalinity during land application include:

- Dissolution of calcium carbonate in the soil releases both calcium and bicarbonate. This carbonate equilibrium is common in soils and groundwater throughout the Western United States. The datasets collected in this study demonstrate increases in both constituents. Studies conducted at the U.S. Salinity Laboratory (Bower, 1974) have demonstrated that a) salinity increases in agricultural drainage water, as compared to irrigation water; and b) drainage waters contain higher proportions of bicarbonate when the sodium adsorption ratio (SAR) is also high.

- Reaction of carbon dioxide produced during biodegradation of organics and the oxidation of BOD releases carbon dioxide. Bicarbonate will be formed to maintain charge balance with the ionized organic acids that are degraded. This is, in effect, a “biological” source of this ion. Under saturated or near-saturated soil conditions where carbon dioxide cannot escape, additional carbon dioxide may dissolve calcium carbonate in the soil. (Bohn et al., 1979). This reaction may be controlled to some extent and at times reversed by re-aeration of the soil profile. It is likely that aeration and drying out during the non-crush season may change the amount of bicarbonate present by reversing the calcium carbonate precipitation-dissolution cycle.

- Nitrogen transformations from organic-N to ammonia-N and denitrification increase alkalinity while nitrification consumes alkalinity. As a result, alkalinity levels should cycle during the loading-resting cycles in spreading basins.

- Reduction of iron and manganese, concurrent with denitrification, increases alkalinity as well as converts iron and manganese to soluble forms (*note: if iron and manganese are subsequently oxidized, they precipitate and consume alkalinity).* This cycle also can be controlled by either load-rest cycling or non-crush season soil aeration.

3.4 BOD_5 Reduction

The majority of process water BOD_5 removal during land application involves microbial oxidation, primarily near the soil surface. Heterotrophic respiration of BOD_5 can quickly consume available oxygen in process water and soil pore gas leading to anaerobic conditions in the subsurface. BOD_5 loading must be managed within the soil to a) control the oxidation-reduction environment and b) accomplish total nitrogen reduction and removal. Direct treatment of BOD_5 is addressed in this section; additional treatment effects are addressed in the following sections.

BOD_5 levels applied in process water applications were found to significantly decrease in percolate from both test sites (Table 7) during both years. The microbial community within the soils in the test basins appears to be capable of removing readily degradable organic constituents in both aerobic and anaerobic environments, determined by the reduction of nitrate (denitrification) and increase in Fe and Mn levels (see Section 3.6). Aerobic BOD_5 removal occurred rapidly while organic compound degradation by microbial means in the absence of oxygen appears to occur at slower rates which is consistent with anaerobic microbial degradation.

3.4.1 Non-Stillage Test Site

During the 2002 study season, process water was applied to the test basins in volumes that yielded BOD_5 application rates between 1,770 and 4,120 lbs/acre for the day of application and between 142 and 553 lbs/acre/day for complete cycles. During the second study season, BOD_5 application rates were between 4,250 and 10,280 lb/acre and between 286 and 734 lb/acre/day. BOD_5 levels were observed to significantly decrease during soil treatment. Maximum average five foot lysimeter concentrations were 1,300 mg/l (58% of average process water concentrations) for the 2002 study season and 1.5 mg/l (<1% of average process water concentrations) for 2003. On an annual load basis (i.e., lb/acre), 89% and >99% of the applied BOD_5 was treated in the top five feet of soil for 2002 and 2003, respectively. The first cycles each year showed good removal (90% by concentration in 2002 and >99% by concentration in 2003) suggesting that the microbial community did not need a significant acclimation period before efficiently removing readily degradable organic compounds.

3.4.2 Stillage Test Site

During the 2002 study season, process water was applied to the test basins in volumes that yielded BOD_5 application rates between 54 and 10,200 lbs/acre for the day of application and between 3 and 885 lbs/acre/day for complete cycles. During the second study season, BOD_5 application rates were between 3,650 and 8,510 lb/acre and between 248 and 867 lb/acre/day. Maximum average five foot lysimeter concentrations were 2,500 mg/l (48% of average process water concentrations) for the 2002 study season and 1,810 mg/l (23% of average process water concentrations) for 2003. On an annual load basis (i.e., lb/acre), 91% and 93% of the applied BOD_5 was treated in the top five feet of soil for 2002 and 2003, respectively. In 2002, BOD_5 levels in the lysimeter samples were higher in the first cycle but significantly lower in subsequent cycles. It was observed that first cycle percolation rates were very high. This may have been partly related to preferential flow during the initial infiltration into the lysimeter cores. Flow slowed and BOD_5 treatment greatly increased after the first cycle. When there was adequate time for treatment in the soil profile, effective BOD_5 removal was observed.

Different results were obtained in the 2003 study season. Effective BOD_5 removal was observed immediately as initial lysimeter samples collected possessed very low BOD_5 levels. Process water did not reach the five foot depth as quickly in 2003 versus 2002 indicating retention in the soil profile and effective treatment.

In regards to BOD_5 removal, the data suggest that adequate infiltration rate is more important than the BOD_5 load applied to the test basin. It was observed that although higher BOD_5 loads caused greater Fe and Mn dissolution and mobilization (see Section 3.6), attenuation of BOD_5 was near complete in most cycles.

3.5 Nitrogen Transformations and Removal

Nitrogen transformations and removal are complex to control in land application / spreading basin management. Overall total nitrogen removal during process water application is only realized when periods of aerobic conditions are balanced with periods of BOD_5-degradation induced anaerobic conditions. Initial process water loading consists primarily of organic nitrogen (organic-N) although, depending on processes within a winery, varying amounts of ammonium (ammonia-N) can also be present. In the soil, organic-N is mineralized to ammonia-N. Mineralization can occur under either aerobic or anaerobic conditions while nitrification occurs under aerobic conditions. Ammonia-N readily absorbs onto the soil surface before being oxidized (nitrified) to a more mobile nitrate (nitrate-N) form via microbial processes. Subsequent applications of water mobilize nitrate concentrated in the upper reaches of the soil and can lead to elevated nitrate levels at five foot lysimeter depth. This phenomenon, referred to as “nitrate spiking” is discussed in each of the next two sections. The primary decrease of TN in the soil profile occurs when nitrate is converted to nitrite-N or nitrogen gas under anaerobic conditions. This process is called denitrification. Total nitrogen can accumulate in the upper soil because the organic-N and ammonia-N forms are not mobile in most soil systems. If these forms are not converted to nitrate and denitrified, they will be nitrified in the spring and could be leached. Cropping of the spreading basins will result in plant uptake of nitrate and aid in removal of nitrogen from the soil profile. Nitrogen flushing was observed at both test sites and is described below.

Effective nitrogen removal will only occur if the applied water remains in the soil and underlying vadose zone for a sufficient period of time to accomplish both the aerobic and anaerobic nitrogen transformations. Aerobic conditions are common at the soil surface as re-aeration occurs relatively quickly after process water infiltration. Two years of field study demonstrates that the nitrogen transformations outlined above do occur during spreading basin cycles of loading and resting. Results for Stillage and Non-Stillage sites are presented separately below.

3.5.1 Non-Stillage Test Site

During the 2002 test season, total nitrogen treatment at the Non-Stillage Test Site was successful. There was an initial nitrate spike in lysimeter results during the first application cycle that reached the one foot depth during cycle 1 and reached the 5 foot depth during cycle 2. This was likely caused by existing soil nitrate-N conditions at the beginning of the crush season; the nitrate-N levels observed were higher than the applied process water TN levels.

After two cycles, nitrogen concentrations in lysimeter samples were low. Table 8 shows the detailed results including data for individual lysimeters. Except for the nitrate-N spikes noted above, treatment was good for organic-N, ammonia-N, and nitrate-N. Much of the apparent TN concentration removal occurred in the surface foot (approximately 85 percent based on the shallow lysimeter based results). At five feet, removal was similar. Annual total nitrogen load-based calculations indicated that 34% of the TN was removed (Table 6). Nitrogen is stored in the soil and it is apparent that significant amounts of TN in lysimeter samples did not originate from process waters. It is difficult to assess the fraction of total nitrogen applied that was denitrified.

In 2003, prolonged aerobic conditions in the soil, indicated by the lack of iron and manganese mobilization (Table 10), resulted in effective organic and ammonia nitrogen transformation and ineffective nitrate treatment (Table 8). The lysimeter samples collected after the first two cycles had elevated levels of nitrate likely due to soil nitrogen release. In subsequent cycles, concentrations more closely resembled applied total nitrogen levels. Annual total nitrogen load calculations indicated that more TN was recovered (i.e., 1172 lb/acre) from the lysimeters than applied (i.e., 806 lb/acre) (Table 6).

The Non-Stillage test basin was deep ripped between the two study seasons. Prior to the 2002 study season, the basin had not been deep ripped for approximately five years. The deep ripping may have increased hydraulic conductivity (and increased re-aeration rates), and allowed rapid water flow past the depth of the lysimeters. These effects therefore, may not have allowed the establishment of anaerobic conditions needed for denitrification. The soil matrix is an integral part of the treatment process. Proper basin management is necessary not only to assure that ponding does not occur for extended periods of time, but also to assure that water remains in an anaerobic zone long enough for denitrification to occur.

In addition, corn was planted in the summer of 2003 in the test basin prior to the study season. The corn was allowed to reach adult height (i.e., 5 to 10 feet) but the ears were not mature prior to plant removal and installation of instrumentation. In addition, the soil in the test basin was not tilled after plant harvest allowing the corn roots to remain in place prior to study applications. Preferential flow and near immediate re-aeration through channels produced by plant roots may be the cause of not establishing an anaerobic environment for effective denitrification.

Initial lysimeter samples from both study years indicate flushing of total nitrogen deposited from previous use of the land application basins. Total nitrogen values in the lysimeters greatly exceed total nitrogen applied (Table 8). In addition, Total Nitrogen has been observed to accumulate in the soil profile from beginning to the end of the study crush seasons (Section 3.7). The water budget analysis was utilized to determine which lysimeter samples were under the influence of the first flush of water through the test basin soils. The five foot lysimeter sample results influenced by the first flush are highlighted by italicized table values (Tables 8 and 9). It is worth noting that excluding flush-influenced values yields much greater treatment efficiency results. Therefore, removal of nitrogen stored in the soils prior to crush season application (i.e., cropping) would greatly reduce nitrogen mobilization beyond the five foot depth.

3.5.2 Stillage Test Site

During the 2002 study season, total nitrogen treatment was more dependent on hydraulic and BOD_5 loads as well as resting period lengths. This is mainly due to the greater strength process water and its' impact on soil environment conditions. Three distinct phases of nitrogen transformation behavior occurred at the Stillage Test Site. During cycle 1, percolation of all three nitrogen forms occurred. Organic-N and ammonia-N were approximately 27 mg/l and nitrate-N was approximately 11 mg/l. This result supports the theory that the first cycle of process water was not treated by the soil due to preferential flow and minimal retention time in the soil column.

The second phase occurred during relatively high BOD_5 loadings in cycles 2 through 5. These applications caused prolonged anaerobic conditions in the soil column. The basin was apparently overloaded during this period in the study and did not achieve the aerobic-anaerobic cycling requirements needed for efficient TN removal. TN in the lysimeters was present as organic-N and ammonia-N. Very little nitrate-N was found in the lysimeter samples during these cycles indicating either: a) efficient denitrification, and for b) insufficient oxygen to induce organic-N mineralization and nitrification of ammonia-N to nitrate-N. As a result, TN was not entirely removed during these cycles.

The third phase, which is represented by cycles 6 and 7, shows nitrate-N spikes, possibly as a result of increased resting periods and reduced BOD_5 loading. Organic-N and ammonia-N were efficiently converted during this phase but nitrate-N was not reduced. In fact, the nitrate-N dataset is strongly affected by the results from lysimeter 2. This device did not yield water samples during the first 5 cycles but began to provide samples during cycles 6 and 7. These samples had high nitrate-N concentrations.

Determining optimum loading rates to ensure effective TN removal is complex and depends on soil characteristics as well as process water quality. It is apparent that repeated high BOD_5 loading for consistent saturated conditions do not allow for aerobic/anaerobic cycling while low loadings with long rest cycles are not conducive to providing anaerobic environments for denitrification. Annual total nitrogen load calculations indicated that 68% of the TN was removed (Table 6) during the 2002 study season.

In 2003, nitrogen load-based results show that 73% of applied total nitrogen did not percolate below five feet. In contrast to 2002, nitrification occurred but denitrification was not sufficient to lower nitrate concentrations in lysimeter samples. Soil test results (Section 3.7) show that ammonia-N accumulated in the soil profile.

A solution to achieve greater nitrogen removal is application of relatively large loads with longer resting periods. The large initial application rate accomplishes development of anaerobic conditions for organic-N and ammonia-N conversions. Longer drying allows control of the basin hydraulics while allowing the top two to three feet of soil to drain, establishing an aerobic zone for treatment.

There were two major differences in the initial application conditions during the 2003 study season at the Stillage Test Site; hydraulic loading rates were consistent and total nitrogen loading was more than twice the load applied in the 2002 season. Effective organic and ammonia nitrogen treatment occurred throughout the study season and although high nitrate values were measured in the lysimeter samples, these were mostly in samples influenced by the flush (Table 9). Annual total nitrogen load calculations indicate that 73% of the TN was removed (Table 6) during the 2003 study season. Efficient TN treatment was shown to occur at relatively high TN application with appropriate BOD_5 loading and sufficiently long resting periods.

3.6 Dissolved Oxygen Levels and Iron and Manganese Mobilization

As previously discussed, cycling between aerobic and anaerobic environments is essential for efficient total nitrogen removal. The mobilization of precipitated Fe and Mn in the soil is a clear indicator of anaerobic conditions (Sposito, 1989). Process water is not the source of iron and manganese in lysimeter samples (Table 10).

3.6.1 Non-Stillage Test Site

In 2002, iron and manganese levels in lysimeter samples demonstrated good control of the soil treatment environment (Table 10). Application of process water during loading cycles 1 and 2 resulted in little iron and manganese dissolution and mobility. In addition, the nitrate-N spikes discussed previously corroborate the lack of anaerobic conditions. It is not expected that iron concentrations would increase as long as there is nitrate-N available in the spreading basin soils; manganese dissolution can begin in the presence of nitrate. Application cycles 3 and 4 showed 98 percent nitrate-N removal and total nitrogen removal greater than 90 percent (Table 8). The iron and manganese concentration increases that indicate anaerobic conditions in the soil profile are shown in Table 10. The relationship between iron and manganese concentration and total nitrogen for all samples is illustrated in Figure 10. Low total nitrogen levels in lysimeter samples are only achieved when iron plus manganese concentrations are temporarily greater than approximately 10 mg/l.

Results for 2003 indicate less than ideal total nitrogen treatment. It is apparent that anaerobic soil conditions were not well established during the study season. This may be a result of non-crush season basin management (Section 3.5.1). Very low levels of soluble iron and manganese were measured in the lysimeter samples of study year 2003. The results from both study sites during both years indicate that iron and manganese dissolution in the upper reaches of the soil profile is a clear indicator of denitrifying conditions that are necessary for effective total nitrogen treatment.

3.6.2 Stillage Test Site

In the 2002 study season, near total TN removal was not realized at the Stillage site when conditions were either dominantly aerobic or dominantly anaerobic. This is corroborated in Figure 10 which illustrates Fe plus Mn concentrations versus residual TN concentrations with the data separated into the three phases discussed previously. The trend of good nitrogen removal when iron and manganese are present is demonstrated. However, when anaerobic conditions were too long in duration (cycles 2-5), TN concentrations in lysimeter samples range from 10 to 50 mg/l. Cycles 6 and 7 are characterized by high TN with little dissolved iron and manganese. This likely occurred during extensive resting periods with insufficient BOD_5 loading. Again, these values are greatly influenced by lysimeter 2, which produced samples with uncharacteristically high nitrate concentrations. Aerobic conditions decreased iron and manganese concentrations and allowed the nitrate spikes noted previously.

In study season 2003, the more consistent hydraulic loading approach yielded relatively low (< 12 mg/l) iron and manganese levels in lysimeters 2 and 3. The observed iron and manganese mobilization was paired with efficient total nitrogen removal (Section 3.5.2).

3.6.3 Special Soil Gas study at the Stillage Test Site

At the end of cycles 3 and 4 at the Stillage site during study season 2002, the oxygen content was measured in the soil pore gas. At the end of both cycles, oxygen content in top foot of soil was near atmospheric while at 2.5 feet the oxygen concentration was below 2.5%. Oxygen content was near or at zero at 5 feet at the end of both cycles.

3.7 Soil Sampling Results

Soil samples were collected from the test plots and analyzed to document changes in soil profile chemical characteristics during the 2002 and 2003 application seasons. The complete soil sampling dataset is attached in Appendix C. Sample results for key parameters are summarized in Table 11. The approach taken in the summary presentation is to show averages by depth and by date for each site and year. In this form of evaluation, sample-to-sample variation is de-emphasized and the more robust soil chemical differences are demonstrated.

The Stillage and Non-Stillage sites have some soil chemical properties in common. Iron and manganese are present in abundance in both soils for both years. The cation and anion (salts) levels of test site soils are in common agricultural ranges (Appendix C; Arkley, 1964). There is a trend of increasing concentration with depth. Both Exchangeable Sodium Percentage (ESP) and pH values are in acceptable agricultural ranges (Arkley, 1964; Huntington, 1971).The plant nutrients, nitrogen and phosphorus, are in good to abundant supply and generally show decreasing trends with depth. Inorganic nitrogen is present in both the nitrate and ammonia forms.

3.7.1 Non-Stillage Test Site

Soil chemical results (Table 11; Appendix C) corroborate the results of lysimeter percolate sampling discussed previously. For both the 2002 and 2003 experiments, both percolate and soil pH data show no lasting effect of application of acidic process water. All average pH values are greater than 7.5.

Average individual cation concentrations decrease with soil depth. Sodium status, evaluated as exchangeable sodium percentage, is also within agricultural ranges and measured values decrease with depth. Magnesium is unexpectedly high in 2003 soil samples.

Soil nitrogen decreased during the 2002 season, primarily as a result of removal of pre-application soil nitrogen stored near the soil surface. Nitrate-N and ammonia-N are depleted to low levels, particularly in the subsoil. In 2003, ammonia concentration in the subsoil were somewhat higher than in 2002. In both years, average soil inorganic nitrogen was approximately 400 lb/acre. In 2003, there was little decrease in average inorganic nitrogen during the crush season. Soil phosphorus levels remain largely constant although there is some indication of subsurface decreases.

3.7.2 Stillage Test Site

Stillage Test Site process water effects on soil properties are quite similar to the Non-Stillage Test Site application dataset. There is some indication that soil surface pH may be depressed but it remains near neutral pH. The pH increased with depth in both years. In 2003, average profile pH increased from 6.4 to 7.6 during the crush season.

Sodium levels in the Stillage Site soil are always low as are ESP values. In 2002 average soil ESP increased with depth and in 2003, values were uniformly low. Average ion concentrations decreased slightly in 2002 but show the expected increase with depth in 2003. The most notable cation feature of the Stillage Site is the high concentration of potassium at all depths in both years. In 2002, there were also high concentrations of sulfate; this effect was not seen in 2003.

Stillage Test Site soils show concentrations of nitrogen species at the beginning of the 2002 application season that are reduced during the season. Average 2002 soil profile nitrogen was 290 lb/acre. In 2003, both nitrate and ammonia concentrations were very high. Average phosphorus decreases with depth in both years.

Section 4: Vadose Zone Treatment Literature Review

During land application of winery process waters, treatment in the subsurface has been predicted for years. Although nuisance issues were the focus in earlier land application reports, it has been understood that microbial treatment occurs during infiltration and aerobic/anaerobic cycling maximizes the treatment of winery process water constituents (Metcalf & Eddy Engineers, 1980). The regulatory focus of land application of winery process waters is shifting towards a multi-goal approach including groundwater protection. The current Wine Institute study was developed to investigate water quality transformations in the surface layers of the soil (<5 feet); treatment that occurs in the vadose zone below 5 feet was not addressed in the experimental study plan.

Aerobic and anaerobic BOD_5 degradation and multi-step total nitrogen transformations have been documented for three decades (Bouwer et al., 1974; Bouwer et al., 1980; Bouwer et al., 1984; Amy et al., 1993). The detailed mechanisms were observed in well-designed bench-scale experiments (Lance et al., 1972; Lance et al; 1973; Whisler et al., 1974; Enfield, 1977; Gilbert et al., 1979). Recently, in-situ treatment efficiency and evidence of deep vadose zone treatment has been extensively studied and demonstrated. The physics and chemistry of vadose zone treatment of municipal effluent and winery process water are based on the same principles. There is an important distinction between the two water sources: the absence of human pathogens in winery process water significantly decreases the potential for direct public health and disease impacts of subsurface treatment.

There are many similarities between groundwater recharge of municipal wastewater effluent and land application of winery process waters. The application of municipal effluent is commonly performed in leveled shallow large basins where consistent even application can be controlled. Basin soils must possess an adequate minimum hydraulic conductivity and, where possible, unimpeded flow to the aquifer. Groundwater recharge is performed in cycles, separating application periods with resting periods. Basin surfaces are often scarified periodically to maintain hydraulic conductivity and maximize the volume of water recharged.

There are also differences between groundwater recharge and land application of winery process waters. A key management difference for municipal groundwater recharge is that high hydraulic applications and unimpeded flow to the water table is preferred. Slower flows and lower hydraulic loading are common for winery spreading basins. Slower flows can result in longer residence time in the soil profile which can provide the benefit of greater treatment time and potential for denitrification to occur given proper soil conditions, process water characteristics and management. The greatest difference is the concentration of constituents and absence of human pathogens. Recharged municipal wastewater effluent is commonly secondary or tertiary treated. This level of biological treatment yields relatively low BOD_5 levels (i.e., < 20 mg/l). TN levels vary considerably depending on the level of biological treatment. Elevated BOD_5 levels in winery process waters potentially cause the greater use of electron acceptors (NO_3^-, Mn^{2+}, Fe^{3+}, SO_4^{2-}) during microbial degradation. In addition, substantially greater BOD_5/N ratios present in winery process waters can result in more efficient TN treatment by denitrification.

Groundwater recharge has also been investigated with primary treated municipal effluent, which contains substantially higher BOD_5 levels. Consistently good removal of BOD_5 and total nitrogen has been observed (Rice and Bouwer, 1984; Herman Bouwer, personal communication, 2004). Despite successful treatment, primary treated municipal effluents are not commonly applied to land due to the high concentration of human pathogens and the uncertainty of their fate in the subsurface.

The biogeochemical mechanisms that govern the water quality changes that occur in the unsaturated and saturated subsurface during the application of municipal wastewater effluents are similar to those that occur during the application of winery process waters. These natural treatment mechanisms, collectively known as soil aquifer treatment (SAT) in the field of groundwater recharge, are considered effective at polishing treated wastewaters. Currently, the greatest challenges of groundwater recharge lie in the fields of pathogen inactivation and transport and the attenuation of trace levels of industrial derived compounds (Asano and Cortruvo, 2004). Winery process water management focuses on BOD, TN and dissolved solids.

Groundwater recharge is a substantial (and growing) water resource tool in the western United States. Groundwater recharge is a form of polishing and recycling treated wastewater effluents by application to land and subsequent percolation. Applied water eventually reaches the groundwater below. In an effort to develop sustainable practices of groundwater recharge, the National Center for Sustainable Water Supplies (NCSWS) was established to, amongst other tasks, determine data gaps documenting water quality transformations in the subsurface and develop and conduct bench-scale and in-situ experiments to address the gaps. Researchers from four universities and 17 agencies including regulatory, municipal, regional, and national organizations were gathered to investigate chemical and microbiological changes during land application of municipal wastewater effluent. Bench-scale studies were performed primarily at the universities while 8 field sites were instrumented for demonstration scale studies. Although there were numerous agencies contributing to the NCSWS' funding, the majority of the monies to sustain the research effort were provided by the American Water Works Association Research Foundation (AwwaRF) and the USEPA (AwwaRF, 2001). Over a six year period, eight (8) million dollars were utilized in this research effort. (Jörg Drewes, personal communication, 2004).

A review of well-instrumented SAT test sites and a discussion of documented in-situ water quality transformations are presented below.

4.1 Test Sites

Although vadose and saturated zone treatment during groundwater recharge has been documented since the 1970's, this review will primarily focus on three well-instrumented test sites that accumulated data for the NCSWS as these investigations were most comprehensive regarding water quality constituents of concern.

4.1.1 Sweetwater Underground Storage and Recovery Facility, Tucson, Arizona

The Sweetwater Underground Storage and Recover Facility (SUSRF) contains recharge basins and wetlands located adjacent to the Roger Road Wastewater Treatment Plant (RRWWTP) and the Tucson Water Reclamation Plant (TWRP). Eight infiltration basins cover 28 acres and the facility is permitted to recharge approximately 6,500 acre-ft/year of treated municipal wastewater. Recharge water can consist of either secondary treated wastewater from the RRWWTP, tertiary treated water from the TWRP or TWRP water polished through the facility's wetlands.

Recharge Basin 1 (RB-1) has been in operation since 1990 and is directly above approximately 100 feet of vadose zone prior to the groundwater table. Two sets of eight suction lysimeters are located throughout the vadose zone directly under RB-1. An extraction well is located immediately adjacent to RB-1. Lysimeter and extraction well samples were routinely sampled for a three-year period in addition to several high frequency sampling campaigns. An intrinsic tracer study including inorganic ions as well as boron isotope ratios determined that lysimeter and extraction well samples are virtually 100% recharge water (AwwaRF, 2001).

4.1.2 Northwest Water Reclamation Plant, Mesa, Arizona

The Mesa Northwest recharge basins are located in Mesa, Arizona, adjacent to the Northwest Water Reclamation Plant Mesa and the Salt River bed. There are four recharge basins totaling approximately 30 acres. The water reclamation plant discharges approximately 3,200 acre-ft/year of denitrified tertiary treated municipal wastewater to the spreading basins. The spreading basins have been in operation since 1990 with a restructuring and expansion of basin area in 1995. In 1989, four monitoring wells were installed. By the year 2000, 23 monitoring wells, four sets of multi-depth samplers, and two clusters of piezometers were operational at the Mesa Northwest site.

First encountered groundwater at the Mesa site is perched at 10 to 20 feet below ground surface (bgs) when recharging and the top of the unconfined aquifer is at 65 feet bgs. The alluvial deposits below the recharge basins include unconsolidated and consolidated clastic sediments that render three alluvial units. These units are connected in points and are separated by periodic clayey lenses.

The town of Mesa utilizes three different drinking water source waters: local groundwater, Colorado River water, and Salt River Project water. These waters possess significantly different inorganic ion concentrations and these differences, carried over to wastewater quality, were used to quantify the fraction of recharge water and travel times to numerous sampling locations.

4.1.3 San Gabriel Spreading Grounds, Los Angeles County, California

The San Gabriel Spreading Grounds are recharge basins that are a part of the Montebello Forebay Groundwater Recharge Project (MFGRP). The spreading basins cover an area of 128 acres of the approximate 700 acres that are used by the MFGRP. An average of 50,000 acre-ft/year of effluent from three tertiary treatment wastewater treatment plants are blended with surface water and local run-off prior to application to the recharge basins. The spreading grounds have been recharging runoff since the 1930's and began using municipal wastewater effluent in 1962.

The depth of the vadose zone changes significantly due to the water level in the adjacent unlined San Gabriel River, ranging from 0 to 25 feet. A well-instrumented test basin was used to recharge unblended wastewater treatment plant effluent and monitor water quality transformations during recharge. Data collected from the test site consists primarily of applied water and monitoring wells very near the recharge basins as lysimeter problems eliminated the opportunity to collect representative vadose zone samples.

4.2 Treatment Results

4.2.1 BOD_5 Removal

The attenuation of BOD_5 during the application of waters and via SAT has been predicted and/or observed for decades. The ability of microorganisms to degrade organic molecules has been known since the 1800's (Baird and Smith, 2002).

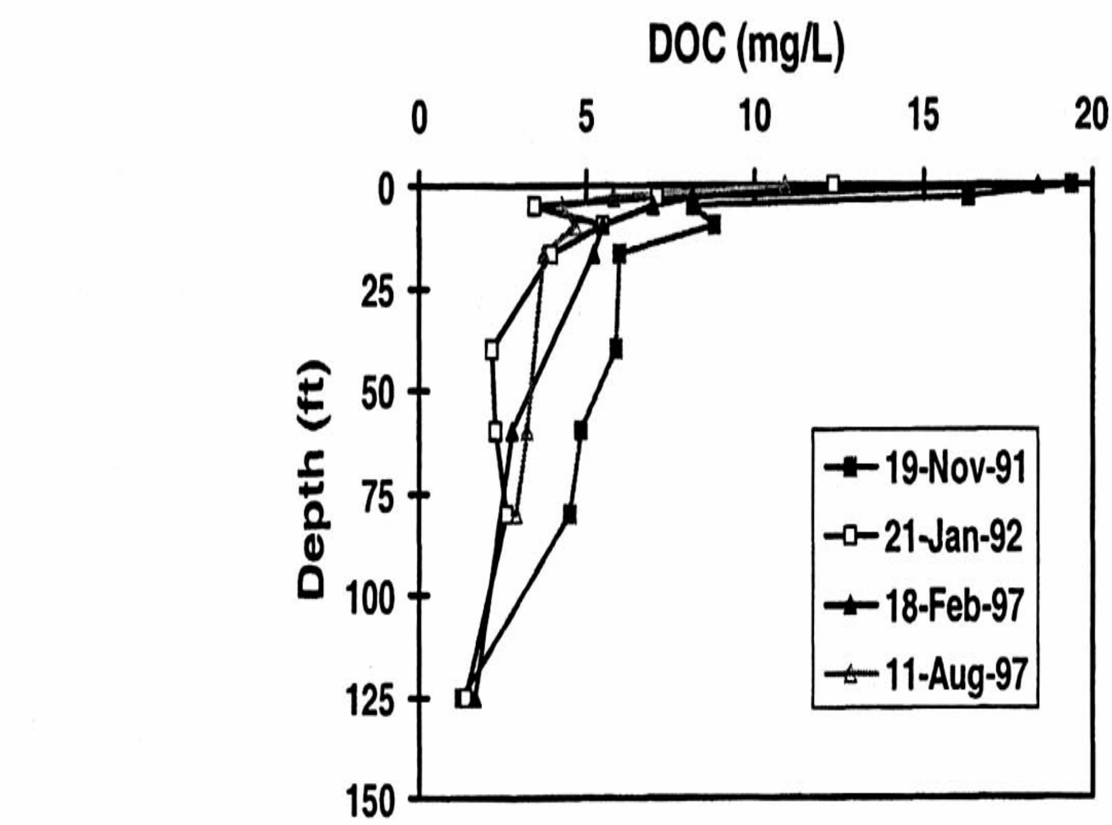
The degradation of organic compounds in the subsurface can occur in aerobic and anaerobic conditions. Microbial degradation of organics in the presence of oxygen (i.e., aerobic respiration) utilizes oxygen as an external electron acceptor and allows the complete oxidation of carbon to carbon dioxide (CO_2). This process allows a far higher yield of energy than mechanisms that use internal electron acceptors (e.g., fermentation). Other compounds found in the subsurface can act as terminal electron acceptors (e.g., NO_3^-, Mn^{2+}, Fe^{3+}, SO_4^{2-}) and allow for complete oxidation of carbon but the reduction potential of oxygen makes it most energetically favorable (Brock et al., 1994).

As groundwater recharge most often occurs with low BOD_5 waters due to biological treatment prior to application, organics levels are more often monitored by total organic carbon (TOC) or dissolved organic carbon (DOC) levels. As the majority of particulate organic carbon is typically removed in the upper inches of soil, DOC is used when measuring organics in subsurface samples (AwwaRF, 2001). The correlation between DOC and BOD_5 is not straightforward as it is dependent on the oxidation state of carbon and the quantity of other elements that comprise the organic compounds, the degradability of the organic compounds during the length of the analysis, and the BOD_5 of non-carbonaceous compounds in the sample (Baird and Smith, 2001). DOC is commonly associated with drinking water quality analysis and, since ground water recharge uses waters with low BOD_5, DOC is the accepted analysis to capture the quantity of bulk organic compounds. Although the composition and strength of winery process waters can vary considerably at a given site, BOD_5/DOC ratios for winery process waters in France averaged 1.38 (Bories, 1978).

A procedure that more directly determines the quantity of degradable organic compounds found in water samples is the biodegradable dissolved organic carbon (BDOC) analysis. The BDOC analysis, although analytically different, is conceptually similar to the BOD_5 analysis but the change in DOC is measured over a five-day period. It has been found that levels of non-BDOC found in post-SAT waters are dependent on source water quality and the character of these refractory compounds are similar to non-biodegradable material found in the drinking water used in the community (Drewes and Fox, 2000). This material is mostly comprised of humic and fulvic acids which are ubiquitous in waters around the world (Thurman, 1985).

Typical subsurface DOC profiles indicate a large decrease in DOC levels in the very upper reaches of the soil and then continued removal with increasing depth. Sustainable consistent removal has been observed over 10 years of application at recharge basins (Figure 11). It is important to note that low DOC levels observed in the mounded groundwater, represented by the 125 ft data points, are due to deep vadose zone treatment as tracer studies indicate that those samples are nearly 100% recharge water. This is consistent with observations at the winery process water test sites during 2002 as the majority of BOD_5 removal was observed in the first foot of soil.

Figure 11: DOC as a Function of Depth at the SUSRF – Test Basin RB-001 (Courtesy of AwwaRF, 2001)



The DOC levels after vadose zone treatment are comparable to source water DOC as the BDOC has been completely attenuated through the soil column.

At the Mesa Site, the average DOC level in the recharge water, 5.6 mg/l, was observed to decrease by 50% as consistent levels of between 2 and 3 mg/l of DOC were measured in five-foot samples. DOC levels decreased to between 1.2 and 1.6 mg/l after travel in the lower vadose zone to the first monitoring well. After 3000 feet of horizontal saturated flow transport, DOC levels reached source water (groundwater) levels, 0.8 to 1.1 mg/l, with similar character.

At the SGSB, DOC reductions were observed below 5 feet yet fluctuations from cycle to cycle and discontinuous depth profiles were observed. It was determined that the subsurface below the recharge basins may be too heterogeneous and flow too erratic to provide typical DOC depth profiles in the vadose zone.

The data from these test sites indicate that treatment mechanisms continue through the entire vadose zone regardless of depth. Different mechanisms may dominate at different depths due to concentrations of necessary reactants but microbial mediated water quality changes occur throughout the vadose zone. In addition, treatment continues in the saturated zone if degradable compounds persist and/or microbial environments change.

4.3 Redox Conditions

As observed in the two years of study at the winery test sites, the consumption of oxygen by bacteria is essential to create the anoxic or anaerobic conditions necessary for microbial nitrate reduction, which results in optimal total nitrogen treatment. Soil gas samples were taken at the Stillage test site in 2002 and redox conditions have been monitored by Fe and Mn mobilization. It has been recommended that re-aeration of the top one foot of soil is necessary to re-develop aerobic conditions that are necessary for nitrification and optimal BOD_5 removal. The data collected at the SAT test sites indicate redox conditions and re-aeration in the soil profile. A review of these data is presented below.

At the SUSRF site, sampling locations were installed throughout the vadose zone that allowed the researchers to sample the soil gas oxygen concentration and dissolved oxygen concentration in the recharge water under saturated conditions. Soil gas oxygen concentrations were observed to return to near atmospheric concentrations in the first 2.5 feet of soil within the first three days after application. Re-aeration rates below the recharge basins decreased with depth resulting in approximately 15, 11, and 6% oxygen concentrations in soil gas at 5, 7.5, and 10 feet bgs, respectively after 40 days of resting (Hafer et al., 2003)

During recharge operations at the Mesa Northwest basins, dissolved oxygen below 5 feet was near zero mg/l. At the top of the unconfined aquifer, DO was consistently 0.4 mg/l. Anoxic conditions were observed throughout the upper reaches of the unconfined aquifer yet increased to background groundwater levels (1.2 mg/l) within the upper aquifer 200 feet down gradient from the recharge basins. Similar results were observed at the SGSB facility; the redox conditions below twenty feet were represented by consistent dissolved manganese levels between 0.6 to 1.1 mg/l.

It appears that, during repeated groundwater recharge, the rate of oxygen depletion is greater than re-aeration below five feet yielding anoxic conditions in the deep subsurface. This may be due to much larger hydraulic loads during groundwater recharge (i.e., 100 to 300 ft/year) than those applied for during land application of winery process waters (i.e., 20 to 67 in/crush season for this study).

4.4 Total Nitrogen Treatment

The cycling between aerobic and anaerobic conditions in the subsurface is important to the total nitrogen treatment. The conversion of organic nitrogen and ammonia to gaseous nitrogen;

mineralization, nitrification and denitrification have been observed for some time in the laboratory and in the field.

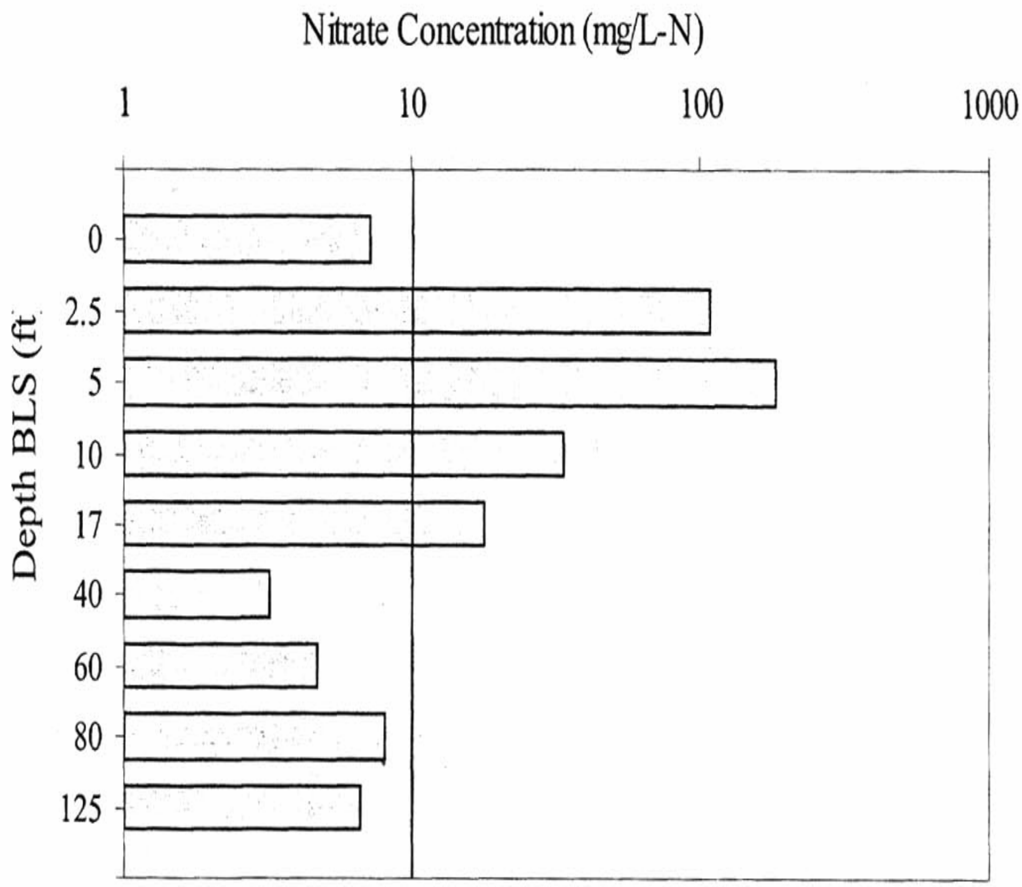
Complete total nitrogen treatment via nitrification and denitrification is rarely realized and factors that determine the relative efficiency include BOD_5/TN ratio, the residence time in the soil, redox conditions, and microbial populations (Lance et al, 1973; Whisler et al., 1974; Enfield, 1977). Elevated BOD_5 levels can assist denitrifying bacteria in two ways: BOD_5 consumes oxygen removing this electron acceptor from the water matrix, and the organic compounds act as energy sources during anaerobic respiration. Threshold BOD_5/TN ratios of 2:1 have been suggested to obtain significant (50%) denitrification (Metcalf & Eddy Engineers, 1980).

When applying waters onto land, the majority of organics are degraded in the upper reaches of the soil via aerobic degradation. Organic nitrogen is mineralized and ammonium remains absorbed to soils close to the surface. Nitrifying bacteria transform the ammonia to a more mobile nitrate ion, which moves down the soil column. The BOD_5/TN ratio during these transformations decreases with depth. Total nitrogen treatment has been shown to continue below depths of ideal conditions. Denitrifying bacteria either utilize remaining organics left in solution or organic matter present in the soils or other mechanisms achieve TN treatment. Anaerobic ammonia oxidation (anammox) has been hypothesized to significantly reduce TN levels in less than ideal denitrifying conditions (Broda, 1977; Van de Graaf et al., 1997). This is often the case during groundwater recharge where low BOD_5 waters are applied to sandy soils and significant TN treatment is realized.

Anammox consists of microbially mediated ammonia oxidation and nitrite and/or nitrate reduction to form dinitrogen gas under anaerobic conditions (Broda, 1977). This mechanism has been hypothesized in the field and observed at the bench scale. In addition, the bacteria responsible for anammox treatment have been isolated in the laboratory (Van de Graaf et al., 1997). Currently, SAT researchers believe that anammox treatment plays a significant role in TN treatment in the groundwater recharge (AwwaRF, 2001)

High nitrate concentration events, previously referred to as nitrate spikes, that have been observed at the winery test sites are also common during aquifer recharge. At the SUSRF facility, samples with nitrate concentrations as high as 500 mg-N/l or greater have been collected at the one foot level after reapplication of wastewater. Despite routine nitrate spiking at shallow depths, relatively low nitrate levels have been observed at greater depths. Maximum levels of nitrate-nitrogen below 17 feet bgs never exceeded 10 mg/l (Figure 12).

Figure 12: Minimum and Maximum Nitrate Concentrations as a Function of Depth at SUSRF, Test Basin RB–001
(Courtesy of AwwaRF, 2001)



Results from the Northwest Mesa recharge basins also indicate an increase in nitrate in the vadose zone prior to reduction in the deep unsaturated and saturated zones. Monitoring wells with reclaimed water contributions of 32 to 87% never exceeded 6.4 mg-N/l. It is noted that samples from select wells on the west side of the property are suspected of being influenced by nitrate fertilizer addition to a neighboring golf course. Nitrate spiking was observed at the SGSB facility in samples collected between 5 and 10 feet bgs. Nitrate concentrations averaged approximately 7 mg-N/l between 10 and 20 feet then substantially decreased below 20 feet corresponding to the samples where dissolved manganese was found. Samples collected at 50 feet bgs were between 0.10 and 0.15 mg-N/l yet dilution could not be accurately quantified.

4.5 Conclusions

The physical, chemical, and biological mechanisms of treatment are similar for vadose zone treatment of winery process water and municipal wastewater. Winery process water generally has higher concentrations of constituents with the important exception of human pathogens. Treatment has been documented to occur in the vadose zone below five feet of depth during groundwater recharge. Moreover, treatment at deeper unsaturated depths appears to significantly improve water quality beyond five-foot levels. At this point in time, there is no scientific reason to believe that treatment of winery process waters during land application ceases below five feet. To the contrary, from the literature review, it is clear that treatment of water quality constituents continue during travel through the deep vadose zone and into the saturated zone.

Section 5: Proposed Guidelines

5.1 Approach

Proposed guidelines for winery process water treatment using spreading basin methodology are presented in the following paragraphs and figures. These recommendations are based on two seasons of operational loadings at each of two sites. These studies provide necessary information to develop guidelines to determine application amounts and methods that will result in effective process water treatment.

Previous guidelines for stillage process water have been cast as simple hydraulic loading rates with resting cycle times based on season of application (Metcalf and Eddy, 1980) (see Table 12). In addition, the 1980 guidelines specify that infiltration be complete within 24 hours to address potential odor generation and other nuisance conditions. In separate studies dating from the same era, total BOD_5 loading rate limits expressed in units of average daily load (pounds per acre per day) have been suggested based on general process water management observations (EPA, 1977). Each of these approaches has merit and has been used in winery process water land application permits. A more thorough approach is recommended in the proposed guidelines to account for more specific site and process water characteristics.

The guidelines proposed in this document address both Stillage and Non-Stillage land application. They are separated into the four topic areas shown in Table 12. A detailed procedure to evaluate new sites addresses specific site, groundwater, and process water conditions. The section on load limiting constituent determination expands consideration of spreading basin process water management to address additional factors including:

- **pH** control near the surface soil
- **BOD** management: oxidation at the soil surface; odor control; controlled iron and manganese dissolution
- **Nitrogen** transformation and removal
- **IDS** management
- **Hydraulic loading:** amount per application and resting time between loading events.
- Other management practices are required to manage nitrogen, maintain optimum soil properties, and allow for flexibility between the crush and non-crush seasons. These are addressed in the sections on crush season management and overall program management.

Table 12: Summary of 1980 and Current Proposed 2003 Guidelines

Guidelines Topic	1980 Guidelines	Proposed 2003 Guidelines
Site Characterization and Selection	Soil permeability of at least 2 inches/hr for the surface 10 feet	Assess soil hydraulic properties (infiltration and drainage), soil chemical properties, depth to groundwater, groundwater quality (if available) and process water characteristics. This dataset will determine suitability as well as the need for site specific management practices.
Identify Load Limiting Constituent	2.5 to 3.7 inches per cycle, depending on season 24-hour maximum infiltration time	Evaluate total nitrogen, BOD_5, IDS pH and (iron & manganese) are evaluated but do not directly affect loading rate determination.
Crush Season Management	6-13 days rest cycle, roto-till or disk to remove "leathers"	Rest cycle extends until re-aeration occurs. Adjust application amounts based on strength of previous applications. Resurface checks to promote uniform distribution as needed (roto-till, rill-and-pack, reshape).
Non-Crush Season Management/Program Management	Crop the checks, re-level, deep ripping (if necessary)	Determine overall acreage needs for the Facility. Cropping required for nitrogen management, salt uptake, and soil drying. Soil sample to assess whether other treatment is needed. If deep ripping is being considered to restore infiltration, careful planning and evaluation of site specific characteristics is warranted to minimize impacts to soil profile that may interfere with nitrogen treatment by eliminating temporary anaerobic conditions necessary for denitrification. Re-level checks and maintain water application system. Develop a protocol for application of non-crush flows.

5.2 Review of Basic Experimental Results

The experimental results of the field study are presented in Section 3 of this report. A brief summary is provided here along with general conclusions addressing how the results should be incorporated into guidelines.

Parameter	Effect
pH control	Neither Stillage nor Non-Stillage process water applications result in a significant decrease in soil water pH. In fact, pH of the lysimeter samples is higher than the process water applied. In addition, soil pH does not show a consistent decrease. Because pH decreases during loading and rebounds during the year, pH control does not constitute an important management factor for either process water quality or operation of spreading basins. In addition, pH adjustment prior to application is not recommended due to IDS and/or TN impacts.
BOD_5 management	Oxidation of BOD_5 ranges from 70-90 percent removal in the surface foot and is at overall levels of 85 percent removal in lysimeter samples from the 5 foot depth. Simple BOD_5 removal does not appear to be a design constraint for spreading basin land application; proposed BOD_5 guidelines are established to accomplish control of odor, nitrogen, iron, and manganese.
Odor control	Odor was a minor issue in this study. Effective cycling and appropriate constituent loading minimized odor generation, although later in the season, process water took several days to infiltrate.
Iron and manganese mobilization	For Non-Stillage process water, Fe and Mn are solubilized in the surface but levels are still low in samples from the 5-foot lysimeters. For Stillage process water, levels are low for 5-foot lysimeter samples except when high hydraulic loads combined with high BOD_5 loads and insufficient resting periods. This effect and its related effect on denitrification are the basis for BOD_5 loading limits.

Parameter	Effect
Nitrogen removal	Nitrogen loading was variable for the Stillage Site and consistent for the Non-Stillage applications. Treatment was also variable and aerobic/anaerobic cycling appears to be imperative for efficient nitrogen removal. Prolonged anaerobic conditions without sufficient aerobic cycling resulted in minimal nitrification. Application of BOD_5 loads too small to produce an effective anaerobic treatment zone resulted in incomplete denitrification and nitrate “spiking”.
Inorganic dissolved solids management	Total salt ion load in lysimeter samples increased at the Non-Stillage Test Site and remained the same at the Stillage Test Site as a result of spreading basin applications. Alkalinity concentrations increased as a direct result of treatment of organic acids in the process water. Calcium also increased in lysimeter samples. Chloride load was approximately constant and potassium load decreased, presumably because of fixation or exchange in the soil
	Control of basin hydraulics
Per application loading rate	Hydraulic applications for the 2002 experiments were variable but based on the 1980 Stillage application guidelines; 2003 applications were in general conformance with the proposed guidelines based on the 2002 dataset. With the possible exception of some cycles of Non-Stillage process water, loading rates were lower than the soil water storage capacity. Therefore, applied process water had a residence time in the soil and did not automatically pass through the soil profile. Hydraulic application amount should match site soil/subsurface water storage characteristics.
Resting time	Resting time was lengthened during the field study when saturated soil profile conditions limited treatment of process water for both Stillage and Non-Stillage flows. For spreading basin sites, resting time needs must be established based on site hydraulic characteristics so that aerobic and anaerobic conditions alternate in the soil profile to maximize nitrogen removal and control iron and manganese concentrations.

In this study, it was found that on a load basis land application treatment of winery process waters within the upper five feet of soil is comparable to treatment obtained during typical engineered biological treatment (e.g., aerated sequencing batch reactors) (Houbron et al., 1998). BOD_5 and pH is treated very effectively, 30 to 70% of TN is removed and IDS load is conserved. Anaerobic conditions needed for TN treatment between two and five feet bgs dissolve iron and manganese but precipitation of these constituents are expected when they encounter aerobic conditions (or possibly dissolved electron acceptors, e.g., NO_3^-). Further TN treatment is expected below five feet as significant denitrification has been observed between five and 100 feet bgs at other test sites (see Section 4.4).

5.3 Draft Guidelines

Guidelines proposed for Stillage and Non-Stillage process water land application are based on field studies conducted at two sites for two crush seasons. The field studies incorporated detailed measurements in order to provide some characterization of the processes that occur during treatment. As a result, the proposed guidelines are not based on simple quantities of process water or process water constituents that can be applied. The proposed guidelines address spreading basin treatment variables and are affected by site specific characteristics, process water characteristics, and application methods. At present, the guidelines are cast to address both Stillage and Non-Stillage process water management. The guidelines incorporate assessments of process water strength that dictate certain management requirements. These, to an extent, separate management practices and constraints for the higher strength Stillage process water.

Two flow charts (Figures 13 and 14) are useful for demonstrating how the proposed guidelines can be implemented. The flow chart focuses on developing management guidelines for application throughout the year. Because non-crush or non-stillage season flows are lower in volume and can be lower in constituent concentrations, management for treatment is less difficult than during the typical higher flow season. The flow charts provide a protocol for characterizing sites (Figure 13) as well as one for determining maximum loading rates (Figure 14). The following sections provide more detail regarding the steps shown.

5.3.1 Spreading Basin Site Characterization

The procedure summarized in Figure 13 is intended for use when evaluating the suitability of a site for use as a spreading basin. The factors in the procedure are also relevant to operation of existing basins.

Soil and subsurface hydraulic and chemical characteristics must be known at a site. Key required measurements include: 1) assessment of infiltration rate or soil permeability; 2) determination of soil water storage capacity; 3) knowledge of soil layers, particularly those that restrict downward flow of water; 4) basic soil chemical characterization (pH, salts status, nutrient status); 5) depth to groundwater; and 6) groundwater quality assessment beneath the application basins. Uses for these datasets will be referenced below.

The primary measurement-based limitation on site selection is measured infiltration rate. If this rate is too slow, then the site may not be suitable, both because penetration of water into the soil is too slow and re-aeration of the soil profile is also too slow. Although, not a direct outcome of the 2002 study, a soil permeability limit of 0.6 inches per hour is proposed as the lower limit for automatic site suitability. This permeability value is a common upper limit for soils with a clay content of 20 percent or more. If soil permeability of the surface soils is lower than 0.6 inches per hour, a site-specific evaluation should be performed to assess whether the site is suitable for spreading basin land application in terms of infiltration rate and potential impediments to re-aeration. A site may have restricted infiltration or air flow if fine-textured or impermeable layers are present.

Previous spreading guidelines specified a minimum permeability of 2 inches per hour for the surface 10 feet of soil. While this is a sensible specification when the objective is discharge of water, it may not be workable for treatment of process water nitrogen which requires anaerobic conditions for denitrification. A subsoil that is too permeable is likely to have excessive drainage that prevents establishment of these conditions. Subsurface layers promote temporary slowing of downward flow and should result in anaerobic conditions. A site with uniform coarse textured soils such as loamy sands and sands may not be suitable for complete process water treatment in the near surface soils.

Basic soil chemical characterization is also recommended to identify any factors that might affect spreading basin performance. Excessive sodium can be a site limitation; therefore, evaluation of sodium adsorption ratio (SAR) of the process water and exchangeable sodium percentage (ESP) of the soil is recommended.

Local groundwater conditions including depth to groundwater and average groundwater quality should be assessed. Although the decision must be made on a site-specific basis, a free draining depth of 15 feet below ground surface allows adequate subsurface treatment time. For shallower depths, additional management restrictions and monitoring may be required.

The soil moisture characteristic most important for a spreading basin is the amount of water stored in the surface 5 feet of soil. This value can be obtained from local soil survey reports based on mapped soil type; direct measurement methods are also available (Klute, 1986). In the guidelines, it is proposed that this amount of storage be used as the maximum hydraulic loading rate. This volume establishes the amount of water that can be applied without immediate percolation of the applied water. Applications to a spreading basin should not exceed this value or there will not be sufficient residence time in the soil to accomplish process water treatment for nitrogen.

5.3.2 Limiting Constituent Analysis

The first column of the flowchart on Figure 14 presents the limiting constituent analysis. The per-application loading rate for a given site will be established by the process water limiting constituent. The limiting constituent is defined as the constituent that reaches its allowable maximum loading value first among the constituents of importance. Once this determination is made, the per-application amount is known and the required acreage of spreading basins can be established. The following bullets identify proposed limits:

- **pH. –** Process water pH was not a limiting constituent for land application loading based on field study results for both lysimeter samples and soil. Therefore, we recommend expanding the allowable range from the observed experimental pH range of 3.8 to 6.9 to 3 to 10 for applied process water. If this range is exceeded, then the process water should be treated to moderate pH. Adjustment of pH using chemicals that result in salt and/or nitrogen additions is unnecessary within the pH range of 3 to 10 and inappropriate for spreading basin discharge. Spreading basin soil pH should be assessed annually to verify that soil pH buffering capacity continues to be adequate.

- **Nitrogen Loading and BOD_5:Total Nitrogen Ratio. –** The relationships between BOD_5, iron & manganese, and nitrogen are discussed in Section 3.0. For the total nitrogen values in applied process water during this study, removal percentages greater than 90% were achieved in most cases for the 5-foot lysimeter samples. The relationship between BOD_5 concentration, total nitrogen concentration, and denitrification has been addressed in other rapid infiltration basin studies (EPA, 1984, 1981). The ratio of BOD_5 to total nitrogen must be large enough so that there is sufficient oxygen demand to accomplish near complete denitrification (the aerobic removal of ammonia-N is addressed in the section on resting cycle duration). Available data from EPA suggest that nitrogen removal of greater than 90 percent was reached for effluents with a BOD_5:total N ratio greater than approximately 8. Since winery process water is of higher strength than municipal effluent and contains a higher proportion of organic nitrogen (average BOD:TN = 53, range = 10 – 156), we propose that an average BOD_5:total N ratio of 20 be used to assess the suitability of process water for spreading basin application. If the ratio is lower, the process water stream should either be pre-treated to remove some nitrogen or less cycles applied to the soil may be required to achieve adequate treatment during cropping prior to additional loading.

- **BOD_5 loading. –** Maximum BOD_5 loading can be constrained by rate of BOD_5 oxidation, the potential for odor generation, the effect of BOD_5 on denitrification, or increase in soluble iron and manganese concentrations in the soil water. Field study results showed that neither BOD_5 oxidation nor odor generation limited BOD_5 loading rate. The proposed BOD_5 limit is, therefore, based on iron, manganese, and nitrogen chemistry. This topic was addressed in the previous section, including Figure 10 that relates nitrogen reduction to iron and manganese dissolution. This figure shows that some iron and manganese present in percolate correlates with a high total nitrogen removal (low total nitrogen concentration in lysimeter samples). Figures 15 and 16 shows that lysimeter BOD_5 concentration is the control on iron and manganese dissolution in spreading basins. The 2003 Non-Stillage site lysimeter samples did not demonstrate high iron and manganese, low total nitrogen, or appreciable BOD_5.

The relationships shown for the field study dataset suggest that iron and manganese concentrations do not reach excessive values for process water BOD_5 concentrations of 7,000 lb/acre per cycle or less. Pending additional experimental verification, we propose that an application rate of 7,000 lb/acre be used as a temporary upper BOD_5 loading limit.

- **Hydraulic loading** for an individual process water application event is calculated as the lower of these two values:

  - *The maximum soil water storage capacity of the site between the basin surface and 5 feet depth* cannot be exceeded for a single loading event. This is measured as the difference between soil field capacity and wilting point. This hydraulic limitation ensures that, on average, applied water will be retained in the soil profile for treatment instead of immediately percolating into the subsurface. There is almost certainly additional treatment capacity below the surface 5 feet of soil, especially for site with at least 15 feet of unsaturated zone above the water table. This, however, is treated as additional capacity for the purpose of these guidelines. The basic treatment capacity is assumed to be in the surface 5 feet.

  - The BOD_5-limited hydraulic load is calculated from Figure 15 using the process water BOD_5 concentration for the site.

    An additional hydraulic limit used in the 1980 guidelines is the requirement that infiltration be complete within 24 hours. While this is, apparently, not based on rigorous study, there is some merit in this form of restriction. It may be that, during hot summer days, limited duration of surface ponding is appropriate. During the cooler parts of the land application season, longer infiltration times may be acceptable because the risk of odor, insect breeding, or other nuisance conditions is low. We propose that infiltration into spreading basins should be complete within 5 days of application unless nuisance conditions occur sooner at the site.

At this point, the proposed guidelines branch in two directions. One branch addresses development of protocols to perform the process water applications and maintain the basins for continued use. The second branch continues with planning calculations designed to establish a complete process water management approach for a facility.

5.3.3 Process Water Program Planning

Once the cycle hydraulic load is determined from the limiting constituent analysis, total acreage required per day for process water management can be determined from daily process water flow and hydraulic load per acre. Daily flows for crush season and winter and/or non-crush seasons should be determined from the facility dataset or flow projections. These daily flow values will be affected by the range in daily flow values for each season and the amount of process water storage at a facility. Once a daily acreage requirement is established for each season, then the acreage necessary to accommodate both application and resting can be estimated. Resting times will be longer in the winter months than in summer.

An example of a method to estimate resting cycle duration is shown in Figure 8. In the bottom table, information about the soils at the Stillage Site is taken from the soil survey for the area. This is used to estimate the amount of soil water that must be removed to create good soil aeration. Average monthly evaporation from a local weather station is used to calculate number of days to remove soil water for each month.

Total acreage required for a facility can be estimated in the following manner:

1. Daily acreage required = $\dfrac{\text{average daily flow}}{\text{allowed hydraulic load}}$

   Make this calculation monthly for the year

2. Total acreage = The maximum of monthly values for:
   Daily acreage * (drying days plus application days)

It is common for the maximum acreage to be calculated during the winter months. During the summer, required acreage is much smaller. During this period some acreage can be cropped, tilled, or otherwise used for annual maintenance.

Other spreading basin operational needs should be forecast so that they can be incorporated into an overall plan for basin management. The following paragraphs address some of these considerations:

- **Irrigation Uniformity.** Good irrigation uniformity is an essential part of spreading basin operation. The 1980 guidelines advocate use of laser leveling in spreading basins. This and other leveling (e.g., surface packing and rilling) and water spreading aids would benefit water application uniformity and more consistent process water treatment. In order to apply process water and promote treatment using application – rest cycles and careful control of the flows are essential. For surface irrigation systems, it is especially difficult to apply small irrigation amounts uniformly at a site. There are a number of useful resources for planning, designing, and retro-fitting irrigation systems (Burt, 1995; Pair et al., 1983; Roy F. Weston, 1982).

- **Annual Basin Maintenance.** A number of basin management activities must be done on an annual or seasonal cycle. Management of soil nitrogen and salt are sufficiently critical to basin performance that they are discussed individually below. An additional required activity is an annual inspection and evaluation of all land application areas. The following are some of the items that should be scheduled on an as-needed basis: rebuilding side walls, tilling, soil sampling to assess treatment performance, re-leveling, and modifying irrigation piping and delivery systems. In most cases, tillage within the root zone to maintain initial infiltration characteristics of the site is beneficial. Deep ripping can be prescribed but must be conducted so that excessive drainage does not result. In fine-textured soils or soils with hard pans, deep ripping may be useful. In coarse textured soils commonly used for spreading basins (loamy sands and sands), deep ripping may create drainage conditions that prevent the temporary anaerobic conditions essential to nitrogen removal by denitrification.

- **Basin Nitrogen Management.** Under most conditions, cropping is required to maintain spreading basins for continued removal of nitrogen and other plant nutrients (commonly phosphorus and potassium). Although routine planting and harvest of crops with high nitrogen uptake capacity can be effective, a soil sampling program to quantify the soil nitrogen supply can allow a customized cropping plan that can remove the required nitrogen, target certain soil depths with nitrogen accumulation, and allow more efficient supplemental irrigation if needed.

- **IDS Loading.** It is a general principle that, in the western United States as in other arid lands around the world, water cannot be used without causing an increase in salinity (Tanji, 1990). This results from the effect of evaporation as well as other processes. This guideline is intended to help minimize increases in soil and percolate salinity during spreading basin operations.

  Proper operation of most spreading basins that meet the site characterization guidelines should result in successful IDS management. The following analyses should also be conducted to evaluate potential IDS issues:

  - Be sure that growing season cropping makes use of varieties with substantial salt ion uptake. In general, crops with a high biomass yield remove considerable salt from the soil.
  - Carefully review soil chemistry datasets for spreading basins. If site soils indicate a trend of increasing salt concentration, the Facility IDS management practices should be reevaluated to reduce loadings where feasible. If soils indicate a trend of increasing salt concentration, some basins may need to be loaded with fewer cycles per year. Other management strategies that may arise from review of the available data are use of different crops, changing the season of application and/or water quality of the irrigations (crush versus non-crush), change in irrigation/loading timing, and other practices that alter the pattern of salt accumulation and redistribution.
  - Perform process water IDS source control investigation. Each winery should periodically evaluate internal operations to ensure that all reasonable salt reduction/salt ion specific optimization practices are implemented and are working satisfactorily.
  - Evaluate spreading basin soil and process water sodium, calcium, and potassium levels. If sodium or potassium levels are too high, soil infiltration rates may decrease and cause unacceptably long infiltration and re-aeration times [If SAR/EC > 9 then infiltration rate may be too low and should be evaluated]. If calcium levels in the soil are too low, the ability of the soil to cycle calcium and bicarbonate may be impaired. This can be evaluated using a standard soil test for buffering capacity.
  - Determine the depth to groundwater. The vadose zone between the five-foot level and the water table will have additional treatment/assimilative capacity that

can reduce IDS concentrations. This is an important part of the treatment system because at least two chemical cycles (calcium carbonate equilibrium and iron/manganese redox reactions) must operate in this zone. There should be adequate unsaturated depth to accomplish the bicarbonate cycling (including calcium carbonate dissolution and re-precipitation). Also, iron and manganese can be re-precipitated in this same depth range as long as oxygen is available, even the oxygen associated with nitrate.

- **Timing of Analytical Measurements.** It should be noted that constituent loading cannot always be monitored in real-time during application. Certain analyses (e.g., BOD_5) have a best-case laboratory turn around time of six days. To address this situation, the following approach is recommended. If there have been no substantial changes in process water generation practices, initial crush season loadings should be based on the previous crush/production season's water quality analyses. This approach may well be suitable for the entire season. As current year data are collected, they should be incorporated into calculations of loading for individual spreading basins. A thirty-day moving average of process water constituent concentrations is recommended. Since crush and non-crush (or Stillage production and Non-Stillage production) season process waters vary considerably in constituent concentrations, a similar method should be applied for non-crush/Non-Stillage production season water quality constituent calculations.

5.3.4 Process Water Application Management

The process water application portion of the flow chart (column 2 on Figure 14) starts with the application of the load established previously, and ends with determining when the resting/ re-aeration cycle is complete. The individual steps are as follows:

- **Irrigation Uniformity.** An irrigation method that will produce good application uniformity is required to optimize process water treatment.

- **Ponding and Odor.** The next step of the application cycle is managing the time for infiltration of ponded water. The proposed guideline specifies that basins should be maintained so that complete infiltration occurs within five days. In practice, this guideline will be applied differently if there is a potential for odors or other nuisances. If these factors are of importance, shorter ponding times will likely be used. In our studies, there was not an effect of ponding time on treatment efficiency.

- **Resting Cycle Duration.** Application of process water is based on the limiting constituent analysis shown in the previous section. Once this is accomplished, the resting cycle begins and lasts until re-aeration of the soil profile occurs. In the field study, soil moisture measurements were used to assess desaturation of the spreading basin soils. Although resting cycle duration was not initially intended to be an experimental variable in the field studies, it became clear that the study site soils were not desaturating rapidly enough to create aerobic soil conditions during resting cycle durations between 6 and 13 days, as specified in the old guidelines. (Metcalf & Eddy, 1980).

  The presence of significant amounts of ammonia-N and organic-N in 5-foot lysimeter samples suggests that certain aerobic/resting cycles were too short at the Stillage Test Site.

Because the BOD_5 removal dataset indicates substantial removal of BOD_5 within the top foot of soil, a reasonable criterion for resting cycle duration would be sufficient time to create unsaturated soil conditions to at least 1-foot depth. Monitoring at two feet would allow an indirect determination of aeration conditions at 1 foot (the soil must be aerated at 1 foot before drying occurs at 2 feet) as well as direct measurement of conditions at 2 feet.

Soil moisture measurement techniques that could be used include use of permanent or portable tensiometers, grab samples for soil moisture determination, or any of a variety of electronic sensors. As noted previously, the electronic sensors have proven to require considerable hands-on management to achieve useful results.

- **Assessment of Treatment Conditions.** Field studies have demonstrated that soluble iron and manganese are an indicator of soil conditions conducive to nitrogen removal via denitrification. As part of evaluating whether a basin is operating well, the presence of anaerobic conditions should be monitored. Techniques include direct measurement of oxygen status, measurement of soil water content to determine whether saturated conditions occur at depth, and measurement of soluble iron and manganese.

- **Between-Cycle Maintenance.** Once the resting cycle is complete, the spreading basins should be inspected and repaired or refurbished, if necessary. If there are deposits of organic solids on the surface ("leathers"), they should be removed or disrupted if they create a hydraulically restrictive layer. Roto-tilling, disking, chiseling, re-leveling, and creation of corrugations or rills may be part of reconditioning the spreading basin prior to the next application cycle. Any machine tillage conducted during the resting cycle must be managed carefully to avoid soil compaction. During initial drying, soils are susceptible to compaction because of moist subsurface conditions. If the surface is sealed during tillage operations, this may also reduce the rate of drying.

5.3.5 Example of Flowchart Analysis

This section illustrates the sampling, analyses and calculations needed to evaluate a site for land application under the proposed guidelines (Figures 13 and 14). Two examples, Non-Stillage and Stillage wineries, are presented side-by-side to illustrate typical process water quality and site characteristics. For these examples, it is assumed that the wineries have been performing land application for at least 10 years, historical process water quality has been compiled, and the wineries are capable of managing land application operations.

Characterization for Initial Site Selection. The two wineries obtain representative soil samples and have them analyzed for soil permeability, soil chemistry, soil water storage capacity, and infiltration rates. Each winery checks monitoring wells for depth to groundwater and obtains samples from a background well for water quality analyses. The results of these analyses can be found in Table 13. All of these results indicate that the sites are viable process water land application sites.

Soil water storage capacity at the Non-Stillage Winery is measured to be 16% of total volume (this value can be obtained from local survey reports based on mapped soil type or direct measurement (Klute, 1986)), yielding:

16% X (5 feet) X (12 inches/foot) = 9.6 inches of maximum hydraulic load per application.

Likewise, the maximum hydraulic load per application at the Stillage Winery is calculated to be 7.2 inches.

Soil tensiometers are chosen as the soil moisture monitoring equipment at the Stillage Winery and electrical resistance sensors are chosen for the Non-Stillage Winery. The devices are installed in representative checks to measure soil moisture during application cycles.

Limiting Constituent Analysis. As no major changes have been implemented to the winery processes that would adversely affect the water quality of the process waters, the wineries can use average historical water quality data to perform the analyses.

As the maximum hydraulic load is greater than three inches for both sites, application can occur by flooding the prepared checks from one side (past method for both wineries). The pH levels and the calculated BOD_5:TN ratio meet the guidelines requirements (pH range 3-10; BOD_5 concentration in mg/l divided by TN concentration in mg/l should be greater than 20 BOD_5:TN>20). Therefore, pH and total-N are not limiting constituents.

To determine how BOD_5 concentrations affect the hydraulic loading, the maximum BOD_5 load that does not adversely affect iron and manganese dissolution is utilized (Figure 15). The proposed guidelines suggest that the upper BOD_5 load limit is 7,000 lb/acre. However, site conditions may indicate that limit should be adjusted upward or downward.

To calculate the hydraulic load associated with 7,000 lbs/acre BOD_5 at the Non-Stillage Site, the following calculations are performed:

920 mg/L BOD_5 X (1lb/454,000 mg) X (1 L/0.264 gal) X (7.48 gal/ft^3) =

0.0574 lb BOD_5/ft^3

Maximum BOD_5 load translates to:

7,000 lb BOD_5/acre X (1 acre/43,560 ft^2) = 0.160 lb BOD_5/ft^2

This yields a cycle hydraulic load rate of:

0.160 lb BOD_5/ft^2 X (1/0.0574 lb/ft^3) X (12 inches/foot) = 33.5 inches

Similarly, the BOD_5-limited hydraulic load for the Stillage Winery equals 4.5 inches. As the Non-Stillage Winery hydraulic load is greater than the calculated maximum hydraulic load (i.e., 9.6 inches), the Non-Stillage Winery should not apply more than maximum hydraulic load.

Program Management. Both wineries conduct an analysis of how much acreage is needed to apply anticipated process water quantities through the higher-volume processing season (see Section 5.3.3). This analysis indicates that the Non-Stillage Winery will apply the complete 9.6 inches for the first application cycle while the Stillage Winery realizes that an application of 4.5 inches will be sufficient. These hydraulic loads correspond to approximate BOD_5 loads of 2,000 and 7,000 lb/acre for the Non-Stillage and Stillage Wineries, respectively.

A management plan is written for the upcoming year that includes: a cropping strategy for nutrient and salt removal; as-needed basin management capabilities; and a basin rotation plan to optimize basin treatment.

Process Water Application Management. The wineries apply process water at the start of cycle 1 onto spreading basins as it is generated while monitoring the soil moisture during the resting cycle. At the Non-Stillage Winery, infiltration is completed within 7 hours, while at the Stillage Winery, infiltration is completed in 4 hours. The first cycle of application needs 12 and 8 days of resting to reach acceptable moisture levels at the Non-Stillage and Stillage Wineries, respectively. At this point, the basins are rototilled and the basins are ready to begin cycle 2.

Table 13: Application of the Proposed Guidelines for Hypothetical Non-Stillage and Stillage Wineries

	Non-Stillage Winery	Stillage Winery
Site characterization and monitoring		
Soil analyses		
Infiltration rate (inches/hr)	0.9	1.2
SAR	7	4.5
% Clay	< 10%	< 10%
Available soil water storage, percentage of soil volume	16%	12%
Calculated maximum hydraulic loading rate (inches)	9.6	7.2
Depth to groundwater (ft)	32	45
Limiting constituent analysis		
BOD_5 (mg/l)	920	6,850
TN (mg-N/l)	17	180
BOD_5 : N	54	38
IDS (mg/l)	750	1,200
pH	5.8	5.1
Calculated cycle hydraulic loading rate (inches)	33.5	4.5
Chosen cycle hydraulic loading rate (inches)	9.6	4.5

Section 6: Conclusions

6.1 Study Results

Field experiments were conducted between September 2002 and January 2003 and August and December 2003 according to the protocols outlined in the project work plan (Appendix A). Twenty two loading cycles were completed; ten at the Non-Stillage Test Site and twelve at the Stillage Test Site. Hydraulic application amounts were varied in order to establish a range in BOD, nitrogen, and IDS constituent loadings. Application amounts were above and below both the 1980 guideline limits and the revised limits proposed here. The basic results of the two-year field study are summarized as follows:

- **pH.** Neither stillage nor non-stillage process water applications result in a permanent decrease in soil or soil-water pH. Therefore, *pH is naturally buffered and does not constitute an important management factor for these spreading basins. However, pH should be monitored periodically to assess soil conditions.*
- **BOD_5.** Removal of BOD_5 is above 89 percent at the five foot depth for each site in both years. This calculation is based on comparing the total process water BOD_5 load (lb/acre) for each season with the total percolate BOD_5 content (lb/acre) measured in the lysimeters. *BOD_5 treatment is very effective in spreading basins over the entire range of loading rates used in the study.*
- **Iron (Fe) and Manganese (Mn).** Soluble Iron and manganese are produced in the soil profile under anoxic conditions. The production of these reduced forms is highly correlated with nitrate removal via denitrification. This effect is the basis for BOD_5 loading limits proposed in the draft spreading basin management guidelines. Non-Stillage process water applications resulted in lower soluble iron and manganese production than the Stillage Site applications in both study seasons.
- **Nitrogen.** Total Nitrogen was efficiently removed by the five foot depth in the soil profile when constituent and hydraulic loadings were properly managed. If sufficient anoxic conditions are not established (as indicated by soluble iron and manganese production), nitrate-N may not be effectively denitrified. If high process water loadings and/or insufficient (short) resting periods do not allow the spreading basin to drain and establish aerobic conditions, organic-N and ammonia-N are not effectively nitrified. At the stillage site, overall total nitrogen removal was approximately 70%. In 2002, total removal was 68% and was limited by the nitrification rate for ammonia-N. In 2003, nitrification of ammonia was satisfactory but denitrification was incomplete. The Non-Stillage study site was limited in both years by incomplete denitrification. (See detailed discussion in Section 3.5.1). Percentage removal was 34% and 23% for the 2002 and 2003 field seasons. *Proper aerobic/anaerobic cycling is critical for high total nitrogen removal.*
- **IDS.** TDS is a poor indicator of inorganic ions in winery process waters as organic acids contribute to TDS levels. Inorganic Dissolved Solids (IDS) is a better indicator. The IDS process water load was approximately the same as the amount measured in the percolate for both sites and years. Calcium and alkalinity in applied process water were lower than values observed in five-foot lysimeter samples and potassium generally decreased. Sodium was higher in the percolate than in process water at the Stillage site. *Although the ionic*

proportions changed, IDS was measured to be approximately the same for the load and percolation.

- **Per-Application Loading Rate.** Loading rates were generally lower than the soil water storage capacity. Therefore, applied process water had a residence time in the soil and did not immediately pass through the soil profile*. Hydraulic application amount should match site soil/subsurface characteristics.*
- **Duration of Resting Cycle.** Resting time was lengthened during the 2002 and 2003 field studies because saturated soil profile conditions limited treatment of process water for both Stillage and Non-Stillage flows. *Resting time must be established based on site hydraulic characteristics so that aerobic and anaerobic conditions alternate in the soil to maximize nitrogen removal and control iron and manganese concentrations.*

Additional treatment in the subsurface below five feet results in a decrease of the constituents measured at 5 feet depth during the field studies reported here. A review of available literature for deep vadose zone treatment (Section 4) indicates that treatment is well documented to reduce percolate concentrations during subsurface flow.

6.2 Development of Guidelines

The proposed guidelines expand consideration of spreading basin process water management from the 1980 guidelines (application rate and duration of the resting cycle) to address additional process water constituents including: pH control within the surface soil; BOD_5 management (oxidation, odor control, minimization of iron and manganese mobilization); Nitrogen transformation and removal; IDS management; and hydraulic loading (per-application rate and resting time between loading events)

The guidelines proposed here for spreading basin process water treatment are separated into the four topic areas:

- **Site selection** based on evaluation of process water quality, and spreading basin soil and groundwater conditions.
- **Identification of the application rate-limiting constituent** (usually hydraulic, nitrogen, or BOD_5 load).
- **Management of individual application events** to address infiltration rates, resting cycle duration, verification of treatment, and basin maintenance.
- **Planning for the overall process water management program** including determination of acreage required, annual maintenance, cropping to remove additional soil nitrogen, and evaluation of salt management.

The field experiments conducted for this study addressed spreading basin treatment of winery process water. The methods of application and control provided detailed information about spreading basin management but, in addition, provide useful information that bears on other land application practices. Though crop irrigation was not evaluated directly as part of this study, the same fundamental biochemical reactions (Refer to Appendix E) apply to land application processes regardless of the method of process water application.

The 2002/2003 Wine Institute field study provides a detailed dataset for spreading basin treatment of winery process water. A work plan was prepared and reviewed by the Regional Board (Appendix A). Two sites were selected for intensive study, field plot instrumentation was installed, and the study was conducted during Summer and Fall, 2002 and 2003.

This report provides a summary of project activities and measurements as well as an analysis culminating in proposed guidelines for management of spreading basins at wineries (see Figure 14). These guidelines expand the previous 1980 guidelines (Metcalf and Eddy, 1980) in several ways:

- Both Stillage and Non-Stillage operations are addressed in a consistent manner
- Site-specific characteristics have been incorporated into the management guidelines
- A number of evaluations are recommended for assessing site suitability for developing spreading basins
- Process water control parameters for BOD_5, nitrogen, IDS, and hydraulic load are added.

The proposed guidelines build upon twenty years of land application management under the previous guidelines. In this manner, the guidelines reflect not only the management of odor control and infiltration rates but also proactive environmental protection through the management of soil pH; IDS, BOD_5, and total N removal; and subsurface aerobic/anaerobic conditions. The proposed guidelines reflect the wine industry's move towards sustainable practices.

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Tables

Table 3: Hydraulic Loading/Constituent Loading

			Hydraulic Loading		Constituent Loading									
	Application Date	Cycle Length (days)	Applied Volume (gal)	Applied Volume (inches)	BOD_5 (mg/l)	BOD_5 Loading (lb/acre)	BOD_5 Loading (lb/acre/day)	BOD_5:TN	TN (mg/l)	TN Loading (lb/acre)	TN Loading (lb/acre/ day)	IDS (mg/l)	IDS Loading (lb/acre)	IDS Loading (lb/acre/ day)
Non-Stillage Test Site														
2002 SEASON														
Cycle 1	9/13/02	6	2,300	4.7	3,100	3,320	553	70	44.3	47.4	7.9	768	822	137
Cycle 2	9/19/02	7	2,000	4.1	1,900	1,770	253	127	14.9	13.9	2.0	1,010	940	134
Cycle 3	9/26/02	20	3,760	7.7	2,000	3,500	175	41	49.2	86.1	4.3	1,140	2,000	100
Cycle 4	10/16/02	29	4,350	8.9	2,033	4,120	142	113	18.0	36.5	1.3	1,150	2,330	80.3
2003 SEASON														
Pre-wet	8/17/03	10	4,830	12.4	32	90	9	10	3.1	7	0.7	740	2,077	208
Cycle 1	8/27/03	12	3,050	7.8	2,400	4,250	354	56	42.6	74	6.2	800	1,420	118
Cycle 2	9/8/03	16	3,150	8.1	2,500	4,580	286	61	40.9	75	4.7	1,100	2,010	126
Cycle 3	9/24/03	14	3,930	10.1	4,500	10,280	734	30	149	343	24.5	1,800	4,110	294
Cycle 4	10/8/03	13	3,540	9.1	2,200	4,530	348	48	45.8	95	7.3	790	1,625	125
Cycle 5	10/21/03	9	3,540	9.1	2,800	5,760	640	58	48.1	99	11.0	1,400	2,880	320
Cycle 6	10/30/03	19	3,540	9.1	3,900	8,020	422	77	50.5	103	5.4	1,400	2,880	152
Stillage Test Site														
2002 SEASON														
Cycle 1	9/11/02	7	1,000	5.0	1,400	1,590	227	156	9	10.2	1.5	283	321	46.0
Cycle 2	9/18/02	8	800	4.0	7,800	7,080	885	65	120	109	13.6	2,910	2,640	330
Cycle 3	9/26/02	14	650	3.3	7,200	5,310	379	23	316	233	16.7	3,180	2,350	168
Cycle 4	10/9/02	12	380	1.9	660	285	24	39	17	7.3	0.6	307	132	11.0
Cycle 5	10/21/02	9	600	3.0	1,300	885	98	94	13.9	9.5	1.1	255	174	19.3
Cycle 6	10/30/02	20	400	2.0	120	54	2.7	11	11.2	5.1	0.3	230	104	5.2
Cycle 7	11/19/02	21	500	2.5	18,000	10,200	486	46	392	222	10.6	2,600	1,480	70.3
2003 SEASON														
Pre-wet	9/4/03	11	750	4.7	4.9	5	0.5	25	0.2	0	0	5	5	0.5
Cycle 1	9/15/03	16	500	3.1	5,600	3,970	248	16	356	255	15.9	4,300	3,050	190
Cycle 2	10/1/03	9	500	3.1	11,000	7,800	867	19	572	411	45.7	4,800	3,410	379
Cycle 3	10/10/03	7	500	3.1	6,500	4,610	659	52	124	91	13	2,700	1,920	274
Cycle 4	10/17/03	12	500	3.1	5,000	3,650	304	20	255	170	14.2	5,520	3,920	327
Cycle 5	10/29/03	20	500	3.1	12,000	8,510	426	21	571	404	20.2	5,200	3,690	185

Table 4: pH Dataset of Process Water and Lysimeter Samples

Non-Stillage Test Site

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Median
	2002 SEASON							
C1	9/13/02	5.7	9/18/02	7.4	7.5	6.9	7.2	7.2
C2	9/18/02	5.3	9/26/02	7.2	7.0	7.5	7.3	7.3
C3	9/26/02	5.5	10/3/02			7.9		7.9
			10/9/02	6.8	7.5	7.7	7.4	7.5
			10/16/02		7.1	7.5	7.4	7.4
C4	10/16/02	6.9	10/21/02	6.9	7.1	7.5	7.3	7.3
			10/30/02	6.7	7.2	8.0	7.2	7.2
			11/14/02	6.9	7.4	7.3	7.4	7.4
			11/19/02				7.5	7.5
			12/17/02	8.4	7.9	7.0	7.6	7.6
Median		**5.4**		**6.9**				**7.4**
Range		5.3 – 6.9		0.59				7.2 – 7.9
	2003 SEASON							
Pre-wet	8/17/03	7.1	8/27/03	NA	6.9	6.8	6.9	6.9
C1	8/27/03	5.5	9/8/03	NA	7.0	7.0	6.9	7.0
C2	9/8/03	5.0	9/24/03	NA	6.6	7.0		6.8
C3	9/24/03	7.3	10/8/03	NA	7.0	7.2		7.1
C4	10/8/03	6.2	10/21/03	NA	7.0	6.9		7.0
C5	10/21/03	6.0	10/30/03	NA	6.9	7.1		7.0
C6	10/30/03	6.7	11/8/03	NA	6.7	6.8		6.8
Median		**6.1**[(a)]						**7.0**
Range		5.0 – 7.3[(a)]						6.8 – 7.1

Table 4: pH Dataset of Process Water and Lysimeter Samples

Stillage Test Site

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Median
	2002 SEASON							
C1	9/11/02	4.7	9/13/02	7.6	6.9		4.5	5.7
C2	9/18/02	3.8	9/26/02	6.4			5.5	5.5
C3	9/26/02	4.2	10/3/02	6.6	6.4		5.7	6.1
			10/9/02	8.4				
C4	10/9/02	4.9	10/21/02	8.3	6.9		7.0	7.0
C5	10/21/02	4.6	10/30/02	8.3	8.0		7.7	7.9
C6	10/30/02	6.1	11/14/02		7.4	8.0	7.1	7.4
			11/19/02			8.2	7.6	7.9
C7	11/19/02	3.7	12/2/02	8.6	7.0	7.5	7.7	7.5
			12/10/02		7.4	8.0	7.8	7.8
			12/17/02		7.5	7.9	7.7	7.7
Median		**4.6**		**8.3**				**7.5**
Range		3.7 – 6.1		6.4 – 8.6				5.5 – 7.9
	2003 SEASON							
Pre-wet	9/4/03	6.0	9/15/03	NA			6.8	6.8
C1	9/15/03	3.7	10/1/03	NA				
C2	10/1/03	4.5	10/10/03	NA	6.6	6.6		6.6
C3	10/10/03	3.5	10/17/03	NA	6.4	6.6	6.8	6.6
C4	10/17/03	3.3	10/29/03	NA	4.8	6.5	6.8	6.5
C5	10/29/03	4.1	11/18/03	NA	5.3	6.4	6.5	6.4
Median		**3.7**[(a)]						**6.6**
Range		3.3 – 4.5[(a)]						4.8 – 6.8

NA – Not applicable

(a) Does not include Pre-wet sample.

Table 5: Inorganic Dissolved Solids (IDS) (mg/l) in Process Water and Lysimeter Samples

Non-Stillage Test Site – Concentration (mg/l)

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Average
	2002 SEASON							
C1	9/13/02	768	9/18/02	4,158	*1,570*	*2,935*	*1,290*	*1,932*
C2	9/18/02	1,010	9/26/02	2,223	*3,040*	*2,586*	*2,668*	*2,765*
C3	9/26/02	1,135	10/3/02	2,135		1,375	2,620	1,998
			10/9/02		1,845	1,543	1,783	1,724
			10/16/02		1,985	1,333	1,753	1,690
C4	10/16/02	1,200	10/21/02	1,923	1,998	1,892	2,008	1,966
			10/30/02	1,620	1,733	1,300	1,995	1,676
			11/14/02	1,118	1,643	1,765	1,798	1,735
			11/19/02				1,710	1,710
			12/17/02	1,428	1,463		1,593	1,528
Average		**1,028**		**2,086**				**1,872**
Standard deviation		190.8		994.0				346.7
Annual Load (lb/acre)[a]		**6,180**				**Annual 5' Percolate Load (lb/acre)**		**6,924**
	2003 SEASON							
Pre-wet	8/17/03	740	8/27/03	NA	*2,300*	*2,200*	*2,100*	*2,200*
C1	8/27/03	800	9/8/03	NA	*1,700*	*1,600*	*1,800*	*1,700*
C2	9/8/03	1,100	9/24/03	NA	1,800	1,400	1,700	1,630
C3	9/24/03	1,800	10/8/03	NA	1,800	1,200	1,800	1,600
C4	10/8/03	790	10/21/03	NA	1,800	1,300		1,550
C5	10/21/03	1,400	10/30/03	NA	1,900	1,200	1,900	1,670
C6	10/30/03	1,400	11/8/03	NA	1,800	1,200	1,800	1,600
Average		**1,147**						**1,707**
Standard deviation		402						318
Annual Load (lb/acre)[a]		**17,440**				**Annual 5' Percolate Load (lb/acre)**		**10,220**

Table 5: Inorganic Dissolved Solids (IDS) (mg/l) in Process Water and Lysimeter Samples

Stillage Test Site – Concentration (mg/l)

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Average
	2002 SEASON							
C1	9/11/02	283	9/13/02	1,910	*200*		*1,630*	*915*
C2	9/18/02	2,907	9/26/02	1,667			*1,612*	*1,612*
C3	9/26/02	3,179	10/3/02	2,235	*913*		*1,433*	*1,173*
			10/9/02				*1,398*	*1,398*
C4	10/9/02	307	10/21/02	2,100	1,018		1,423	1,221
C5	10/21/02	255	10/30/02				1,480	1,480
C6	10/30/02	230	11/14/02		930	3,960	1,533	2,141
			11/19/02			4,100	1,578	2,839
C7	11/19/02	2,597	12/2/02			4,313	1,675	2,994
			12/10/02			4,400	1,658	3,029
			12/17/02			4,160	1,585	2,873
Average		**1,394**		**1,978**				**1,970**
Standard deviation		1,413.7		246.5				823.1
Annual Load (lb/acre)(a)		**7,190**				**Annual 5' Percolate Load (lb/acre)**		**6,841**
	2003 SEASON							
Pre-wet	9/4/03	5	9/15/03	NA			*3,600*	*3,600*
C1	9/15/03	4,300	10/1/03	NA	*560*	*3,300*		*1,930*
C2	10/1/03	4,800	10/10/03	NA	*3,700*	*4,400*		*4,050*
C3	10/10/03	2,700	10/17/03	NA	*2,510*	*3,750*	*2,920*	*3,060*
C4	10/17/03	5,520	10/29/03	NA	2,600	2,700	2,200	2,500
C5	10/29/03	5,200	11/18/03	NA	2,700	2,100	1,800	2,200
Average		**3,755**						**2,890**
Standard deviation		2,087						828
Annual Load (lb/acre)(a)		**15,980**				**Annual 5' Percolate Load (lb/acre)**		**7,322**

Italicized values indicate influence of first water flushing

NA – Not applicable

(a) Annual load based on the sum of individual sample contributions and Annual 5' Percolate Load based on the sum of individual sample contributions adjusted to water budget estimate percolation value.

Table 6: Water Quality Parameter Load Changes after Soil Treatment in Spreading Basins

Constituent	Applied (lb/acre)	Percolate (lb/acre)	Percolate % of Applied
Non-Stillage Test Site			
2002 SEASON			
IDS	6,180	6,924	112%
BOD_5	12,640	1,387	11%
Total Nitrogen	186	123	66%
Organic-N	114	9	8%
Ammonia-N	50	2	3%
Nitrate-N	22	113	512%
Fe and Mn	30	51	168%
Calcium	785	1,330	170%
Magnesium	241	244	101%
Sodium	879	637	72%
Potassium	525	308	59%
Chloride	669	481	72%
Sulfate[a]	3,303	882	27%
Alkalinity	2,249	4,511	201%
Estimated water flux, inches[b]	25.5	20.1	
2003 SEASON			
IDS	17,440	19,250	110%
BOD_5	38,576	12	0%
Total Nitrogen	806	1,172	145%
Organic-N	668	9	1%
Ammonia-N	72	6	8%
Nitrate-N	66	1,158	1,750%
Fe and Mn	54	0	0%
Calcium	1,745	3,263	187%
Magnesium	558	514	92%
Sodium	3,179	1,796	56%
Potassium	1,539	1,058	69%
Chloride	1,892	1,223	65%
Sulfate	2,423	6,338	262%
Alkalinity[c]	9,410	3,080	36%
Estimated water flux, inches[b]	67.1	53.5	

Table 6: Water Quality Parameter Load Changes after Soil Treatment in Spreading Basins

Constituent	Applied (lb/acre)	Percolate (lb/acre)	Percolate % of Applied
Stillage Test Site			
2002 SEASON			
IDS	7,190	6,841	95%
BOD_5	25,420	2,281	9%
Total Nitrogen	597	192	32%
Organic-N	509	57	11%
Ammonia-N	79	92	117%
Nitrate-N	9	42	470%
Fe and Mn	9	210	2260%
Calcium	160	561	352%
Magnesium	136	206	152%
Sodium	138	701	507%
Potassium	1,756	1,218	69%
Chloride	294	324	110%
Sulfate	586	1183	202%
Alkalinity	460	4,225	918%
Estimated water flux, inches[(b)]	22.0	15.0	
2003 SEASON			
IDS	15,980	7,322	46%
BOD_5	28,448	1,996	7%
Total Nitrogen	1,333	364	27%
Organic-N	1,121	20	2%
Ammonia-N	196	26	13%
Nitrate-N	15	318	2074%
Fe and Mn	12	84	677%
Calcium	173	316	183%
Magnesium	133	97	73%
Sodium	124	156	126%
Potassium	3,526	2,306	65%
Chloride	184	86	47%
Sulfate	2,662	1,154	43%
Alkalinity[(c)]	0	1,990	–
Estimated water flux, inches[(b)]	20.4	11.0	

(a) Includes suspected applied water outlier due to ion imbalance.
(b) Cumulative percolate flux was calculated as the sum of application plus rain minus 75% of potential evaporation.
(c) Alkalinity estimated from difference in anion-cation balance minus the portion of the ionized organic acids not titrated at an alkalinity endpoint of pH 4.2. Ionized organic acids estimated from measurement of organic acids in one applied stillage and one applied non-stillage sample, apportioned by the BOD_5 concentration.

Table 7: BOD_5 (mg/l) in Process Water and Lysimeter Samples

Non-Stillage Test Site – Concentration (mg/l)

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Average
	2002 SEASON							
C1	9/13/02	3,100	9/18/02	620	580	< 5	380	322
C2	9/18/02	1,900	9/26/02	770	< 5	< 5	< 5	2.5
C3	9/26/02	2,000	10/3/02	1,400		< 5	< 5	2.5
			10/9/02		910		42	476
			10/16/02		1,300			1,300
C4	10/16/02	2,000	10/21/02	390	1,300		1,100	1,200
			10/30/02	1,100	910		330	620
			11/14/02	270	290	150	220	220
			11/19/02					
			12/17/02		< 5	< 5		2.5
Average		**2,250**		**758**				**461**
Standard deviation		568.6		429.4				497.4
Annual Load (lb/acre)[b]		**12,640**				**Annual 5' Percolate Load (lb/acre)**		**1,387**
	2003 SEASON							
Pre-wet	8/17/03	32	8/27/03	NA				
C1	8/27/03	2,400	9/8/03	NA	< 1	1.7	1.7	1.3
C2	9/8/03	2,500	9/24/03	NA	< 1	< 1	< 3	0.8
C3	9/24/03	4,500	10/8/03	NA	1.2	< 3		1.4
C4	10/8/03	2,200	10/21/03	NA	< 3	< 3		1.5
C5	10/21/03	2,800	10/30/03	NA	1.4	< 1	< 3	1.1
C6	10/30/03	3,900	11/8/03	NA	< 1	< 1		0.5
Average		**3,050[a]**						**1.1**
Standard deviation		931[a]						0.5
Annual Load (lb/acre)[b]		**38,580**				**Annual 5' Percolate Load (lb/acre)**		**7**

Table 7: BOD_5 (mg/l) in Process Water and Lysimeter Samples

Stillage Test Site – Concentration (mg/l)

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Average
	2002 SEASON							
C1	9/11/02	1,400	9/13/02	480			2,500	2,500
C2	9/18/02	7,800	9/26/02	1,100			1,600	1,600
C3	9/26/02	7,200	10/3/02	1,700	< 5		1,000	501
			10/9/02				790	790
C4	10/9/02	660	10/21/02	2,100				
C5	10/21/02	1,300	10/30/02				83	83
C6	10/30/02	120	11/14/02				11	11
			11/19/02				< 5	2.5
C7	11/19/02	18,000	12/2/02				< 5	2.5
			12/10/02				< 5	2.5
			12/17/02				< 5	2.5
Average		**5,210**		**1,093**				**551**
Standard deviation		6,464		610				860.3
Annual Load (lb/acre)[b]		**25,420**				**Annual 5' Percolate Load (lb/acre)**		**2,281**
	2003 SEASON							
Pre-Wet	9/4/03	5	9/15/03	NA			1.5	1.5
C1	9/15/03	5,600	10/1/03	NA	< 3			1.5
C2	10/1/03	11,000	10/10/03	NA	24	6.8		15.4
C3	10/10/03	6,500	10/17/03	NA	870	7.4	34	304
C4	10/17/03	5,000	10/29/03	NA	5,400	13	17	1,810
C5	10/29/03	12,000	11/18/03	NA	3,300	7.7	77	1,130
Average		**8,020[a]**						**543**
Standard deviation		3,241[a]						758
Annual Load (lb/acre)[b]		**28,450**				**Annual 5' Percolate Load (lb/acre)**		**1,996**

NA – Not applicable

(a) Does not include Pre-wet sample
(b) Annual load based on the sum of individual sample contributions and Annual 5' Percolate Load based on the sum of individual sample contributions adjusted to water budget estimate percolation value.

Table 8: Nitrogen Forms in Process Water and Lysimeter Samples – Non-Stillage Test Site

Total Nitrogen (mg/l)

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Average
	2002 SEASON							
C1	9/13/02	44.3	9/18/02	195.3	*28.6*	*128.3*	*27.6*	*61.5*
C2	9/18/02	15.2	9/26/02	5.2	*173.1*	*3.6*	*160*	*112.2*
C3	9/26/02	49.2	10/3/02	1.9		9.5	71.7	40.6
			10/9/02		2.8	1.4	1.9	2.0
			10/16/02		2.8	1.6	1.4	1.9
C4	10/16/02	19.0	10/21/02	0.8	2.7	0.9	0.8	1.5
			10/30/02	3.4	1.9	6.7	3.1	3.3
			11/14/02	0.7	0.3	1.2	0.3	0.6
			11/19/02				3.1	3.1
			12/17/02	2.5	3.0	47.2	3.8	18.0
Average		**31.9**		**30.0**				**24.5**
Standard deviation		17.3		72.9				37.1
Annual Load (lb/acre)[b]		**186**				**Annual 5' Percolate Load (lb/acre)**		**123**
	2003 SEASON							
Pre-wet	8/17/03	3.1	8/27/03	NA	*141*	*152*	*102*	*131*
C1	8/27/03	43	9/8/03	NA	*122*	*182*	*81*	*128*
C2	9/8/03	41	9/24/03	NA	121	37		79
C3	9/24/03	149	10/8/03	NA	114	26		70
C4	10/8/03	46	10/21/03	NA	97	28		63
C5	10/21/03	48	10/30/03	NA	112	30		71
C6	10/30/03	51	11/8/03	NA	95	19		57
Average		**63[a]**						**86**
Standard deviation		42[a]						50
Annual Load (lb/acre)[b]		**806**				**Annual 5' Percolate Load (lb/acre)**		**622**

Table 8: Nitrogen Forms in Process Water and Lysimeter Samples – Non-Stillage Test Site

Organic-N (mg/l)

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Average
	2002 SEASON							
C1	9/13/02	32.8	9/18/02	7.7	*9.6*	*3.5*	*14.2*	*9.1*
C2	9/18/02	10.8	9/26/02	2.7	*0.4*	*1.7*	*0.3*	*0.8*
C3	9/26/02	31.6	10/3/02	1.7		8.9	2.6	5.8
			10/9/02		2.6	1.2	1.7	1.8
			10/16/02		< 0.1	1.3	0.9	0.8
C4	10/16/02	6.7	10/21/02	0.2	0.5	0.6	0.6	0.6
			10/30/02	1.8	0.9	3.7	2.9	2.5
			11/14/02	< 0.1	< 0.1	0.8	< 0.1	0.3
			11/19/02				2.9	2.9
			12/17/02	1.9	1.8	0.5	1.5	1.3
Average		**20.5**		**2.3**				**2.6**
Standard deviation		13.7		2.6				2.8
Annual Load (lb/acre)[b]		**114**				**Annual 5' Percolate Load (lb/acre)**		**9**
	2003 SEASON							
Pre-wet	8/17/03	2.4	8/27/03	NA	*< 2*	*< 2*	*< 2*	*1.0*
C1	8/27/03	34	9/8/03	NA	*< 2*	*< 2*	*< 2*	*1.0*
C2	9/8/03	30	9/24/03	NA	< 1	< 1		0.5
C3	9/24/03	140	10/8/03	NA	< 1	< 1		0.5
C4	10/8/03	30	10/21/03	NA		< 1		0.5
C5	10/21/03	30	10/30/03	NA	< 2	< 2		1.0
C6	10/30/03	39	11/8/03	NA	< 2	< 2		1.0
Average		**51[a]**						**0.8**
Standard deviation		44[a]						0.2
Annual Load (lb/acre)[b]		**668**				**Annual 5' Percolate Load (lb/acre)**		**5**

Table 8: Nitrogen Forms in Process Water and Lysimeter Samples – Non-Stillage Test Site

Ammonia-N (mg/l)

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Average
	2002 SEASON							
C1	9/13/02	6.0	9/18/02	2.1	*0.2*	*0.3*	*0.2*	*0.2*
C2	9/18/02	4.3	9/26/02	2.4	*1.2*	*1.5*	*0.4*	*1.0*
C3	9/26/02	14.8	10/3/02	< 0.1		< 0.5	< 0.1	0.3
			10/09/02		0.1	< 0.1	< 0.1	0.1
			10/16/02		2.6	0.2	0.4	1.1
C4	10/16/02	6.8	10/21/02	0.5	2.1	0.2	< 0.1	0.8
			10/30/02	1.5	0.9	2.9	< 0.1	1.3
			11/14/02	0.5	< 0.1	0.3	< 0.1	0.2
			11/19/02				< 0.1	0.1
			12/17/02	0.2	0.9	0.4	2.2	1.2
Average		**8.0**		**1.0**				**0.6**
Standard deviation		4.7		0.9				0.5
Annual Load (lb/acre)[b]		**50**				**Annual 5' Percolate Load (lb/acre)**		**2**
	2003 SEASON							
Pre-wet	8/17/03	< 1	8/27/03	NA	*< 1*	*< 1*	*< 1*	*0.5*
C1	8/27/03	8.4	9/8/03	NA	*< 1*	*< 1*	*< 1*	*0.5*
C2	9/8/03	3.8	9/24/03	NA	< 1	< 1		0.5
C3	9/24/03	7.9	10/8/03	NA	< 1	< 1		0.5
C4	10/8/03	3.6	10/21/03	NA		< 1		0.5
C5	10/21/03	6.0	10/30/03	NA	< 2	< 2		1.0
C6	10/30/03	4.3	11/8/03	NA	< 2	< 2		1.0
Average		**5.7[a]**						**0.6**
Standard deviation		2.1[a]						0.2
Annual Load (lb/acre)[b]		**72**				**Annual 5' Percolate Load (lb/acre)**		**3**

Table 8: Nitrogen Forms in Process Water and Lysimeter Samples – Non-Stillage Test Site

Nitrate-N (mg/l)

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Average
	2002 SEASON							
C1	09/13/02	5.5	09/18/02	185.5	*18.8*	*124.5*	*13.2*	*52.2*
C2	09/18/02	< 0.1	09/26/02	< 0.1	*171.5*	*0.4*	*159.3*	*110.4*
C3	09/26/02	2.8	10/03/02	< 0.1		0.1	69.0	34.6
			10/09/02		< 0.1	< 0.1	< 0.1	0.05
			10/16/02		< 0.1	< 0.1	< 0.1	0.05
C4	10/16/02	5.5	10/21/02	< 0.1	< 0.1	< 0.1	< 0.1	0.05
			10/30/02	< 0.1	0.1	< 0.1	< 0.1	0.05
			11/14/02	< 0.1	< 0.1	< 0.1	< 0.1	0.05
			11/19/02				< 0.1	0.05
			12/17/02	0.4	0.3	46.3	<0.1	23.3
Average		**3.5**		**26.6**				**22.1**
Standard deviation		2.6		70.1				36.1
Annual Load (lb/acre)[b]		**22**				**Annual 5' Percolate Load (lb/acre)**		**113**
	2003 SEASON							
Pre-wet	8/17/03	0.2	8/27/03	NA	*140*	*150*	*100*	*130*
C1	8/27/03	0.2	9/8/03	NA	*120*	*180*	*79*	*126*
C2	9/8/03	2.5	9/24/03	NA	120	36		78
C3	9/24/03	0.2	10/8/03	NA	113	24.9		69
C4	10/8/03	11.3	10/21/03	NA	97	27		62
C5	10/21/03	9.9	10/30/03	NA	110	28		69
C6	10/30/03	7	11/8/03	NA	93	17		55
Average		**5.2[a]**						**84**
Standard deviation		4.9[a]						50
Annual Load (lb/acre)[b]		**66**				**Annual 5' Percolate Load (lb/acre)**		**615**

Italicized values indicate influence of first water flushing

NA – not applicable

(a) Does not include Pre-wet sample.

(b) Annual load based on the sum of individual sample contributions and Annual 5' Percolate Load based on the sum of individual sample contributions adjusted to water budget estimate percolation value.

Table 9: Nitrogen Forms in Process Water and Lysimeter Samples – Stillage Test Site

Total Nitrogen (mg/l)

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Average
	2002 SEASON							
C1	9/11/02	9.0	9/13/02	29.5	*5.5*		*125.5*	*65.5*
C2	9/18/02	120	9/26/02	40.7			*71.8*	*71.8*
C3	9/26/02	316	10/3/02	41.8	*24.6*		*52.3*	*38.5*
			10/9/02	19.3			*17.1*	*17.1*
C4	10/9/02	17.0	10/21/02	55.7	20.9		42.5	31.7
C5	10/21/02	14.0	10/30/02	34.4	12.2		29.5	20.9
C6	10/30/02	11.2	11/14/02		8.5	250	18.3	92.3
			11/19/02			312	15.8	164
C7	11/19/02	392	12/2/02	15.4	11.3	335	9.0	118.3
			12/10/02		14.5	358	8.4	127
			12/17/02		22.0	392	7.7	140.6
Average		**125.7**		**33.8**				**80.7**
Standard deviation		162.5		13.9				51.3
Annual Load (lb/acre)[b]		**597**				**Annual 5' Percolate Load (lb/acre)**		**192**
	2003 SEASON							
Pre-wet	9/4/03	1	9/15/03	NA			*301*	*301*
C1	9/15/03	356	10/1/03	NA				
C2	10/1/03	572	10/10/03	NA	*228*	*386*		*307*
C3	10/10/03	124	10/17/03	NA	*22*	*273*	*133*	*143*
C4	10/17/03	255	10/29/03	NA	119	129	12	87
C5	10/29/03	571	11/18/03	NA	63	60	9	44
Average		**375[a]**						**176**
Standard deviation		197[a]						122
Annual Load (lb/acre)[b]		**1,333**				**Annual 5' Percolate Load (lb/acre)**		**364**

Table 9: Nitrogen Forms in Process Water and Lysimeter Samples – Stillage Test Site

Organic-N (mg/l)

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Average
	2002 SEASON							
C1	9/11/02	5.9	9/13/02	28.3	*2.9*		*51.9*	*27.4*
C2	9/18/02	102.9	9/26/02	15.7			*23.1*	*23.1*
C3	9/26/02	263.0	10/3/02	39.7	*4.6*		*49.2*	*26.9*
			10/9/02	7.9			*< 0.1*	*0.1*
C4	10/9/02	3.9	10/21/02	17.6	7.1		13.7	28.7
C5	10/21/02	3.0	10/30/02	12.1	0.6		2.5	1.6
C6	10/30/02	3.6	11/14/02		0.3	0.9	0.2	0.5
			11/19/02			3.7	2.7	3.2
C7	11/19/02	369.8	12/2/02		1.0	2.6	< .1	1.2
			12/10/02		2.2	0.9	0.2	1.1
			12/17/02		2.7	35.3	2.3	13.4
Average		**107.4**		**20.2**				**11.6**
Standard deviation		150.4		11.7				12.5
Annual Load (lb/acre)[b]		**509**				**Annual 5' Percolate Load (lb/acre)**		**57**
	2003 SEASON							
Pre-wet	9/4/03	< 1	9/15/03	NA			*< 1*	*0.5*
C1	9/15/03	310	10/1/03	NA				
C2	10/1/03	500	10/10/03	NA	*< 2*	*< 2*		*1.0*
C3	10/10/03	110	10/17/03	NA	*7*	*< 3*	*< 3*	*3.3*
C4	10/17/03	190	10/29/03	NA	70	< 3	7.3	26.3
C5	10/29/03	470	11/18/03	NA	19	< 2	4.2	8.1
Average		**316[a]**						**7.8**
Standard deviation		170[a]						10.7
Annual Load (lb/acre)[b]		**1,121**				**Annual 5' Percolate Load (lb/acre)**		**20**

Table 9: Nitrogen Forms in Process Water and Lysimeter Samples – Stillage Test Site

Ammonia-N (mg/l)

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Average
	2002 SEASON							
C1	9/11/02	0.9	9/13/02	1.1	*0.6*		*54.2*	*27.4*
C2	9/18/02	13.7	9/26/02	24.9			*48.6*	*48.6*
C3	9/26/02	51.5	10/3/02	2.0	*12.1*		*3.0*	*7.6*
			10/9/02	11.3			*16.9*	*16.9*
C4	10/9/02	10.8	10/21/02	38.0	13.7		28.7	21.2
C5	10/21/02	10.9	10/30/02	22.2	11.5		26.9	19.2
C6	10/30/02	5.6	11/14/02		7.5	3.1	18.0	9.5
			11/19/02			1.4	13.0	7.2
C7	11/19/02	22.4	12/2/02	15.2	6.2	0.9	8.8	5.3
			12/10/02		2.5	< 0.1	7.3	3.3
			12/17/02		3.9	0.6	4.1	2.9
Average		**16.5**		**16.4**				**15.4**
Standard deviation		16.8		13.2				13.7
Annual Load (lb/acre)[(b)]		**79**				**Annual 5' Percolate Load (lb/acre)**		**92**
	2003 SEASON							
Pre-wet	9/4/03	< 1	9/15/03	NA			*< 1*	*0.5*
C1	9/15/03	43	10/1/03	NA				
C2	10/1/03	71	10/10/03	NA	*< 2*	*< 2*		*1.0*
C3	10/10/03	9.7	10/17/03	NA	*12*	*< 3*	*< 3*	*5.0*
C4	10/17/03	52	10/29/03	NA	48	< 3	< 3	17.0
C5	10/29/03	100	11/18/03	NA	43	< 4	4.3	16.4
Average		**55[(a)]**						**8.0**
Standard deviation		34[(a)]						8.2
Annual Load (lb/acre)[(b)]		**196**				**Annual 5' Percolate Load (lb/acre)**		**26**

Table 9: Nitrogen Forms in Process Water and Lysimeter Samples – Stillage Test Site

	Nitrate-N (mg/l)							
Cycle	**Application Date**	**Process Water**	**Sample Date**	**Lysimeter 4 1-foot depth**	**Lysimeter 1**	**Lysimeter 2**	**Lysimeter 3**	**Average**
	2002 SEASON							
C1	9/11/02	2.2	09/13/02	< 0.1	*2.0*		*19.4*	*10.7*
C2	9/18/02	3.5	09/26/02	< 0.1			*0.1*	*0.1*
C3	9/26/02	1.8	10/03/02	< 0.1	*7.9*		*< 0.1*	*4.0*
			10/09/02	< 0.1			*< 0.1*	*0.1*
C4	10/09/02	2.3	1021/02	0.1	< 0.1		< 0.1	28.7
C5	10/21/02	< 0.1	10/30/02	< 0.1	0.1		< 0.1	0.1
C6	10/30/02	2.0	11/14/02		0.7	246.0	< 0.1	82.3
			11/19/02			307.0	0.1	153.6
C7	11/19/02	< 0.1	12/02/02	0.2	4.1	331.0	< 0.1	111.7
			12/10/02		9.8	357.0	0.9	122.6
			12/17/02		15.4	356.0	1.3	124.2
Average		**1.7**		**0.1**				**58.0**
Standard deviation		1.2		0.0				61.0
Annual Load (lb/acre)[b]		**9**				**Annual 5' Percolate Load (lb/acre)**		**42**
	2003 SEASON							
Pre-wet	9/4/03	< 0.4	9/15/03	NA			*300*	*300*
C1	9/15/03	3.0	10/1/03	NA				
C2	10/1/03	< 2	10/10/03	NA	*226*	*384*		*305*
C3	10/10/03	3.8	10/17/03	NA	*< 6*	*270*	*130*	*134*
C4	10/17/03	13	10/29/03	NA	< 1	126	3.2	43.2
C5	10/29/03	< 1	11/18/03	NA	0.8	57	< 0.4	19.3
Average		**4.3[a]**						**160**
Standard deviation		5.1[a]						137
Annual Load (lb/acre)[b]		**15**				**Annual 5' Percolate Load (lb/acre)**		**318**

Italicized values indicate influence of first water flushing
NA – Not applicable

(a) Does not include Pre-wet sample.
(b) Annual load based on the sum of individual sample contributions and Annual 5' Percolate Load based on the sum of individual sample contributions adjusted to water budget estimate percolation value.

Table 10: (Iron plus Manganese) in Process Water and Lysimeter Samples

Non-Stillage Test Site – Concentration (mg/l)

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Average
	2002 SEASON							
C1	9/13/02	2.2	9/18/02	0.3	4.2	0.7	0.7	1.8
C2	9/18/02	3.0	9/26/02	16.0	0.7	1.7	0.4	0.9
C3	9/26/02	8.9	10/3/02	24.8		7.2	1.5	4.4
			10/9/02		49.2	14.6	5.9	23.2
			10/16/02		37.5	19.2	6.6	21.1
C4	10/16/02	4.7	10/21/02	16.0	11.8	13.7	7.8	11.1
			10/30/02	24.4	16.3	17.2	14.5	16.0
			11/14/02	5.0	80.6	14.9	17.5	37.7
			11/19/02				15.1	15.1
			12/17/02		5.2	0.6	106.6	37.5
Average		**4.7**		**14.4**				**16.9**
Standard deviation		3.0		10.0				13.3
Annual Load (lb/acre)(b)		**30**				**Annual 5' Percolate Load (lb/acre)**		**51**
	2003 SEASON							
Pre-wet	8/17/03	0.43	8/27/03	NA	0.059		0.059	0.06
C1	8/27/03	1.0	9/8/03	NA	0.057	0.057		0.06
C2	9/8/03	1.7	9/24/03	NA	0.06	0.057		0.06
C3	9/24/03	13.3	10/8/03	NA		0.023		0.02
C4	10/8/03	2.8	10/21/03	NA				
C5	10/21/03	2.8	10/30/03	NA	0.053	0.057		0.06
C6	10/30/03	1.8	11/8/03	NA	0.15	0.13		0.14
Average		**3.9[a]**						**0.07**
Standard deviation		4.6[a]						0.04
Annual Load (lb/acre)(b)		**54**				**Annual 5' Percolate Load (lb/acre)**		**0**

Table 10: (Iron plus Manganese) in Process Water and Lysimeter Samples

Stillage Test Site – Concentration (mg/l)

Cycle	Application Date	Process Water	Sample Date	Lysimeter 4 1-foot depth	Lysimeter 1	Lysimeter 2	Lysimeter 3	Average
	2002 SEASON							
C1	9/11/02	0.7	9/13/02	4.9	0.5		106.8	53.6
C2	9/18/02	1.8	9/26/02	42.1			111.1	111.1
C3	9/26/02	2.9	10/3/02	113.3	11.0		87.1	49.1
			10/9/02	51.5			63.3	63.3
C4	10/9/02	4.7	10/21/02				46.6	28.7
C5	10/21/02	0.8	10/30/02	16.2	11.6			11.6
C6	10/30/02	0.7	11/14/02		9.9	1.0	32.8	14.6
			11/19/02			0.6	27.7	14.2
C7	11/19/02	3.2	12/2/02		8.9	0.7	34.4	14.7
			12/10/02			0.7	24.7	12.7
			12/17/02		10.3	0.8	11.8	7.6
Average		**2.1**		**45.6**				**34.6**
Standard deviation		1.5		42.3				32.0
Annual Load (lb/acre)[(b)]		**9**				**Annual 5' Percolate Load (lb/acre)**		**210**
	2003 SEASON							
Pre-wet	9/4/03	0.058	9/15/03	NA				
C1	9/15/03	8.8	10/1/03	NA				
C2	10/1/03	2.9	10/10/03	NA	2.1	2.0		2.1
C3	10/10/03	1.4	10/17/03	NA	50	5.1	2.6	19.2
C4	10/17/03	1.7	10/29/03	NA	159	8.6	10.6	59.4
C5	10/29/03	2.7	11/18/03	NA	129		11.2	70.1
Average		**3.5[(a)]**						37.7
Standard deviation		3.0[(a)]						32.2
Annual Load (lb/acre)[(b)]		**12**				**Annual 5' Percolate Load (lb/acre)**		**84**

NA – not applicable

(a) Does not include Pre-wet sample.
(b) Annual load based on the sum of individual sample contributions and Annual 5' Percolate Load based on the sum of individual sample contributions adjusted to water budget estimate percolation value.

Table 11: Summary Soil Characteristics for 2002 and 2003

Non-Stillage Test Site – Average by Date

Date	Fe mg/kg	Mn mg/kg	ESP	Ca % cations	Mg % cations	Na % cations	K % cations	SO_4-S % anions	Cl % anions	PO_4-P mg/kg	pH	Profile Totals NO_3-N lb/ac	Profile Totals NH_4-N* lb/ac
2002 SEASON													
9/6/2002	16955	209	1.1	51%	11%	16%	22%	85%	15%	28	7.7	500	103
10/3/2002	11778	148	3.7	35%	15%	36%	14%	78%	22%	21	7.6	242.8	213
10/9/2002	16004	205	3.0	31%	9%	33%	27%	67%	33%	40	7.7	140	14.8
10/16/2002	12253	175	3.5	33%	12%	37%	19%	70%	30%	25	7.9	136	5.2
2003 SEASON													
1/20/2003	15094	203	3.0	30%	9%	31%	30%	70%	30%	49	7.7	108	6.8
8/27/03	13400	182	2.0	57%	33%	2%	8%	50%	50%	5	8.2	80	242
9/24/03	13000	172	2.5	50%	38%	2%	10%	37%	63%	5	7.7	156	242
10/21/03	13000	194	3.3	66%	27%	2%	6%	40%	60%	6	8.0	90	267
11/18/03	13000	170	4.1	60%	32%	2%	7%	36%	64%	5	7.9	102	416
12/16/03	12800	166	3.6	54%	36%	2%	8%	27%	73%	9	8.2	90	360

Table 11: Summary Soil Characteristics for 2002 and 2003

Stillage Test Site – Average by Date

Date	Fe mg/kg	Mn mg/kg	ESP	Ca % cations	Mg % cations	Na % cations	K % cations	SO_4-S % anions	Cl % anions	PO_4-P mg/kg	pH	NO_3-N lb/ac	NH_4-N* lb/ac
2002 SEASON													
08/28/02	8994	137	3.5	7%	4%	15%	74%	87%	13%	40	7.5	108	251
09/18/02	11938	150	6.0	5%	3%	16%	77%	84%	16%	42	7.5	64	197
10/09/02	9883	144	3.3	6%	3%	13%	79%	80%	20%	34	7.3	64	272
10/21/02	9989	135	2.4	3%	3%	8%	86%	82%	18%	41	7.4	56	238
10/30/02	8290	112	1.9	4%	2%	8%	86%	82%	18%	33	7.6	48	202
12/4/2002	10327	154	4.2	4%	2%	13%	81%	79%	21%	31	7.1	24	358
12/09/02	10915	160	3.5	6%	3%	13%	78%	79%	21%	36	7.4	24	137
2003 SEASON													
01/20/03	10614	162	2.8	3%	2%	8%	87%	78%	22%	31	7.2	20	256
9/15/03	12560	206	1.6	15%	57%	2%	26%	27%	73%	21	6.4	393	936
10/10/03	11200	176	1.5	15%	56%	2%	27%	43%	57%	66	6.9	376	1180
10/29/03	12060	170	1.9	16%	50%	2%	31%	41%	59%	23	7.6	198	1164

Table 11: Summary Soil Characteristics for 2002 and 2003

Non-Stillage Test Site – Average by Depth

DEPTH	Fe mg/kg	Mn mg/kg	ESP	Ca % cations	Mg % cations	Na % cations	K % cations	SO_4-S % anions	Cl % anions	PO_4-P mg/kg	pH	Depth Average NO_3-N lb/ac	Depth Average NH_4-N* lb/ac
2002 0-1'	11662	133	3.5	40%	12%	27%	21%	85%	15%	38	7.5	113	15
2002 1-2'	14304	191	2.9	36%	11%	28%	24%	74%	26%	59	7.7	52	6
2002 2-3'	14631	182	2.9	32%	10%	32%	25%	70%	30%	39	7.8	21	39
2002 3-4'	17162	214	2.5	34%	12%	33%	21%	69%	31%	18	7.9	20	4
2002 4-5'	14539	224	2.6	36%	13%	35%	16%	69%	31%	13	7.8	19	5
2003 0-1'	11200	134	4.1	55%	35%	2%	8%	24%	76%	6	8.2	14	126
2003 '1-2'	11400	150	3.6	70%	23%	1%	5%	30%	70%	6	8.1	16	74
2003 2-3'	12000	158	3.2	66%	26%	1%	6%	42%	58%	6	8.0	21	45
2003 3-4'	14600	204	2.5	51%	38%	2%	9%	45%	55%	6	7.9	21	31
2003 4-5'	16000	238	2.1	36%	49%	3%	12%	47%	53%	5	7.8	31	30

Table 11: Summary Soil Characteristics for 2002 and 2003

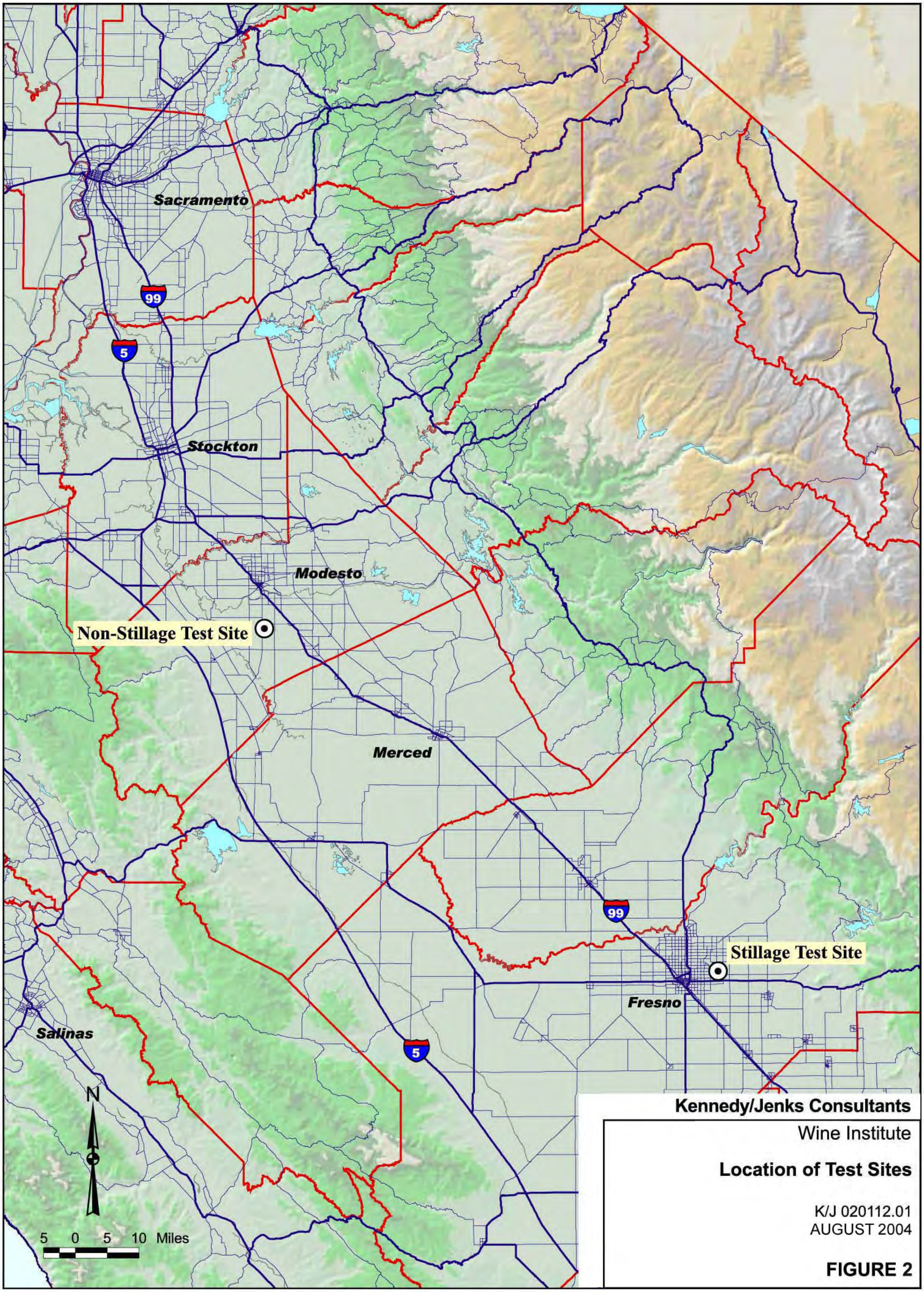
Stillage Test Site – Average by Depth

DEPTH	Fe mg/kg	Mn mg/kg	ESP	Ca % cations	Mg % cations	Na % cations	K % cations	SO_4-S % anions	Cl % anions	PO_4-P mg/kg	pH	Depth Average NO_3-N lb/ac	Depth Average NH_4-N* lb/ac
2002 0-1'	9011	88	1.3	5%	4%	7%	85%	77%	23%	80	6.7	20	117
2002 1-2'	10510	111	2.9	5%	2%	10%	83%	80%	20%	43	7.4	8	54
2002 2-3'	10754	167	3.8	4%	2%	13%	81%	83%	17%	24	7.4	7	34
2002 3-4'	10086	191	3.9	4%	2%	13%	80%	83%	17%	17	7.6	6	20
2002 4-5'	11076	172	4.7	5%	3%	17%	75%	84%	16%	14	7.7	12	12
2003 0-1'	9700	117	1.8	16%	54%	2%	28%	36%	64%	73	6.0	107	619
2003 1-2'	11333	147	2.5	14%	55%	2%	29%	23%	77%	53	6.7	57	123
2003 2-3'	11667	160	1.6	13%	57%	2%	29%	36%	64%	32	6.6	59	87
2003 3-4'	13333	253	1.1	18%	48%	2%	32%	52%	48%	15	7.5	55	144
2003 4-5'	13667	243	1.3	16%	58%	2%	24%	37%	63%	12	8.0	45	121

Notes:
The values for cations are reported as percent of total cations in units of meq/l. Anion concentrations are expressed as percentage of sulfate plus chloride in meq/l.

Fe = Iron
Mn = Manganese
ESP = Exchangeable Sodium Percentage
Ca = Calcium
Mg/ = Magnesium
NA = Sodium
K = Potassium
SO_4-S = Sulfate-sulfur
Cl = Chloride
PO_4-P = Phosphate Phosphorus
NO_3-N = Nitrate as Nitrogen
NH_4-N* = Ammonium - Nitrogen

Figures



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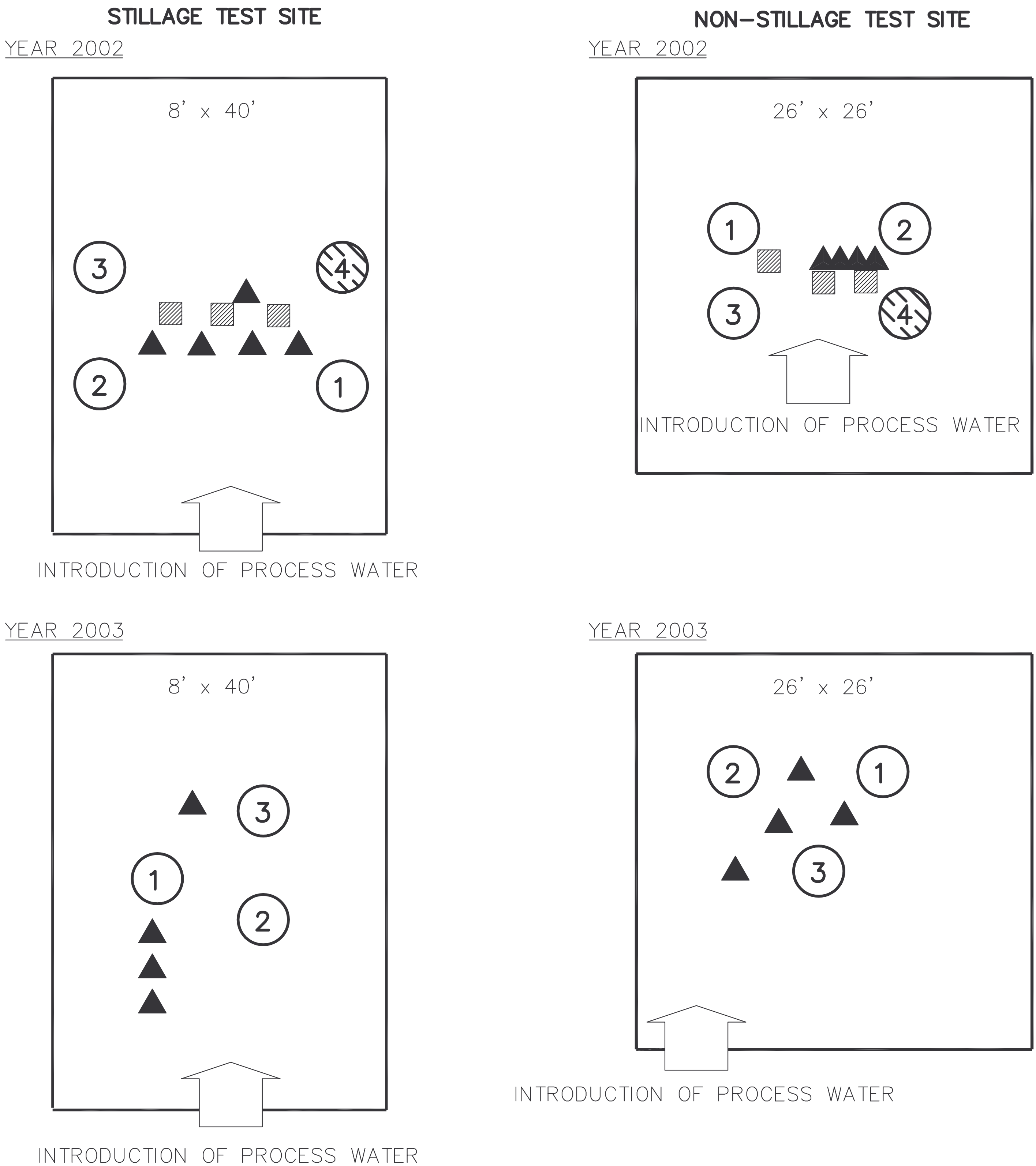
Wine Institute

Location of Test Sites

K/J 020112.01
AUGUST 2004

FIGURE 2



*NOT TO SCALE

LEGEND

1 3 DEEP (5 FEET) LYSIMETERS BELOW SOIL CORE

4 1 SHALLOW (~12 INCHES) LYSIMETER

LYSIMETER EVENT LOGGING TIPPING CUPS

SOIL MOISTURE PROBES

SOIL GAS PROBES (12",30",60")

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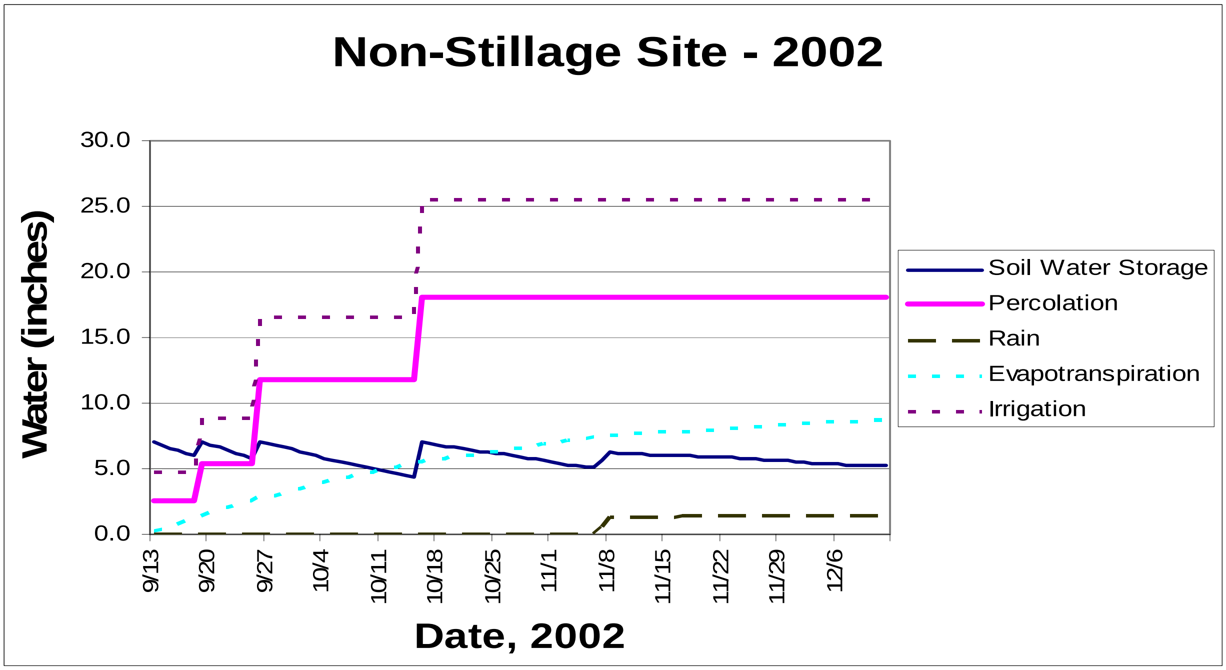
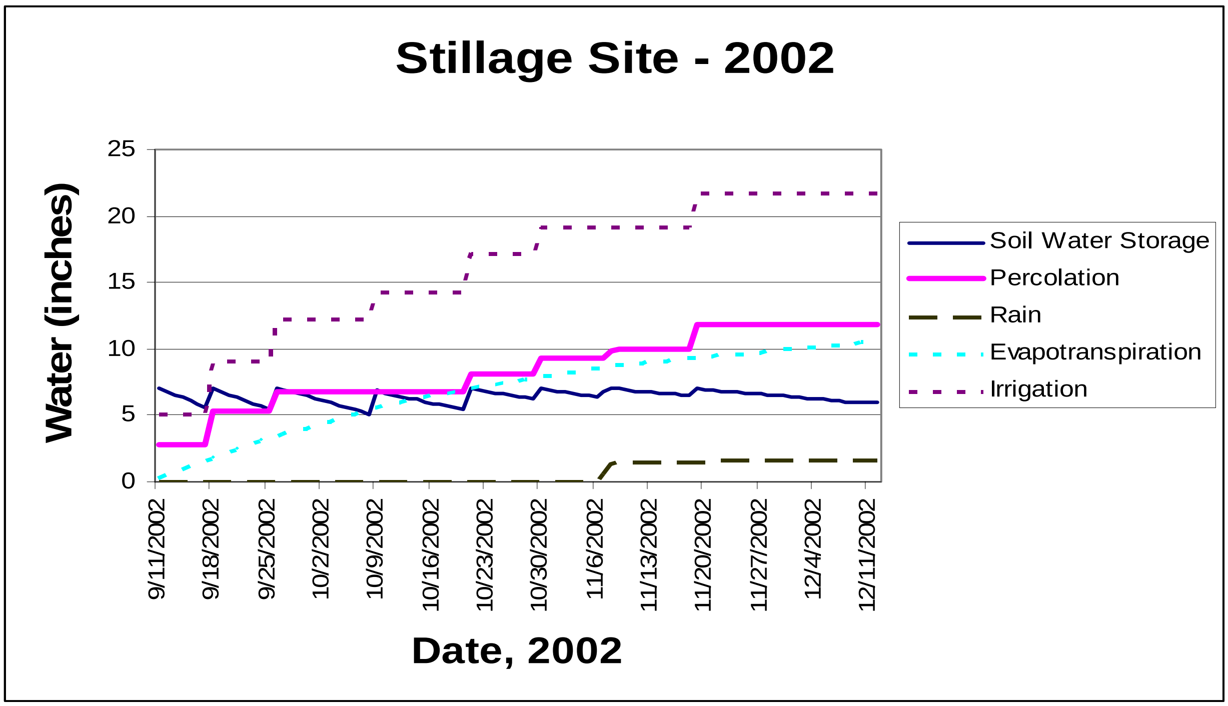
Land Application Study
Test Basins

K/J 020112.01
AUGUST 2004

FIGURE 3

WI FIGURE 3





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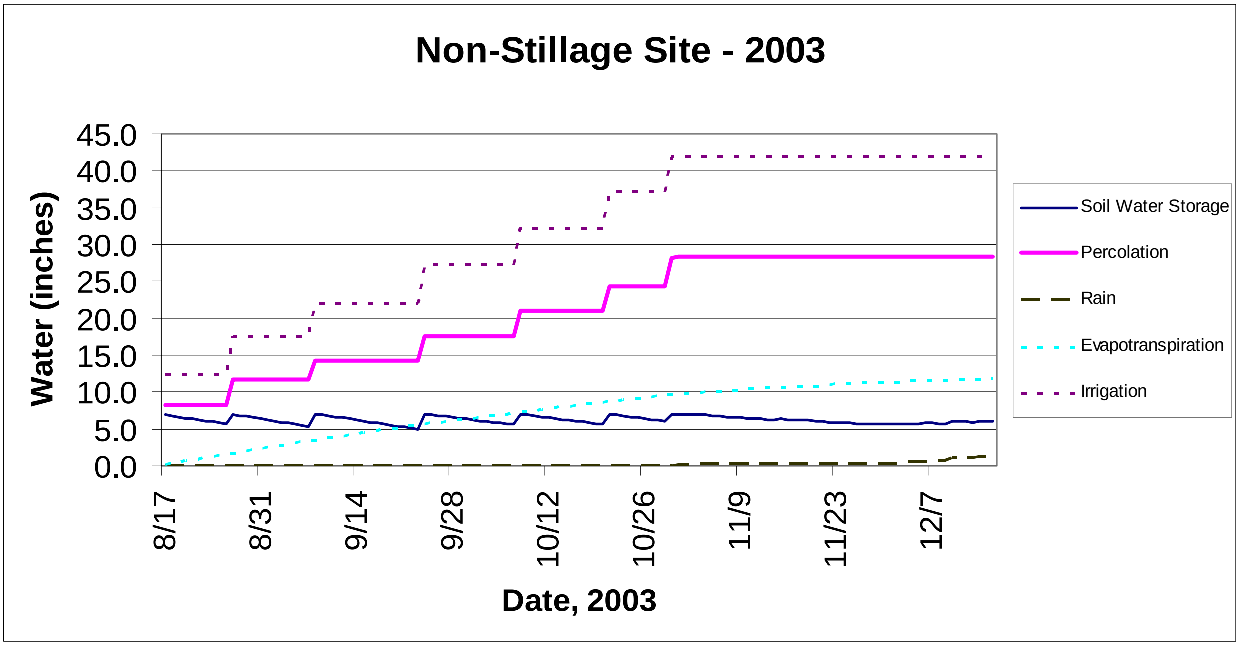
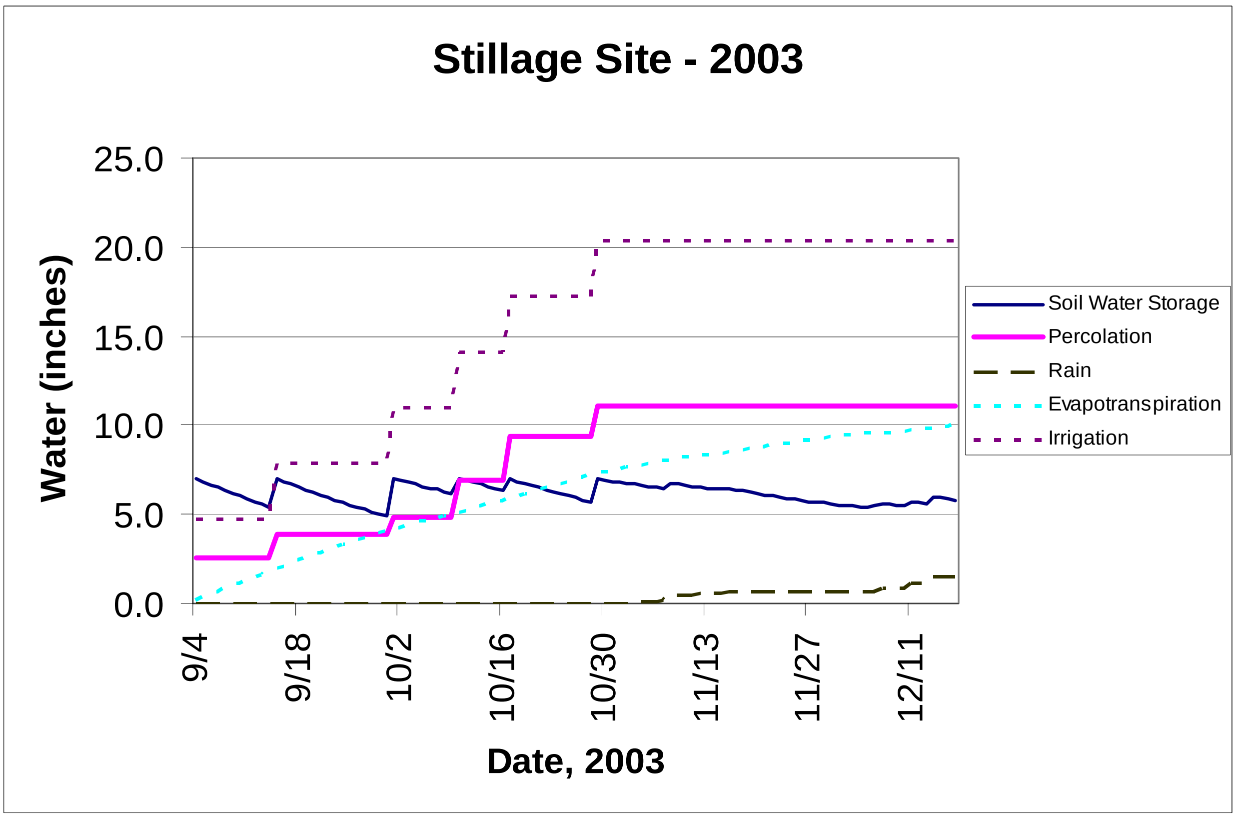
2002 Test Basin Soil Water Balance

K/J 020112.01
AUGUST 2004
FIGURE 4





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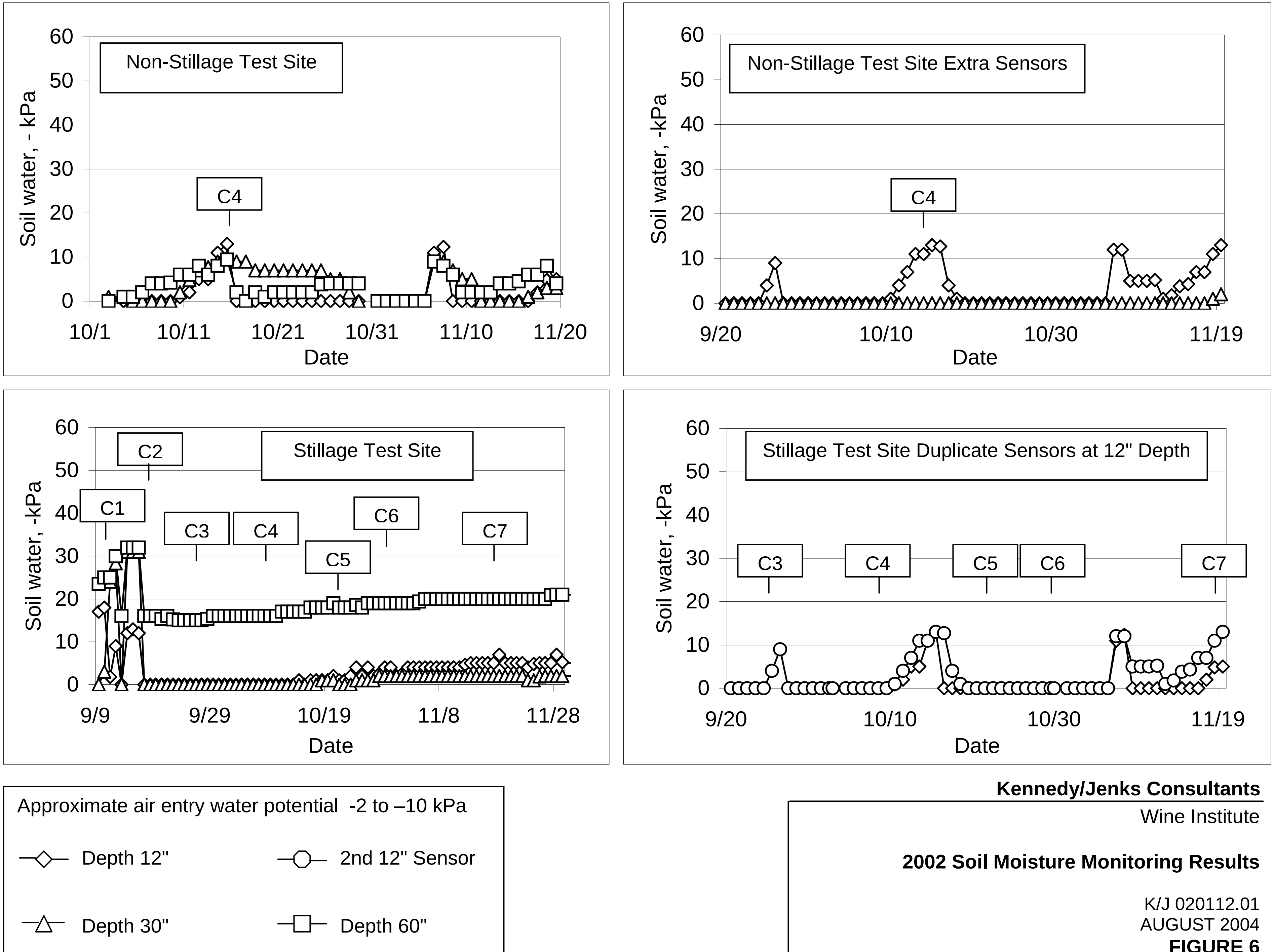
2003 Test Basin Soil Water Balance

K/J 020112.01
AUGUST 2004
FIGURE 5



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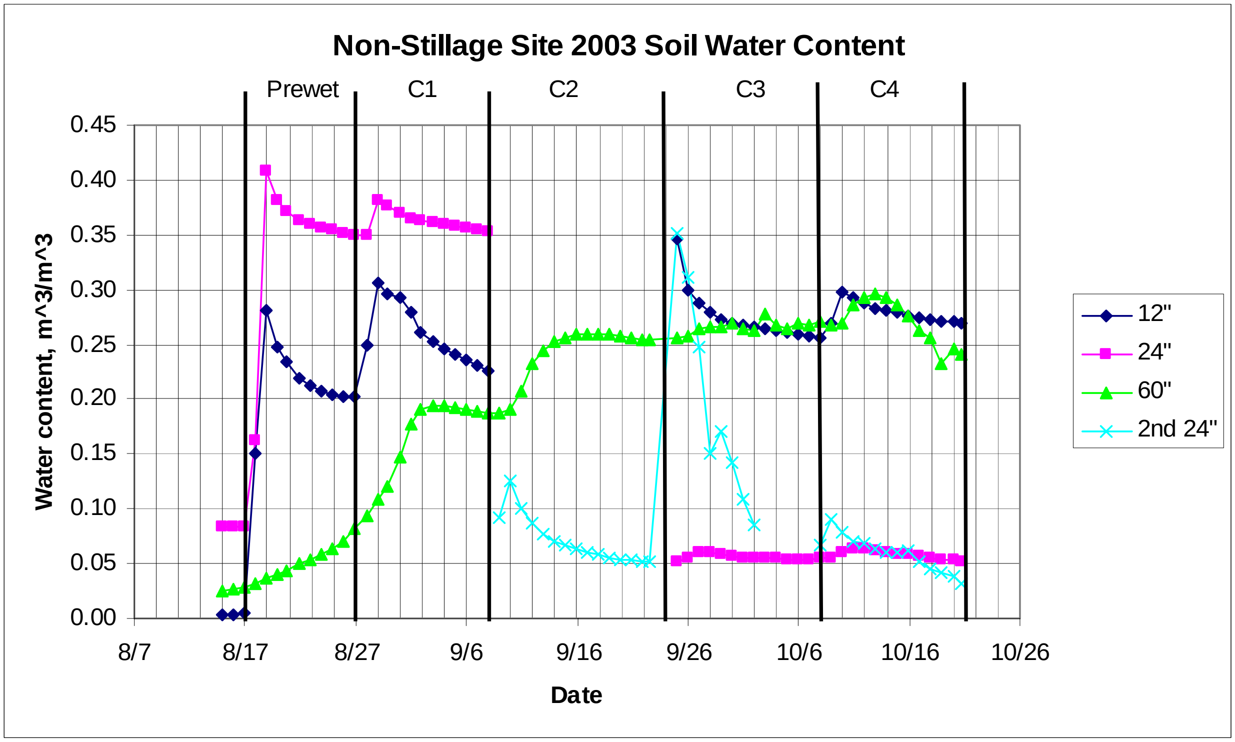
2002 Soil Moisture Monitoring Results

K/J 020112.01
AUGUST 2004
FIGURE 6



Non-Stillage Site Summary

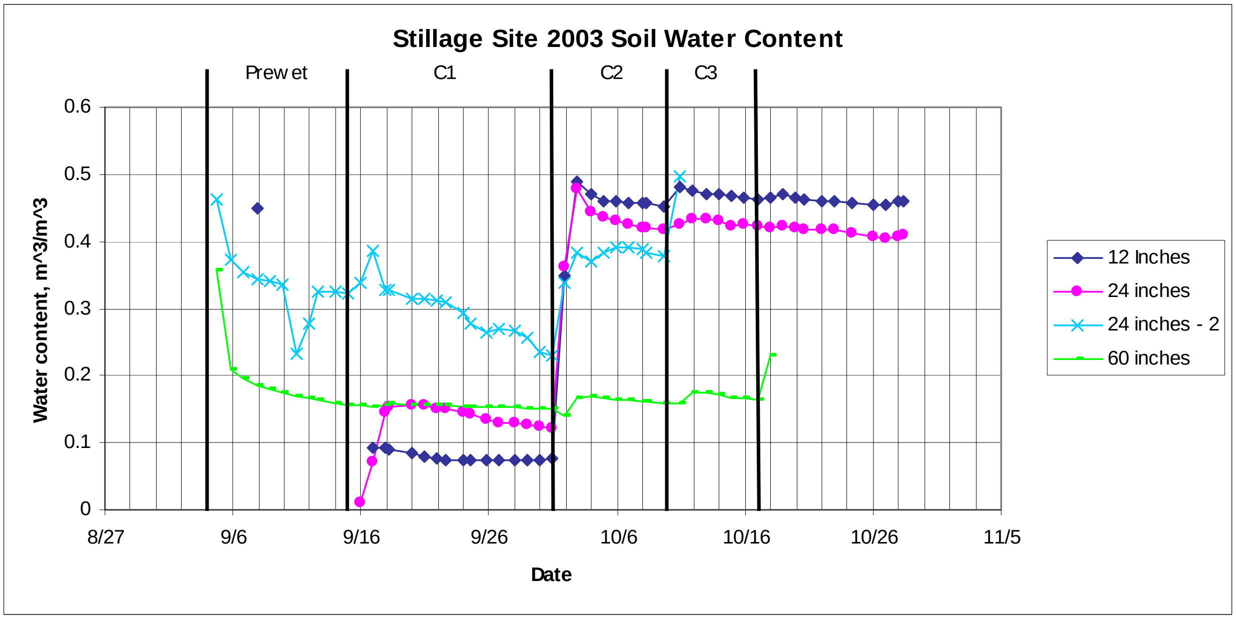
Cycle	Date	Soil moisture change, % volume 12"	24"	24"-2	60"	Approx. drying time, days	Evaporation inches
PreWet	8/17/03	0.08	0.06			9	1.4
C1	8/27/03	0.09	0.04			12	1.2
C2	9/8/03			0.08		13	1.4
C3	9/24/03	0.09		0.29		13	1.0
C4	10/8/03	0.03		0.06		13	1.2
	10/21/03						1.02

Kennedy/Jenks Consultants

Wine Institute

2003 Soil Moisture Monitoring Results – Non-Stillage Site

K/J 020112.01
AUGUST 2004
FIGURE 7



Stillage Site Summary

Cycle	Date	Soil moisture change, m^3/m^3 12"	24"	24"-2	60"	Approx. drying time, days	Evaporation inches
PreWet	9/4/03			0.14	0.2	8	1.6
C1	9/15/03		0.03	0.16		15	1.5
C2	10/1/03	0.04	0.06			7	0.6
C3	10/10/03	0.02	0.01			7	0.5
C4	10/17/03						1.4

Basic Soils Data Map	Name	AWC* est. inches	Est. water to remove, inches	Days to remove soil water Aug	Sep	Oct	Nov
Aoa	Atwater loamy sand	5.0	1.3	5	7	10	19
Ara	Atwater sandy loam	6.6	1.5	6	8	12	21
Dha	Delhi loamy sand	5.0	1.3	5	7	10	19
Hm	Hanford fine sandy loam	7.8	1.7	7	9	13	24
Ra	Ramona sandy loam	6.6	1.5	6	8	12	21
Rc	Ramona loam	11.9	2.5	10	13	19	36
	Average	7.2	1.6	7	9	13	23

* AWC – Available Water Capacity in 5 feet of soil.

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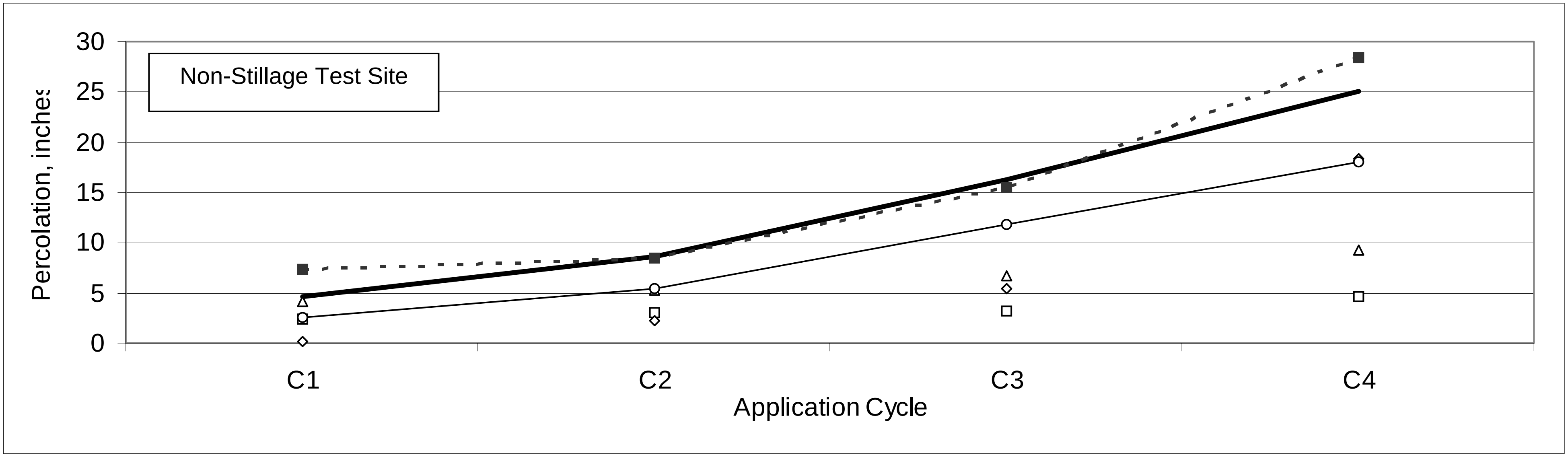
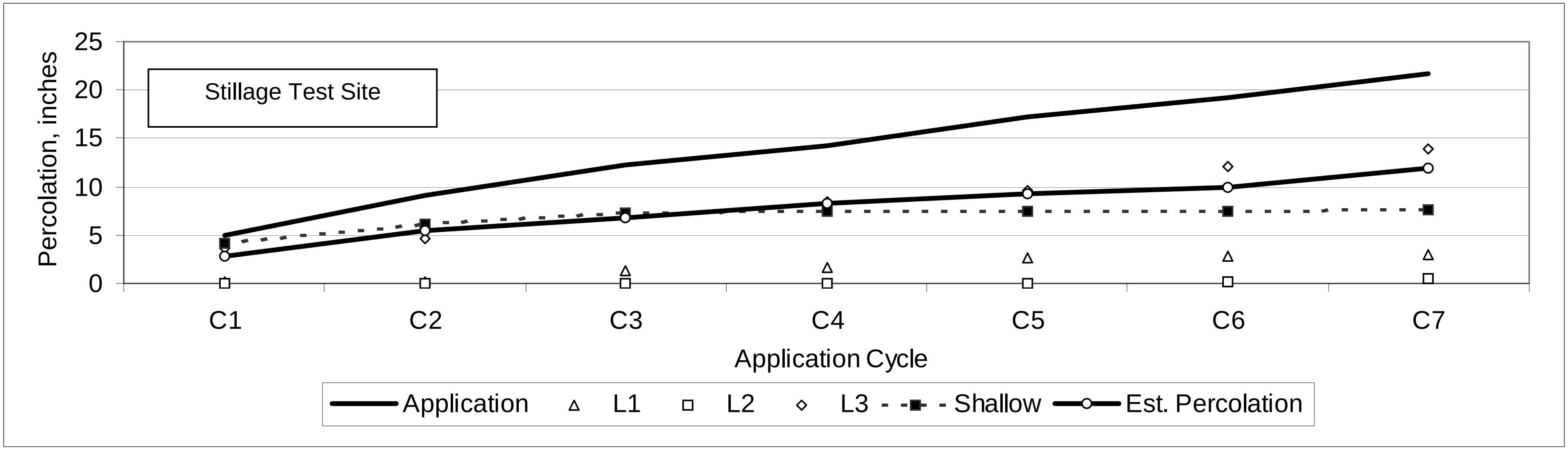
Wine Institute

2003 Soil Moisture Monitoring Results – Stillage Site

K/J 020112.01
AUGUST 2004
FIGURE 8





Kennedy/Jenks Consultants

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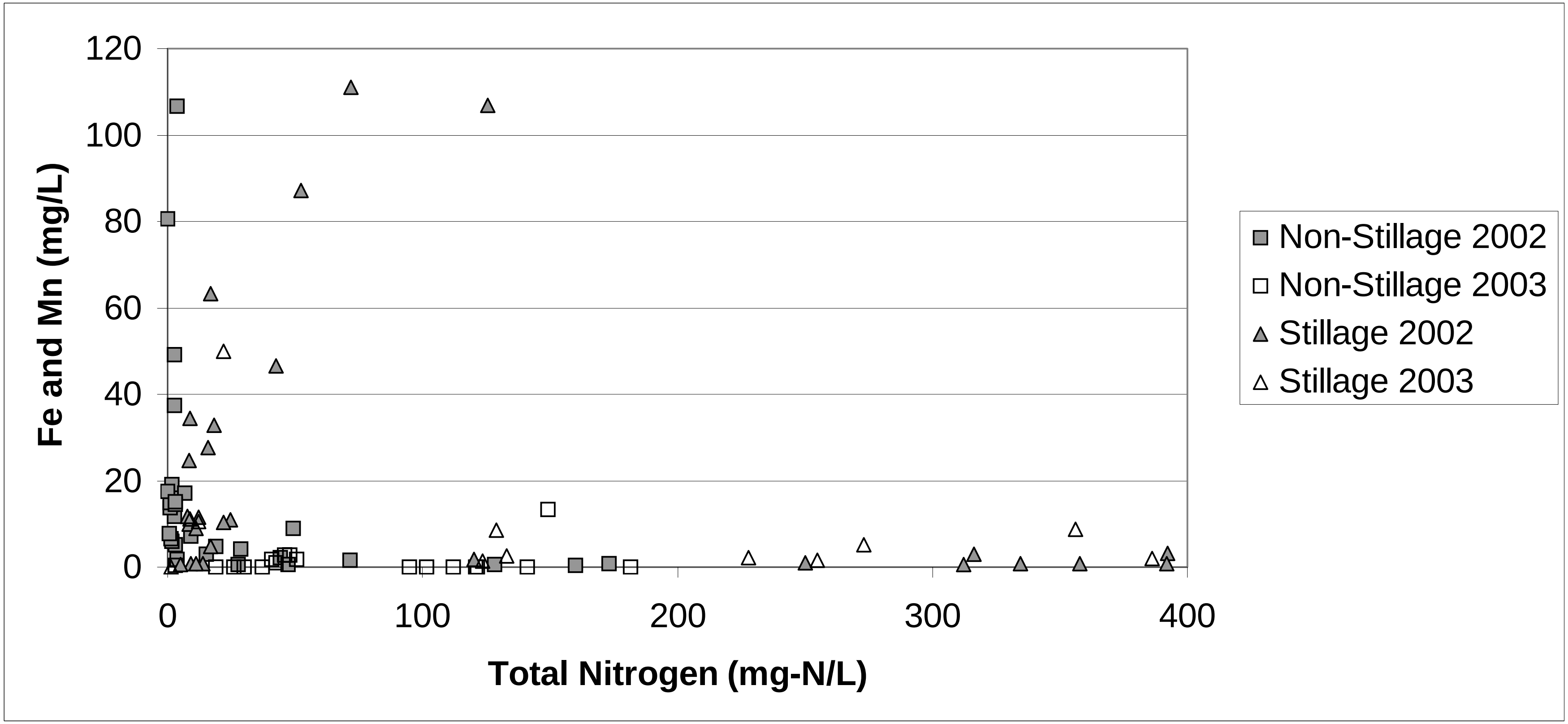
Spatial Variability of Applied Process Water

K/J 020112.01
AUGUST 2004
FIGURE 9



Kennedy/Jenks Consultants

Wine Institute

Relationship Between Total Nitrogen & Iron Plus Manganese

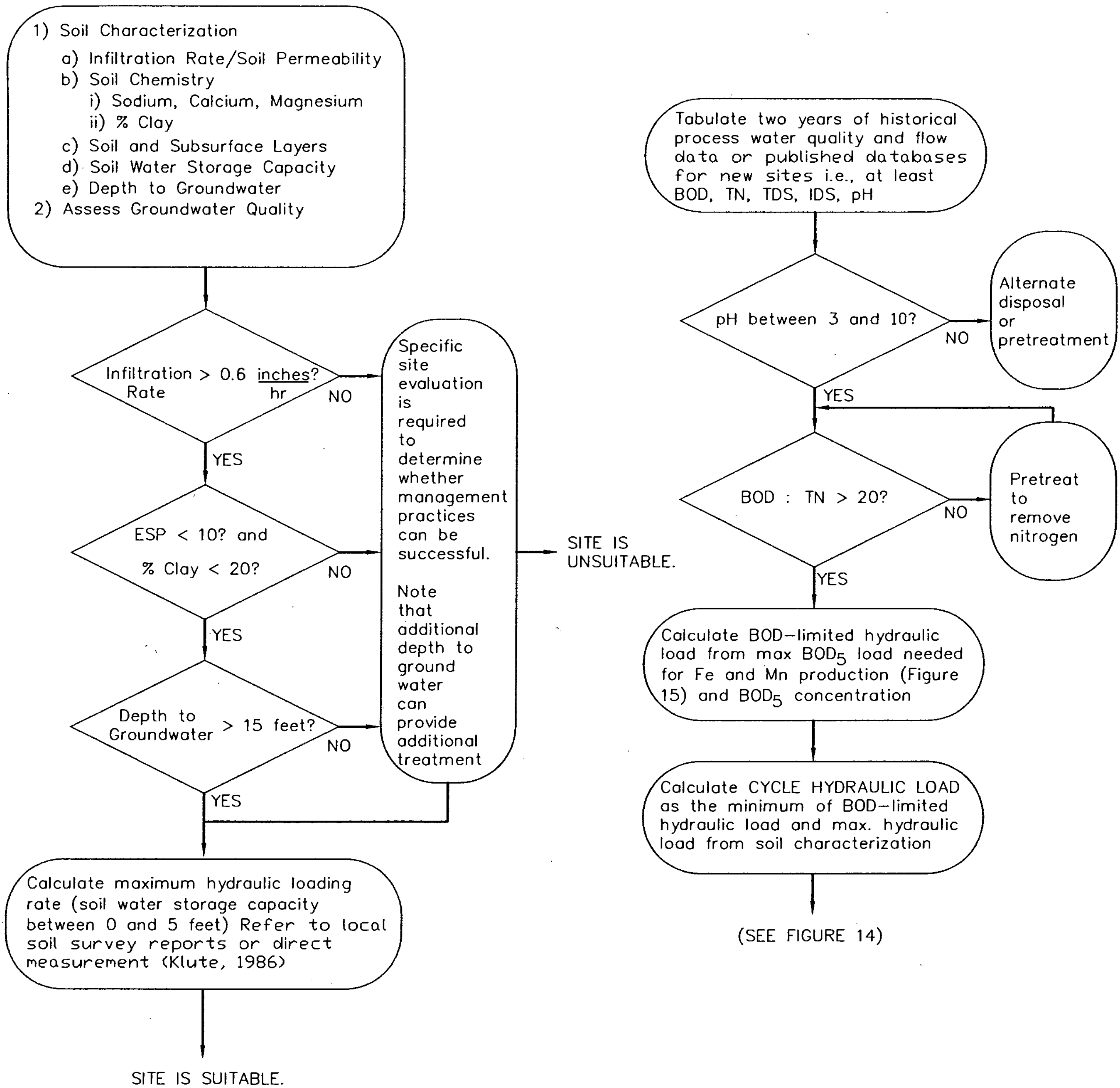
K/J 020112.01

AUGUST 2004

FIGURE 10

CHARACTERIZATION FOR INITIAL SITE SELECTION

LIMITING CONSTITUENT ANALYSIS



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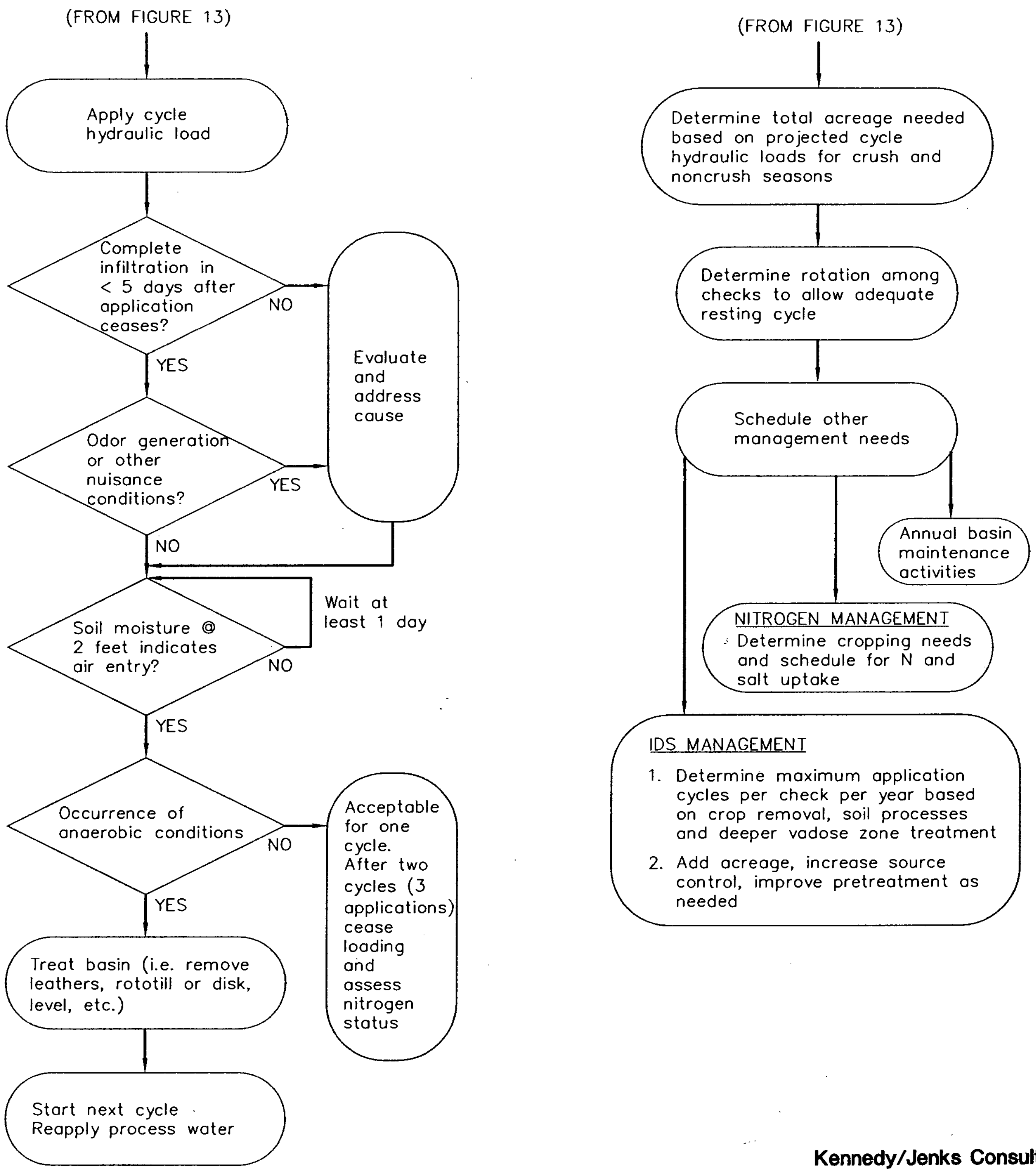
Land Application Guidelines Flowchart

K/J 020112.01
AUGUST 2004

FIGURE 13

PROCESS WATER APPLICATION MANAGEMENT

PROGRAM MANAGEMENT



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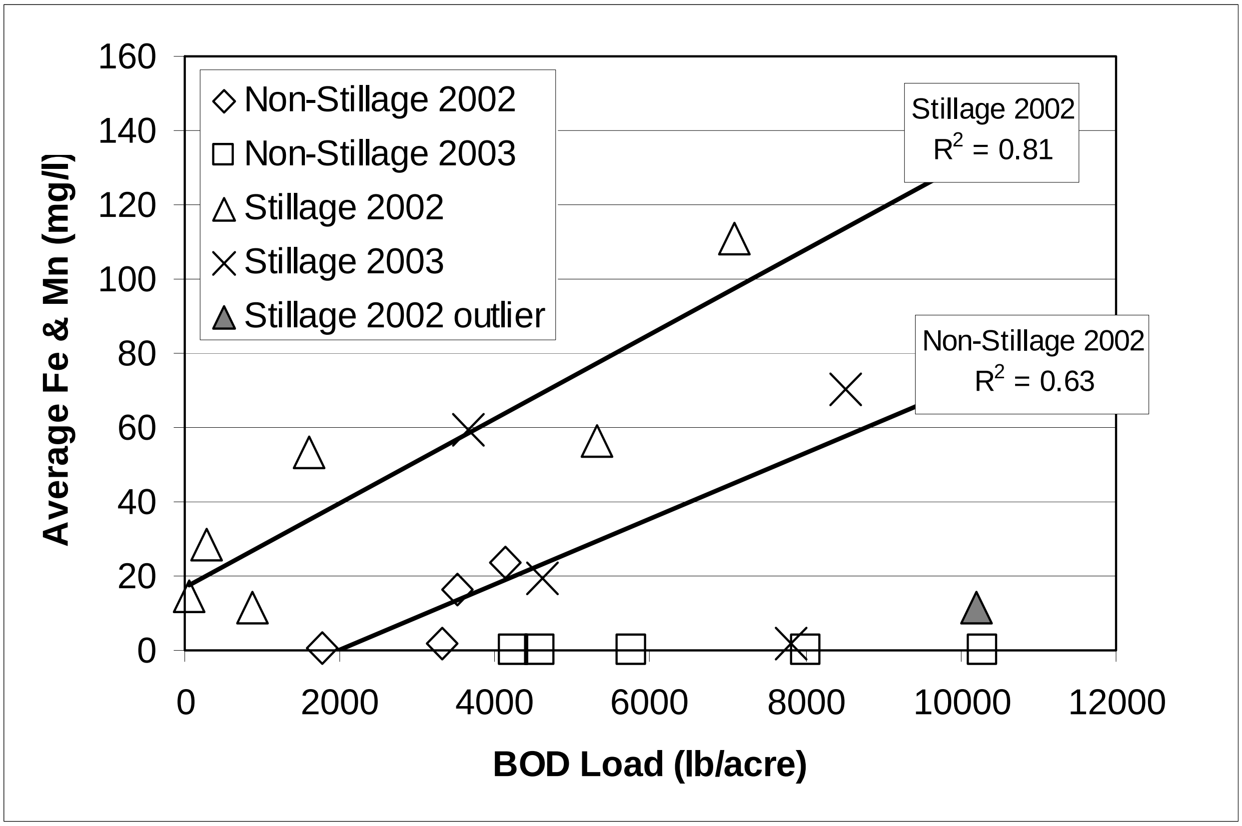
Land Application Guidelines Flowchart (continued)

K/J 020112.01
AUGUST 2004

FIGURE 14



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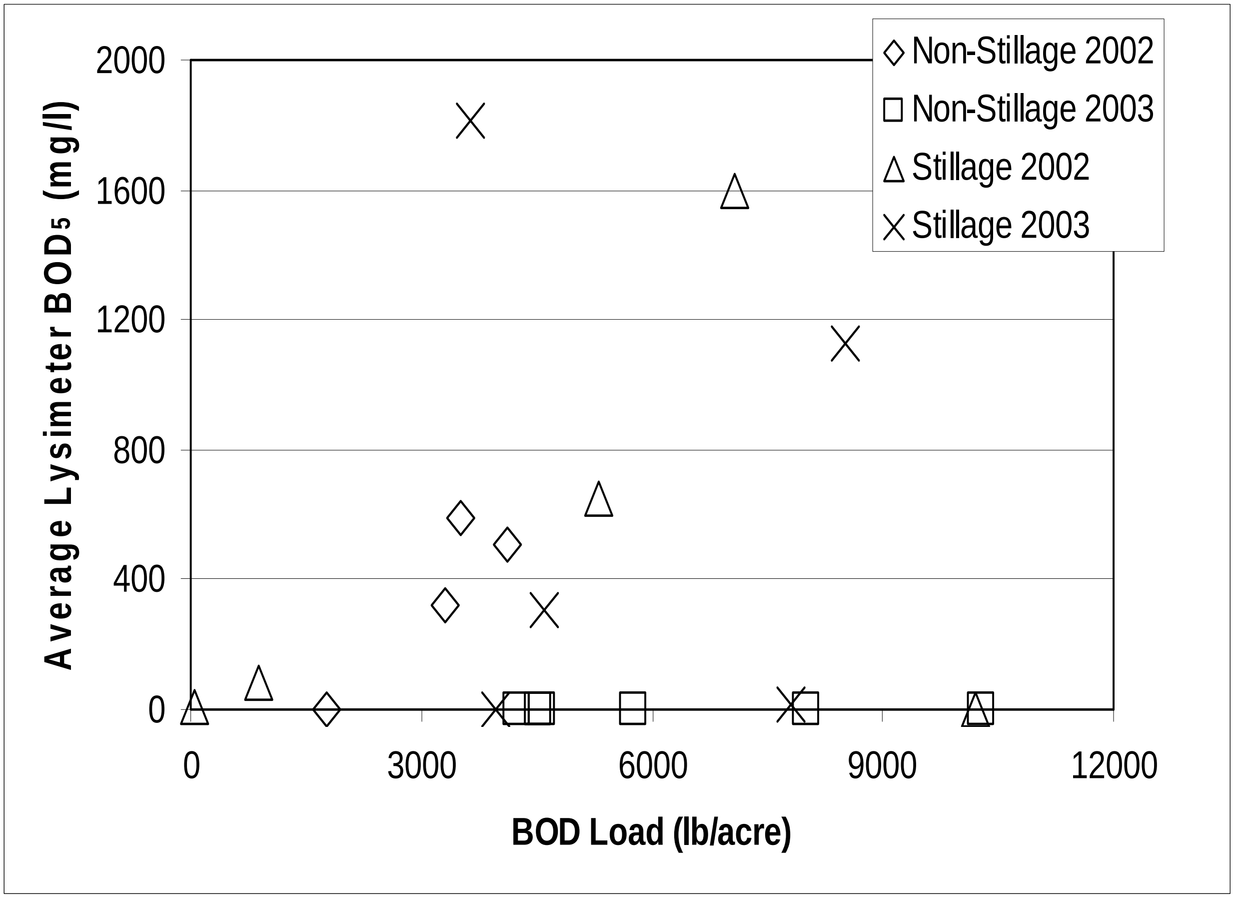
Relationship Between BOD_5 Load and Soluble (Iron plus Manganese) Production

K/J 020112.01
AUGUST 2004
FIGURE 15



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Relationship Between BOD_5 Load and Percolate BOD_5 Concentration

K/J 020112.01
AUGUST 2004
FIGURE 16

Appendix A

27 August 2002 Kennedy/Jenks Work Plan and Review Letters

Work Plan

Kennedy/Jenks Consultants

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San Francisco, California 94107
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415-896-0999 (Fax)

Work Plan for Investigation of Land Application of Stillage and Non-Stillage Process Water

27 August 2002

Prepared for

Wine Institute
425 Market Street, Suite 1000
San Francisco, California 94105

K/J Project No. 020112.00

Table of Contents

List of Tables

Section 1: Background and Objectives

1.1 Introduction

The Wine Institute seeks to update the 1980's application rates and management practices for land application of winery wastewater (Metcalf & Eddy, 1980). E. & J. Gallo Winery in Fresno and Bronco Winery in Ceres have been chosen by the Wine Institute to participate in a field study investigating the efficiency of land application to treat winery stillage and non-stillage process waters. The study will initially be conducted during crush season 2002 (approximately August through November) depending on the operation of each winery.

The proposed basic test procedure is as follows:

- Test basins will be constructed at the two study sites and will include buried pan lysimeters to collect percolate within and below the soil profile, soil moisture and gas measuring devices, and an area for soil sampling. Winery/stillage process water will be applied to the test basins at known constituent loading rates. This application, followed by infiltration and a resting period, constitutes an application cycle. Soil and soil water measurements will be used to establish treatment efficiency within and below the treatment basins.
- A minimum of three loading rates will be tested as part of this study. The proposed test schedule allows sufficient time to add additional tests (either an additional loading rate or a change in rest cycle duration). Treated process water will be collected in the lysimeters during the loading/infiltration part of the treatment cycle. Samples will be analyzed for water quality parameters that address Biochemical Oxygen Demand (BOD) removal, nitrogen transformations, and inorganic salts management. Soil sampling will be performed during the drying cycles and pore water within the soils will be analyzed.
- The basic statistical method for evaluating and proving/disproving the hypothesis will be regression analysis of a dataset consisting of measured constituent reduction at several loading rates covering the common range of application rates.

1.2 Objectives and Approach

The goal of this project is to update the 1980's application rates and management practices for land application of winery wastewater (Metcalf & Eddy, 1980). In doing so, individual constituent loading rates will be determined and these may replace hydraulic loading rates currently in the guidelines. A field study will be conducted at two sites using conventional applied research methods to provide a dataset to support proposed changes.

Field study hypothesis: Land application is a viable process for the treatment of the winery and stillage process waters. There are optimum values of application rates and cycle times that can be determined based on process water type and application basin conditions. Optimization should address groundwater protection, prevention of nuisance odors, and management efficiency.

The field studies proposed will be conducted in a manner conducive to statistical analysis. In statistical terms, the hypothesis to be tested is: ***Significant differences in BOD and nitrogen reduction exist at differing wastewater loading rates.***

The objectives of this work plan are:

- Outline a field study to collect data on constituent removal efficiency for a range of BOD, nitrogen (N), and Total Dissolved Solids (TDS) loading rates.
- Provide details addressing experimental design, equipment needs, laboratory analyses, and statistical evaluation of results.

1.3 Available Site Characterization Data

Kennedy/Jenks Consultants has visited each of the two study sites. During these visits, historical data regarding process water generation and quality, and operational procedures were obtained to the extent possible. The stillage process water at the Gallo site is separated from other waste streams whereas the process water at the Bronco site is the combination of all processes, excepting sewage generation, occurring during operation. Where complete data sets were not available, requests for information have been submitted.

Table 1 below summarizes information important to the experimental design. Additional information has been obtained or requested and these data will be used to complete the final report.

Table 1: Field Study Site Summary Characteristics

	E. & J. Gallo Winery	Bronco Winery
Process Water:		
Winery process water to be studied	Stillage	Non-stillage
Average BOD_5 (min.-max.) mg/l	5,660 (3 – 15,100)	784 (52 – 4,200)
Average total N (min.-max.) mg/l	430 (10 – 1540)	23 (2 – 92)
Average TDS (min.- max.) mg/l	8,845 (272 – 26,400)	1,100 (240 – 3,300)
Application Soil:		
Soil type	Primarily Atwater sandy loam	Dinuba or Hanford sandy loam or Tujunga loamy sand
Typical Application Operation:		
Application depth (inches)	3.7 maximum	Variable
Cycle duration	7 day minimum	Variable
Application/Infiltration period	24 hours maximum	Variable
Basin surface treatment	6 inch rototilling between cycles; deep ripping when needed to maintain infiltration	Disking when needed to maintain infiltration

A limited investigation will be performed on the regional groundwater hydrology and quality. Pertinent existing local monitoring and production well data will be collected and analyzed. Up-gradient as well as down-gradient wells will be included in the investigation.

Section 2: Proposed Work Plan

2.1 Basic Principles of Spreading Basin Treatment

The below table (Table 2) summarizes the study procedures and the anticipated mechanisms of constituent removal from the process water. Also listed is the measurement of time, flow rate, water volume, and other parameters associated with the land application of process water. Finally, the anticipated results at each stage of the study of land application are discussed.

Table 2: Basic Principles of Spreading Basin Treatment

Cycle	Processes	Measurements	Anticipated Results
Loading/ Infiltration	Apply water with known BOD, N, salts	Volume applied (flow), observed rate of infiltration, odor, sample shallow lysimeter	Quantify loading for each constituent; infiltration within 24 hours, minimal odor, reduction in BOD and organic salts almost immediately in lysimeter sample, some nitrogen conversion from organic to ammonia.
Drainage	Process water flow through soil until drainage ceases and the soil is at "field capacity"	Time to cessation of drainage; rate of drainage with time; sample deep lysimeters	Nitrogen conversion to ammonia; BOD consumed (if not, measure Fe, Mn); assess TDS, possibly change in ionic make-up.
Resting/ Drying	BOD eliminated, ammonia-N conversion to nitrate, soil is re-aerated	Soil sampling at the end of the rest cycle (a study of rate of nitrification can be conducted on a one-time basis to determine whether shorter or longer rest cycles are appropriate)	Almost compete nitrification; complete BOD removal, check whether Iron (Fe), Manganese (Mn) are present (indicating too much BOD), assess changes in TDS and ionic make-up.
Loading	Second loading cycle provides BOD for denitrification of nitrate-N	Same as first loading cycle	Same as first loading cycle, plus measurement of both denitrification and mineralization of organic N.

2.2 Test Basin Design

Test basins will be constructed at each study site by adding berms within existing application "checks" to obtain a smaller, more controllable test basin. Basin size will be determined by existing check size, location, soil properties, process water distribution system flow rates and existing control valves.

Basins will be approximately 300 to 1,000 square feet and berms will be installed that will permit at least 12 inches of process water to be applied to the test basin. At the Gallo site, a test basin will be constructed within a check in Irrigation Area 11. A tentative location for the test basin at the Bronco site has been chosen and will be finalized soon.

2.3 Instrumentation Installation Procedures

Test basins will be equipped with instrumentation that will allow the gathering of samples and data to quantify treatment efficacy. This instrumentation will consist of flow meters to measure total application (where necessary), pan lysimeters with ancillary instrumentation, soil moisture tension measuring devices, soil gas probes, and data loggers. Key design criteria are discussed below.

The surrounding basin area will be loaded in a manner similar to that of the test plots. Initial soil sampling will be conducted in these buffer areas. Additionally, nearest weather station data will be collected to determine the effects of atmospheric conditions including rainfall and potential evapotranspiration.

A. Lysimeter installation

1. Four lysimeters will be placed at each site: three at 4 to 5 feet and one at 1 foot below basin surface. Lysimeters will be placed within the test basin to assure equal application to each lysimeter. The surface lysimeter will be used to evaluate percentage of treatment (especially for BOD) that occurs in the surface soil. The deep lysimeters will measure full soil treatment. These are installed in triplicate so that treatment differences among soil loading rates can be evaluated statistically.

2. Soil core monoliths of 10 to 12 inches diameter will be collected from an adjacent area of the site that contains similar soils. These will be attached to the basin lysimeter to create "undisturbed" soil conditions in the measurement column. The apparatus will be installed in 10-12 inch auger holes in the test basin. The lysimeters will be used to:

   i. Measure total volume of percolate,

   ii. Store the entire percolate volume for extraction and analysis, and

   iii. Measure soil moisture tension.

3. Lysimeter specifications: modified 8" GroVision Deep Drainage Monitor Lysimeters with electronic data storage will be used (see Gee et al., 2000 for a technical description).

4. It is anticipated that lysimeters will cease drainage within approximately 48 hours of loading. Drainage timing will be corroborated using field results. Soil water content in the lysimeters will be monitored during the rest cycle to assure that similar drainage and aeration occur in the adjacent field and the lysimeter apparatus.

5. Lysimeters and ancillary equipment will be installed 6 inches below ground surface to allow basin surface treatment between cycles. Sensitive components of the lysimeters and data recording devices will either be buried or constructed so they can be temporarily removed for tillage.

B. Soil moisture tension measuring devices (Watermark) will be placed in the test basin at 1,2.5, 4, and 5 foot depths. This equipment will track the flow of water in the soil column.

C. Soil gas probes will be inserted at 1, 2.5, and 5 foot depths within the test basin. Periodic measurements of soil gas oxygen content will be performed during the drying cycles.

D. Soil sampling area

   1. A portion of the test basin will be left undisturbed for soil sampling. Soil sampling will initially be scheduled at the end of the rest cycle to assess the completeness of treatment (BOD removal, conversion of nitrogen to the nitrate form, storage of salts in the root zone).

E. Process water conveyance and control

   1. Both sites have conveyance to the test site locations.

   2. Pumping will need to be performed at a maximum rate of 70 gal/min.

   3. In-field metering of flow and volume will be required.

2.4 Experimental Design

Experiments will be conducted at the field sites once instrumentation has been installed and tested. Experiments will consist of applying water quality constituent loads to the test basin and subsequent measurement, sampling and analysis. Once optimum constituent loading has been determined, optimum resting period duration will be investigated. Below are the pertinent experimental design criteria:

A. Treatment cycle duration

   1. Application and infiltration period should be a maximum of 24 hours unless odors are not generated.

   2. Resting period will initially be chosen from the current application guidelines (6 days during summer, 9 days during fall). Soil sampling and analysis results will determine if application/resting periods are sufficient for constituent removal.

B. A minimum of two treatment cycles at each loading rate will be performed. Three will be performed if time and resources are available. Tests will proceed from the lowest loading rate to the highest. This method of experimental replication is proposed to take advantage of a well-equipped test plot. Additional soil sampling from the irrigated borders will be used to assess whether the results of the sequential experiment are representative.

C. BOD_5, total N (organic N, ammonia, nitrate, and nitrate), and TDS levels in the process water will be assumed from historical data and confirmed by process water analysis during experimentation. Initially, loading rates will be based on BOD_5 levels. After treatment efficiency is observed during the first several experiments, other constituents may be used to establish hydraulic loading volumes.

1. BOD_5 and N application levels will increase from first cycle to last in an attempt to determine the maximum load that land application can successfully treat. Below is a table (Table 3) of initial potential cycle loading rates. Once the initial seven experiments have been conducted, other constituent loading rates or repeated rates will be used to obtain more information.

Table 3: Proposed Constituent Loading Rates Per Cycle

Cycle/week	BOD_5 (lb/acre/day)	N (lb/acre/day)
1	200	6
2	200	6
3	200	6
4	600	18
5	600	18
6	1200	36
7	1200	36

2. Success will be determined by: a) the removal of BOD_5; b) absence of nitrate-N above 10 mg/l; c) moderate levels of soil nitrogen storage; d) absence of iron and manganese (related to BOD loading); e) salt status; and f) amount of subsoil percolation.

2.5 Sampling Procedures

A. Water sampling

1. Process water flow and volume will be measured using in-field flow meters. Samples will be collected from the discharge port during loading to establish actual loading rates for BOD, nitrogen, and TDS.

2. Volume and flow of percolate will be measured by lysimeter data logger. Sample will be extracted when flow rate decreases below 10% of maximum cycle flow.

3. Samples will be stored in amber bottles at 4°C until transported to Dellavalle Laboratories. Samples will be shipped within 24 hours of sampling.

B. Soil Moisture Tension Sampling

1. Data loggers will record soil moisture tension at five minute intervals and accumulated data will be down loaded periodically.

C. Soil sampling

1. Soil sampling will initially be conducted at the end of the resting portion of the cycle at six depths (0-6, 6-12, 12-24, 24-36, 36-48, and 48-60 inches).

2. Results of the soil analysis will be used to evaluate sampling depths. Additional sampling depths may be added.

3. Once treatment depths have been identified, soil sampling will be used to determine optimum resting cycle length.

D. Soil Gas Sampling

1. Soil gas sampling will be performed at three depths (1, 2.5, and 5 feet)

2. Oxygen concentration will be measured in the soil gas samples in the field using an oxygen probe, an oxygen meter, and an air sampling pump.

2.6 Analytical Matrix

The progress of the experimentation will be determined by the measurement of certain parameters within process water and soil samples that will indicate the efficiency of land application to treat target constituents in the process water.

A. Samples will be sent to Dellavalle Laboratory, Inc. for analysis. These analyses are presented in Table 4 below.

B. Not all samples will be analyzed for all parameters listed in the table. Initially, the complete analytical protocol will be performed on each sample. As the cycles progress and more is known about constituent removal and the duration of the crush season, select analyses will be chosen for select samples.

Table 4: Water Quality Parameters to be Measured in Samples Collected

Analysis	Parameter Measured
Water samples:	
Standard mineral	NH_4^+, NO_3^-, Na^+, Ca^{2+}, Mg^{2+}, Total Fe, Mn, SO_4^{2-}, K^+, HCO_3^-, TDS, EC, pH, Hardness, SiO_2, B, P, Alkalinity
BOD_5	BOD_5
TOC/DOC	DOC
VDS	VDS, FDS
Nitrite	NO_2^-
Soil:	
TOC/DOC	DOC
VDS	VDS, FDS
Nitrite	NO_2^-
Standard mineral (total or individual as needed)	NH_4^+, NO_3^-, Na^+, Ca^{2+}, Mg^{2+}, Total Fe, Mn, SO_4^{2-}, K^+, HCO_3^-, TDS, EC, pH, Hardness, SiO_2, B, P, Alkalinity

Notes:

NH_4^+ – Ammonium ion
NO_3^- – Nitrate ion
Na^+ – Sodium ion
Ca^{2+} – Calcium ion
Mg^{2+} – Magnesium ion
Total Fe – Total iron
Mn – Manganese
SO_4^{2-} – Sulfate ion

K^+ – Potassium ion
HCO_3^- – Bicarbonate ion
TDS – Total dissolved solids
EC – Electric conductivity
SiO_2 – Silicon dioxide
B – Boron
P – Phosphorus

BOD_5 – Biochemical oxygen demand after 5 days
TOC – Total organic carbon
DOC – Dissolved organic carbon
VDS – Volatile dissolved solids
FDS – Fixed dissolved solids
NO_2^- – Nitrite

2.7 Data Analysis and Interpretation

A. Electronic data formatting will be coordinated with Dellavalle Laboratories to assure fast incorporation of results into a database. Periodic review of data will allow analytical and experimental flexibility. It is anticipated that results from the previous test cycle will be available before the second test is initiated (within one week).

B. Dellavalle Laboratories will provide analytical Quality Assurance/Quality Control (QA/QC) in the form of detection and reporting limits, coefficients of variance for each analysis and select experimental sample triplicate analysis results.

C. Triplicate lysimeters will be placed at each site so experimental variation can be observed.

2.8 Report Preparation

Draft and final Operational Guidelines will be prepared following completion of the activities described in this work plan.

References

Crites, R.W., S.C. Reed, and R.K. Bastian. 2000. Land Treatment Systems for Municipal and Industrial Wastes. McGraw-Hill.

Gee, G.W., A.L. Ward, T. Caldwell, and J. Ritter. 2000. A Simple water flux meter for coarse soils. Agronomy Abstracts: 218. Amer. Soc. Agron. Madison, WI.

Metcalf & Eddy Engineers. 1980. Land Application of Stillage Waste: Odor Control and Environmental Effects. Report prepared for the Wine Institute.

Miller, Robert O., et al. 1998. Soil and plant analytical methods. Western States Laboratory Proficiency Testing Program-Version 4.10.

RWQCB's Comments on Work Plan

California Regional Water Quality Control Board
Central Valley Region
Robert Schneider, Chair

Winston H. Hickox
Secretary for Environmental Protection

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3614 East Ashlan Avenue, Fresno, California 93726
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Gray Davis
Governor

28 August 2002

Mr. Robert Chrobak
Kennedy/Jenks Consultants
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San Francisco, CA 93107

COMMENTS ON WINE INSTITUTE WORK PLAN

I reviewed *Work Plan for Investigation of Land Application of Stillage and Non-Stillage Process Water* (Work Plan), dated 27 August 2002, and offer the following comments and suggestions.

Due to the limited nature of the experiment, it is doubtful that the results will be sufficiently conclusive to meet the work plan's goal, "update the 1980s application rates and management practices for land application of winery wastewater (Metcalf & Eddy 1980)." The field study hypothesis is "Land application is a viable process for the treatment of winery and stillage process waters." For statistical analysis purposes, the field study hypothesis becomes "Significant differences in BOD and nitrogen reduction exist at different wastewater loading rates." I recommend you utilize null hypotheses for statistical analyses. There are several that can be tested, including

- BOD (or N) removal is not correlated with organic loading rate
- BOD (or N) removal is not correlated with hydraulic loading rate
- Lower BOD (or N) loadings are correlated with higher removal rates
- Lower BOD loadings are correlated with higher re-aeration rates
- Higher BOD loadings are correlated with lower re-aeration rates
- Lower BOD loadings are correlated with lower percolate concentrations of alkalinity and hardness
- Higher BOD loadings are correlated with higher percolate concentrations of alkalinity and hardness

Other questions that can be addressed with the data include

- Study site soils have remaining assimilative capacity for continued waste loadings – evidenced by concentrations of waste constituents in percolate draining from freshwater applications not exceeding water quality objectives
- Soil buffering capacity is adequate – evidenced by pH levels approaching neutral in percolate draining from application of low pH waste

The work plan does not mention of startup with discharging fresh water onto test plots. I strongly recommend that you conduct at least two tests using fresh water (preferably Mill Ditch water, else groundwater) spaced at the same rest period as experiment runs, and perform the same suite of analytical tests on lysimeter samples as that run during the experiment.

Section 2, Basic Principles of Spreading Basin Treatment. I recommend you examine pH neutralization as a treatment parameter.

Section 2.4, Experimental Design. I recommend you describe how you propose to analyze soil sampling and analysis results to determine how application/resting periods are sufficient for constituent removal. The design has tests being performed from the lowest rate to the highest rate. Page 5 states, "Waste constituent loadings will be assumed from historical data and confirmed by process water analysis during experimentation." How are you going to characterize the waste during the course of the experiment, through time- or flow-weighted composite sampling? Are going to vary BOD loading by reducing hydraulic load, or by diluting process water to achieve the desired BOD load? If you are not going to dilute, your initial applications (low BOD loading) may be so thin you may not get sufficient lysimeter samples. If you vary hydraulic loading to achieve variable BOD loading, you will not know what variable is controlling. I recommend you keep the hydraulic loading the same and vary BOD with dilution. Alternatively, I recommend you provide a technical explanation of how you are going to determine which is the controlling variable, organic or hydraulic loading. Also, you should state somewhere what specifically you mean by loading rate (i.e., is it the average loading rate during the entire application cycle of application day(s) plus rest days, or instantaneous rate during application day(s)). Page 6 states, "Success will be determined by: a) the removal of BOD_5; b) absence of nitrate-N above 10 mg/l; c) moderate levels of soil nitrogen storage; d) absence of iron and manganese (related to BOD loading); e) salt status; and f) amount of subsoil percolation." Please elaborate on how you will determine success for each of these parameters. The nitrate-N parameter is too limited. An experiment that yields a percolate containing nitrate-N less than 10 mg/L and organic nitrogen in appreciable concentrations (i.e., significantly above natural background) cannot be considered a success.

Section 2.6, Analytical Matrix. I strongly recommend you include organic nitrogen in both water and soil analyses, and specify which constituents will require filtration prior to sample preservation.

Please call me at (559) 445-5035 if you have any questions regarding this matter.

Jo Anne Kipps

JO ANNE KIPPS
Senior Engineer
RCE No. 49278

cc: Ms. Wendy Wyels, Central Valley Regional Water Quality Control Board, Sacramento
Mr. Chris Savage, E. & J. Gallo Winery, Modesto
Mr. Robert Calvin, Canandaigua Wine Company, Madera
Mr. Wendell Lee, Wine Institute, San Francisco

CSUF's Comments on Work Plan

Date: August 30, 2002

To: The Wine Institute
Chris Savage
Ph (209) 341-7402
Email: chris.savage@ejgallo.com

From: California State University Fresno
Florence Cassel S.
Ph (559) 278-2066
Email: fcasselss@csufresno.edu

Subject: Review of the document entitled "Work Plan for Investigation of Land Application of Stillage and Non-Stillage Process Water"

The document describes the work plan of a field study that will be conducted at two wineries to determine the optimum application rates and cycle times of stillage and non-stillage process waters to land. In this study, process waters will be applied to test basins constructed at each site to maintain a controlled environment. Several loading rates will be tested with measurements of water flow, infiltration rate, and soil oxygen content. Percolate waters will be collected in lysimeters and analyzed for BOD, nitrogen, and numerous other parameters. Levels of these parameters in the soil matrix will also be determined at the end of each loading cycle. Statistical analyses of the data will be performed to evaluate the loading rates of water parameters that would maintain groundwater quality. Results of the study will be used by the Wine Institute to update the "1980's application rates and management practices for land application of winery wastewater". The proposed work plan is scientifically acceptable but the goals of the study would need to be clearly stated. Comments on the experimental design and suggestions for additional tasks and measurements are presented below, based on our understanding of the objectives.

In Table 2, oxidation –reduction potential measurements should be added to evaluate the period of soil oxygen depletion following process water applications and to determine the optimum cycles for adequate re-aeration time of the soil matrix.

Small-scale basin tests are usually recommended to estimate infiltration rates and optimum loading rates of wastewater at disposal sites. The size range of the basins chosen for this study is adequate, but the greater dimension is recommended for better representation of full-scale operational systems. Location and size of the basins should also be representative of the soil type and topography of the sites. Interpretation of the results and recommendations should then be based on those soil types only (sandy loam and loamy sand).

Number and location of lysimeters will depend on soil homogeneity, wastewater loading rates and application practices. The work plan proposes to place three lysimeters at 4-5 ft depth and one lysimeter at 1 ft depth. Given the potential variability in the field plots, it is recommended that at least three lysimeters be installed for each depth. If possible, a minimum of six lysimeters is usually suggested for statistical comparisons between loading rates. The procedures for installing the lysimeters and efforts to maintain the physical integrity of the soil columns are also important considerations in the eventual interpretation of the data. Any changes in bulk density caused by the installation procedures will significantly affect the infiltration rate and other characteristics of the soil in the lysimeters compared to the undisturbed soil. Additionally, another important factor to consider for disposal to agricultural lands for example is the variability in loading rates with the direction of flow. Loading rates at locations close to the discharge port will be higher than those at the end of the flow run. This factor is often taken into account for permit approval and should be considered in land application studies if the process water is applied at one end of the field. In that case, lysimeters would be placed along the direction of the flow at determined distances from the discharge inlet.

Table 4 could also include measurements of TKN and Cl in water and soil samples.

If not available, soil physical and chemical properties, including texture, structure, porosity, pH, organic matter, electrical conductivity, cation exchange capacity, and exchangeable sodium percentage, will need to be determined at each site (0-5 ft) before application of wastewater. These parameters are important as they affect soil hydraulic characteristics, aeration, ion retention, etc.

The quality assurance and quality control (QA/QC) plan of the study should include submission of QC standards to Delavalle Laboratories to verify the quality of their wastewater analyses. QC standards can be bought by dependable providers, such as Environmental Resource Associates (Arvada, CO). It is also important that certified laboratories be used to ensure reliability of the analyses.

In addition to regression analyses, two-tail tests will be valuable to compare medians of percolate water parameters among wastewater loading rates.

Response to RWQCB's Comments

Kennedy/Jenks Consultants

Engineers & Scientists

622 Folsom Street
San Francisco, California 94107
415-243-2150
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19 September 2002

Ms. Jo Anne Kipps, P.E.
Central Valley Region
California Regional Water Quality Control Board
3614 East Ashlan Avenue
Fresno, CA 93726

Subject: Response to Comments on your letter dated 28 August 2002
Work Plan for Investigation of Land Application of Stillage
and Non-Stillage Process Water
K/J 020112.00

Dear Ms. Kipps:

This letter provides a response to your comments made on behalf of the California Regional Water Quality Control Board, Central Valley Region (CRWQCB) in a letter dated 28 August 2002 (copy enclosed). We appreciate your review of the Work Plan for the study entitled Investigation of Land Application of Stillage and Non-Stillage Process Water being performed for the Wine Institute by Kennedy/Jenks Consultants. Some of these issues were addressed when you met with Kennedy/Jenks and Dellavalle Laboratory's staff at the Gallo study site during the installation of field instrumentation 28 August 2002.

In addition, we have enclosed a copy of an Email from Dr. Florence Cassel S. of California State University, Fresno dated 30 August 2002, and our response to the Email dated 19 September 2002 for your information.

The responses below are separated into two categories: general and specific. The general response discusses the overall experimental approach considering time and resources available whereas the specific responses directly address questions posed in your letter.

General Response – Overall Experimental Approach

The proposed Wine Institute study, like all research projects, is focused on specific areas. We selected a study design and methodology to provide the strongest dataset to evaluate field spreading basin performance in terms of constituent treatment and removal efficiency. In our planning for a study to evaluate appropriate field loading rates for winery wastewater, we assessed the potential for each of three general study designs to provide the most useful data to evaluate spreading basin land application practices. The basic designs are:

a) A statistical study of a small number of well-instrumented field plots to address treatment mechanisms and constituent removal efficiency in some detail;

b) A study of a number of field plots at multiple sites to cover a range of soil and wastewater conditions but with less detail regarding mechanisms; and

c) A more controlled (possibly column or laboratory-based) study of individual constituent loading rates to evaluate removal mechanisms individually.

Each of these experimental approaches will provide an excellent dataset to use in evaluating spreading basin management practices and updating the 1980 Metcalf & Eddy Study. Strengths and limitations of each of the approaches are compared in the following table.

Factor	(a) Small Number of Field Plots	(b) Large Number of Field Plots	(c) Column or Lab. Study
Measurement of variability among sites	Limited to two sites; one with two wastewater types	Extensive	Limited
Measurement of mechanisms in the field	Extensive	Limited	None but lab. Observations will provide some insight
Measurement of treatment mechanisms independently	Hydraulic variable not separated except by analysis	Limited but possible	Extensive but some site factors will not be part of experiment
Measurement of variability within sites	Extensive	Not likely to be addressed	Not likely to be addressed
Expense of single experimental unit	High	Low	Moderate
Statistical methods	Regression analysis to determine trends. Hydraulic load effects may be confounded with levels of other constituents	Conventional statistical design can separate site effects and constituents except for hydraulic load; regression analysis also possible	Conventional statistical design can separate constituents including hydraulic load; regression analysis also possible; site specific/field elements not represented

Design "a" provides the most advantages based on the evaluation in the table. Design "a" also has two additional advantages: the design optimizes the number of statistically-based results obtained in a single measurement season, and the experiment will evaluate both treatment mechanisms as well as field and site specific factors that affect wastewater treatment.

The two sites selected for this study also have different wastewater constituent concentrations so that the relationship of hydraulic load and constituent loading will be different between sites. This will allow our study results to address the effect of overall wastewater strength on treatment efficiency. Overall wastewater strength (in terms of BOD, nutrients, and salts) is correlated with the amount of wastewater applied during a single application. If the wastewater strength is high, the amount of wastewater applied (hydraulic load) to establish a given loading rate is lower than for wastewater with lower concentrations. This may have an effect on treatment efficiency and comparison of results from the two sites will allow an evaluation of this factor. Thus, both the effects of constituent loading and hydraulic loading will be addressed in this study.

Specific Responses to CRWQCB Staff Comments

Item 1. *Page 1. Statistical formulation of hypotheses to test.*

The CRWQCB staff mentioned a number of hypotheses that can be tested. These are more specific than the general hypothesis in the workplan but are appropriate. Our intent is to provide results of the study at two levels: a) an overall assessment of constituent reduction as a function of loading rate and b) a number of observations regarding treatment mechanisms and factors to consider or measure in applying these results at other sites. It is true that each of the level b) mechanisms and factors can be tested statistically; we will add that to our statistical analysis. We feel this is important because one of our study plan's strengths is that we will collect detailed information to assess mechanisms.

Item 2. *Page 1. "Other questions that can be addressed with the data..."*

Two additional questions to address were included in the CRWQCB staff letter. One addresses whether there is assimilative capacity remaining in study site soils. We feel that this question cannot be addressed by evaluating percolate concentrations alone; it is our view that soil assimilative capacity will be regenerated when proper load amounts and rest cycles are applied.

The second question addresses pH and buffering capacity of the soil. We appreciate mention of this topic, which is addressed below.

Item 3. *Page 1-2. Initial testing with fresh water.*

When we met at the Gallo experimental site in Fresno, we discussed this issue and agreed that this could be done during the winter by sampling lysimeters during the rainy season.

Item 4. *Page 2. pH Neutralization.*

The CRWQCB staff recommends that pH neutralization be treated as a treatment parameter. This comment addresses the need for process wastewater and soil pH measurements to assess any changes in the soil pH that might indicate effects on the soil buffering capacity. We agree that this should be included in the field study and analyses performed on our dataset. We anticipate that this dataset will demonstrate that the organic acids of the process wastewater are rapidly consumed in the BOD oxidation process near the spreading basin surface.

Item 5. *Page 2. Establishing actual constituent loading rates.*

The CRWQCB staff noted that any experiment conducted would be done using estimated loading rates. This is correct. Actual loading rate will be determined by collecting and analyzing a sample of the process wastewater actually applied. This is an approach common to almost any field experiment: the concentrations in effluent applied can't be precisely known before the hydraulic loading commences because effluent characteristics vary with time and a sample cannot be analyzed rapidly enough. In our experimental design, impacts of this uncertainty are minimized by using a statistical regression analysis that requires a range of loading rates but does not require specific values.

Item 6. *Page 2. Correlation between hydraulic loading and constituent loading.*

The CRWQCB staff noted that there will be a correlation between water applied and constituent loading at each of our sites. This observation is correct not only for our proposed sites but also for most processing facilities. At a given facility there is a general range in concentration of constituents that is characteristic of the facility's processes and practices. From a practical standpoint, hydraulic application rate must be used to vary constituent loading. By using a high strength wastewater at one site and a lower strength wastewater at a second site, we expect to gather data that challenge the existing constituent guidelines for BOD and total nitrogen and the guideline for hydraulic loading. This approach will help us to identify those conditions where constituent loadings limit application rates as well as those conditions where hydraulic loading limits application rates. Our regression analysis will provide some separation of effects on a mathematical and possibly on a mechanistic basis. As mentioned above, we feel that the benefits of our experimental design approach in measuring both treatment mechanisms and field variability are valuable to improve our understanding of land application processes.

Item 7. *Page 2. Determination of success.*

We propose to base our evaluation of successful wastewater treatment on deep lysimeter water quality. Both percentage removal and concentration of Biochemical Oxygen Demand (BOD), nitrogen species, and salts will be assessed. The lysimeter results will, in turn, be related to soil sample results because we anticipate that soil sample results will be used at other field sites to evaluate spreading basin treatment efficiency.

Item 8. *Page 2. Nitrate as a surrogate for total nitrogen.*

The CRWQCB staff commented that measurement of nitrate-N and ammonia-N is insufficient to characterize total nitrogen (the difference is organic N). We agree that, for our initial loadings, we should measure total Kjeldahl nitrogen (TKN) to evaluate organic nitrogen levels. We expect that organic nitrogen mineralization to ammonia-N or nitrate-N will occur near the soil surface. Therefore, we expect that wastewater organic nitrogen will not be detected in the deep soil or lysimeter samples. If this is corroborated by our initial measurements, we will measure TKN less frequently in subsequent experiments.

Summary

We believe that our responses to your questions should alleviate any doubts you have that the results of this study will be sufficient to meet the work plan's goal, "update the 1980s application rates and management practices for land application of winery wastewater (Metcalf & Eddy 1980)." The field study is focused on field examination of wastewater land application conditions that challenge the existing guidelines for constituent loading rates (e.g., for BOD, salts and total nitrogen) and hydraulic loading rates. Our experimental approach will provide an excellent dataset to use in evaluating spreading basin management practices and updating the 1980 Metcalf & Eddy Study. In addition, our regression analysis will provide a statistical basis for understanding the impacts of both constituent and hydraulic loading rates.

If you have additional questions regarding our responses to your comments, please feel free to contact me directly at (415) 243-2524.

Very truly yours,

KENNEDY/JENKS CONSULTANTS

Robert S. Chrobak

Robert S. Chrobak, P.E.
Project Manager

Enclosures

cc: Tom Pinkos, California Regional Water Quality Control Board, Central Valley Region, Sacramento Office
Wendy Wyels, California Regional Water Quality Control Board, Central Valley Region, Sacramento Office
Bert Van Voris, California Regional Water Quality Control Board, Central Valley Region, Fresno Office
Loren Harlow, California Regional Water Quality Control Board, Central Valley Region, Fresno Office
Wendell Lee, Wine Institute
Wine Institute Technical Committee Wastewater Working Group
Florence Cassel S., California State University, Fresno

Response to CSUF's Comments

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19 September 2002

Dr. Florence Cassel S.
Center for Irrigation Technology (CIT)
California State University, Fresno
5370 North Chestnut Avenue, M/S OF 18
Fresno, California 93740-8021

Subject: Response to Comments in your Email of 30 August 2002
Work Plan for Investigation of Land Application of Stillage
and Non-Stillage Process Water
K/J 020112.00

Dear Dr. Cassel S.:

This letter provides a response to your comments made in an Email dated 30 August 2002 regarding the Work Plan for the field experimentation proposed in the study entitled Investigation of Land Application of Stillage and Non-Stillage Process Water being performed for the Wine Institute by Kennedy/Jenks Consultants.

Kennedy/Jenks Consultants was selected to investigate the water quality and soil character transformations that occur when wine stillage and non-stillage process water is applied to application basins at two selected wineries. The Work Plan for the field experimentation portion of the work was submitted by Kennedy/Jenks Consultants to California State University at Fresno for technical review.

The responses below are separated into two categories: general and specific. The general response discusses the overall experimental approach considering time and resources available whereas the specific responses directly address questions posed in the above-mentioned Email. In addition, we have enclosed a copy of a letter from Ms. Jo Anne Kipps of the California Regional Water Quality Control Board, Central Valley Region, dated 28 August 2002, and our response to the letter dated 19 September 2002 for your information.

General Response – Overall Experimental Approach

The proposed Wine Institute study, like all research projects, is focused on specific areas. In our discussions and planning sessions to design a study to evaluate appropriate field loading rates for winery wastewater, we assessed the potential for each of three general study designs to provide appropriate data to evaluate spreading basin land application practices. The basic designs are:

a) A statistical study of a small number of well-instrumented field plots to address treatment mechanisms and constituent removal efficiency in some detail;

b) A study of a number of field plots to cover a range of soil and wastewater conditions but with less detail regarding mechanisms; and

c) A more controlled (possibly column or laboratory-based) study of individual constituent loading rates to evaluate removal mechanisms individually.

Strengths and limitations of each of these approaches are compared in the following table. Design "a" provides the most advantages based on the evaluation in the table. Design "a" also has two additional advantages: the design optimizes the number of statistically-based results obtained in a single measurement season, and the experiment will evaluate both treatment mechanisms as well as field and site specific factors that affect wastewater treatment.

Factor	(a) Small Number of Field Plots	(b) Large Number of Field Plots	(c) Column or Lab. Study
Measurement of variability among sites	Limited to two sites; one with two wastewater types	Extensive	Limited
Measurement of mechanisms in the field	Extensive	Limited	None but lab. Observations will provide some insight
Measurement of treatment mechanisms independently	Hydraulic variable not separated except by analysis	Limited but possible	Extensive but some site factors will not be part of experiment
Measurement of variability within sites	Extensive	Not likely to be addressed	Not likely to be addressed
Expense of single experimental unit	High	Low	Moderate
Statistical methods	Regression analysis to determine trends. Hydraulic load effects may be confounded with levels of other constituents	Conventional statistical design can separate site effects and constituents except for hydraulic load; regression analysis also possible	Conventional statistical design can separate constituents including hydraulic load; regression analysis also possible; site specific/field elements not represented

Specific Responses to Comments

Item 1. *Page 1. Oxidation-reduction potential measurements.*

Redox potential measurements within the soil column were initially planned as the importance of determining the presence of oxygen was recognized. After review of current field instrumentation, soil gas oxygen concentration measurements were chosen to be most applicable for this study.

Item 2. *Page 1. Small-scale basin tests.*

This is discussed in the general response section of this document. Specifically, small test basins were chosen to control application volume and distribution while maintaining field conditions.

Item 3. *Page 1-2. Number and location of lysimeters.*

For this study, treatment depth during land application has been defined at five feet below ground surface. Therefore, it was determined that three lysimeters were necessary at this depth so that a statistical evaluation could be made. Because treatment versus depth is also of interest, an additional lysimeter was placed at a shallow depth. This will provide information to assess the depth required for some treatment processes, particularly those associated with aeration. This installation was not chosen for replication at this time because results will be used for assessing technical details, not for evaluating the quality and completeness of the soil treatment process.

Item 4. *Page 2. Inclusion of TKN and Cl^-.*

We agree that TKN should be added to our list of analytes, at least for the first series of tests. If it is determined that this measurement is not required, frequency of measurement will be decreased in future tests. Chloride measurement in soil and water was inadvertently omitted from the list of standard mineral analytes. Chloride concentrations will be measured where appropriate.

Item 5. *Page 2.*

Soil physical and chemical properties. Composite soil samples were collected for general characterization. Samples were collected for each foot to five feet.

Item 6. *Page 2. QA/QC plan.*

Dellavalle Laboratory will be providing the analytical QA/QC plan for the study. This comment will be further discussed with a representative from Dellavalle and a description of the plan is forthcoming.

Item 7. *Page 2. Addition of two-tail tests.*

You recommended that testing of differences between means or medians be conducted. We agree that this basic analysis procedure would be a useful addition to the regression analysis we proposed. We may encounter difficulties with this approach because our loading rates may not provide replication of individual loading rates because wastewater quality may vary between successive loading periods.

If you have additional questions regarding our response to your comments, please feel free to contact me directly at (415) 243-2524.

Very truly yours,

KENNEDY/JENKS CONSULTANTS

Robert S. Chrobak

Robert S. Chrobak, P.E.
Project Manager

Enclosures

cc: Tom Pinkos, California Regional Water Quality Control Board, Central Valley Region, Sacramento Office
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Jo Anne Kipps, California Regional Water Quality Control Board, Central Valley Region, Fresno Office
Bert Van Voris, California Regional Water Quality Control Board, Central Valley Region, Fresno Office
Loren Harlow, California Regional Water Quality Control Board, Central Valley Region, Fresno Office
Wendell Lee, Wine Institute
Wine Institute Technical Committee Wastewater Working Group

Appendix B

Laboratory Water Quality Analytical Variability

Table B.1: Dellavalle Laboratory Water Quality Analytical Variability

Parameter	Replication 1	Replication 2	Replication 3	Mean	Standard Deviation	CV (%)	Method
pH	6.9	6.9	6.9				4500H
EC	1487	1495	1509	1497	11	1%	2510B
TDS	1910	1880	1870	1887	21	1%	2540C
VDS	768	783	650	734	73	10%	2540E
IDS	1143	1098	1200	1147	51	4%	2540E
BOD	2200	1900	2000	2033	153	8%	5210B
Fe	4.8	5.0	4.4	4.7	0.31	6%	3120B
Mn	0.3	0.3	0.3	0	0	0%	3120B
TN	17	18	19	18	1	6%	-
NO3-N	6	6	6	6	0	0%	4500F
NH4-N	7.2	7.0	6.8	7	0.2	3%	4500H
Org-N	4.3	5.8	6.7	5.6	1.2	22%	-
SO4	111	111	112	111	0.6	1%	4500E
HCO3	364	350	369	361	10	3%	2320B
Cl	92	86	91	90	3	4%	4500Cl
Ca	148	137	131	139	9	6%	3120B
Mg	46.9	43.5	41.7	44	3	6%	3120B
Na	161	153	139	151	11	7%	3120B
Total K	74.7	69.2	65.1	70	5	7%	3120B

Appendix C

Land Application Study Dataset

Table C.1: 2002 Non-Stillage Winery Cycle by Cycle Data Summary

Constituent	Process Water	12" Lysimeter	5' Lysimeter
Cycle 1			
pH	5.7	7.4	7.2 (6.9 – 7.5)
BOD (mg/L)	3100	620	321 ± 293
TN (mg -N/L)	44	195	61 ± 58
Org-N (mg -N/L)	32.8	7.7	9.1 ± 5.4
NH3-N (mg/L)	6.0	2.1	0.2 ± 0.1
NO3-N (mg/L)	5.5	185.5	52.2 ± 62.7
IDS	768	4160	1930 ± 880
Iron and Manganese	2.2	0	2.0 ± 2.0
Cycle 2			
pH	5.3	7.2	7.3 (7.0 – 7.5)
BOD	1900	770	3 ± 0
TN	15	5	112 ± 94
Org-N	10.8	2.7	0.8 ± 0.8
NH3	4.3	2.4	1.0 ± 0.6
NO3	0.1	0.1	110.4 ± 95.4
IDS	1010	2220	2770 ± 242
Iron and Manganese	3.0	16	0.9 ± 0.6
Cycle 3			
pH	5.5	6.8	7.5 (7.1 – 7.9)
BOD	2000	1400	451 ± 613
TN	49	2.0	11 ± 24
Org-N	31.6	1.7	2.4 ± 2.8
NH3	14.8	0.1	0.5 ± 0.9
NO3	2.8	0.1	8.7 ± 24.4
IDS	1140	2140	1780 ± 409
Iron and Manganese	8.9	24.8	17.7 ± 17
Cycle 4			
pH	6.9	6.9 (6.7 – 6.9)	7.3 (7.1 – 8.0)
BOD	2030	587 ± 449	610 ± 470
TN	18	1 ± 2	2 ± 2
Org-N	5.6	0.7 ± 1.0	1.1 ± 1.3
NH3	7.0	0.8 ± 0.6	0.7 ± 1.1
NO3	6.0	0.1 ± 0	0.1 ± 0
IDS	1150	1550 ± 407	1790 ± 226
Iron and Manganese	5	15.1 ± 10	21.6 ± 22

Table C.2: 2002 Stillage Winery Cycle by Cycle Data Summary

Constituent	Process Water	12" Lysimeter	5' Lysimeter
Cycle 1			
pH	4.7	7.6	5.7 (4.5 – 6.9)
BOD (mg/L)	1400	480	2500
TN (mg -N/L)	9	29	65
Org-N (mg -N/L)	5.9	28.3	27.4
NH3-N (mg/L)	0.9	1.1	27.4
NO3-N (mg/L)	2.2	0.1	10.7
IDS	283	1910	915
Iron and Manganese	1	5	54
Cycle 2			
pH	3.8	6.4	5.5
BOD	7800	1100	1600
TN	120	41	72
Org-N	102.9	15.7	23.1
NH3	13.7	24.9	48.6
NO3	3.5	0.1	0.1
IDS	2910	1670	1610
Iron and Manganese	2	42	111
Cycle 3			
pH	4.2	7.5 (6.6 – 8.4)	6.4 (5.7 – 6.4)
BOD	7200	1700	598 ± 526
TN	316	42	31 ± 19
Org-N	263.0	39.7	15.4 ± 22.7
NH3	51.5	2.0	10.8 ± 5.8
NO3	1.8	0.1	2.0 ± 3.9
IDS	3180	2240	1250 ± 291
Iron and Manganese	3	113	53 ± 32

Table C.2: 2002 Stillage Winery Cycle by Cycle Data Summary

Constituent	Process Water	12" Lysimeter	5' Lysimeter
Cycle 4			
pH	4.9	8.3	7.0 (6.9 – 7.0)
BOD	660		
TN	17	38	21
Org-N	3.9	17.6	10.4
NH3	10.8	38.0	21.2
NO3	2.3	0.1	0.1
IDS	307	2100	1220
Iron and Manganese	5		47
Cycle 5			
pH	4.6	8.3	7.9 (7.7 – 8.0)
BOD	1300		83
TN	14	34	27
Org-N	3.0	12.1	2.5
NH3	10.9	22.2	26.9
NO3	0.1	0.1	0.1
IDS	255		1480
Iron and Manganese	1	16	33
Cycle 6			
pH	6.1		7.8 (7.1 – 8.2)
BOD	120		7
TN	11		146 ± 160
Org-N	3.6		1.9 ± 1.9
NH3	5.6		8.9 ± 9.1
NO3	2.0		138.3 ± 162.5
IDS	230		2790 ± 1440
Iron and Manganese	1		18.5

Table C.2: 2002 Stillage Winery Cycle by Cycle Data Summary

Constituent	Process Water	12" Lysimeter	5' Lysimeter
Cycle 7			
pH	3.7	8.6	7.5 (7.0 – 7.7)
BOD	18000		3
TN	392		117 ± 195
Org-N	369.8		1.2 ± 1.0
NH3	22.4	15.2	4.3 ± 3.6
NO3	0.1	0.2	117.1 ± 175.9
IDS	2600		3010 ± 1550
Iron and Manganese	3		14 ± 14

Table C.3: 2003 Non-Stillage Winery Cycle by Cycle Data Summary

Constituent	Process Water	5' Lysimeter
Cycle 1		
pH	5.5	7.0 (6.9 – 7.0)
BOD (mg/L)	2,400	1.3 ± 0.7
TN (mg -N/L)	42.6	128 ± 51
Org-N (mg -N/L)	34	1.0 ± 0
NH3-N ((mg -N/L)	8.4	0.5 ± 0
NO3-N ((mg -N/L)	0.2	126 ± 51
IDS (mg/L)	800	1,700 ± 100
Iron and Manganese (mg/L)	1.0	0.01 ± 0
Cycle 2		
pH	5.0	6.8 (6.6 – 7.0)
BOD	2,500	0.8 ± 0.6
TN	36.3	79 ± 59
Org-N	30	0.5 ± 0
NH3	3.8	0.5 ± 0
NO3	2.5	78 ± 59
IDS	1,100	1,630 ± 210
Iron and Manganese	1.7	0.01 ± 0
Cycle 3		
pH	7.3	7.1 (7.0 – 7.2)
BOD	4,500	1.4 ± 0.2
TN	149	70 ± 62.3
Org-N	140	0.5 ± 0
NH3	7.9	0.5 ± 0
NO3	0.2	69 ± 62.3
IDS	1,800	1,600 ± 350
Iron and Manganese	13.3	0.02
Cycle 4		
pH	6.2	7.0 (6.9 – 7.0)
BOD	2,200	1.5 ± 0
TN	45.8	62.5 ± 48.8
Org-N	30	0.5
NH3	3.6	0.5
NO3	11.3	62 ± 49.5
IDS	790	1,550 ± 350
Iron and Manganese	2.8	–

Table C.3: 2003 Non-Stillage Winery Cycle by Cycle Data Summary

Constituent	Process Water	5' Lysimeter
Cycle 5		
pH	6.0	7.0 (6.9 – 7.1)
BOD	2,800	1.1 ± 0.6
TN	48.1	71 ± 58
Org-N	30	1.0 ± 0
NH3	6	1.0 ± 0
NO3	9.9	69 ± 58
IDS	1,400	1,670 ± 400
Iron and Manganese	2.8	0.01 ± 0

Constituent	Process Water	5' Lysimeter
Cycle 6		
pH	6.7	6.8 (6.7 – 6.8)
BOD	3,900	0.5 ± 0
TN	50.5	57 ± 53.7
Org-N	39	1.0 ± 0
NH3	4.3	1.0 ± 0
NO3	7.0	55 ± 53.7
IDS	1,400	1,600 ± 350
Iron and Manganese	1.8	0.09 ± 0

Table C.4: 2003 Stillage Winery Cycle by Cycle Data Summary

Constituent	Process Water	5' Lysimeter
Cycle 1		
pH	3.7	
BOD (mg/L)	5,600	2
TN (mg -N/L)	356	
Org-N (mg -N/L)	310	
NH3-N ((mg -N/L)	43	
NO3-N ((mg -N/L)	3.0	
IDS (mg/L)	4,300	1,930 ± 1,940
Iron and Manganese (mg/L)	8.8	
Cycle 2		
pH	4.5	6.6 (6.6 – 6.6)
BOD	11,000	15 ± 12
TN	572	307 ± 112
Org-N	500	1 ± 0
NH3	71	1 ± 0
NO3	1	305 ± 112
IDS	4,800	4,050 ± 495
Iron and Manganese	2.9	2.1 ± 0.1
Cycle 3		
pH	3.5	6.6 (6.4 – 6.8)
BOD	6,500	304 ± 491
TN	124	143 ± 126
Org-N	110	3.3 ± 3.0
NH3	10	5.0 ± 6.0
NO3	4.0	134 ± 134
IDS	2,700	3,060 ± 630
Iron and Manganese	1.4	19.2 ± 26.7
Cycle 4		
pH	3.3	6.5 (4.8 – 6.8)
BOD	5,000	1,810 ± 3,110
TN	255	87 ± 65
Org-N	190	26.3 ± 38
NH3	52	17.0 ± 27
NO3	13	19.3 ± 33
IDS	5,520	2,500
Iron and Manganese	1.7	59.4 ± 86.3

Table C.4: 2003 Stillage Winery Cycle by Cycle Data Summary

Constituent	Process Water	5' Lysimeter
Cycle 5		
pH	4.1	6.4 (5.3 – 6.5)
BOD	12,000	1,310 ± 1,880
TN	571	44 ± 30
Org-N	470	8.1 ± 10
NH3	100	16.4 ± 23
NO3	1	19.3 ± 33
IDS	5,200	2,200 ± 460
Iron and Manganese	2.7	70.1 ± 83.3

Non-Stillage Site Soil Test Results 2002

							meq/l								mg/l	mg/l	mg/kg					% TN	% TC	$CaCO_3$	TOC	mg/kg	mg/kg	%	1:1	1:1	1:1	1:1	1:1	1:1	1:1	Ammonium Acetate Extraction, ppm			Ammonium Acetate Extraction, meq/100g			Sat paste EC* 10/	1:1 extract *Est.	1:1 extract **Ratio
No.	Lab #	DEPTH	Date	SP	pHs	EC, mmho/cm	Ca	Mg	Na	Cl	K	SO_4-S	ESP	Lime	P	B	NO_3-N	NO_2-N	NH_4-N*	PO_4-P	K	combust	combust	equiv	calc	Mn	Fe	P	pH	EC	TDS	VDS	IDS	TC	HCO_3	Ca	Mg	Na	Ca	Mg	Na	Sum Cat.	IDS	EST IDS/IDS
S-B-C0	61997	0-1'	9/6/02	34	7.4	5.0	30	6.4	6.0	2.5	3.3	24	<1.0		0.7	<0.1	86	0.15	10	21	270	0.50	1.52	<0.01		147	14255	0.04	7.9	2.11	1850	150	1700	78.24	2.84	3557	159	87	17.7	1.3	0.4	1.1	1349	0.79
S-B-C0	61997	1-2'	9/6/02	32	7.6	1.6	10	2.4	3.5	1.3	1.7	7.8	<1.0		0.9	0.1	17	0.15	4.6	37	220	0.55	4.25	<0.01		160	14040	0.06	8.1	0.66	530	40	490	41.34	2.70	3807	150	48	19.0	1.2	0.2	0.9	419	0.86
S-B-C0	61997	2-3'	9/6/02	31	7.8	1.1	6.6	1.5	2.9	1.2	0.92	4.4	<1.0		1.7	0.1	8	0.15	3.8	46	150	0.74	5.64	<0.01		166	14120	0.07	8.1	0.43	370	40	330	31.62	2.64	3617	139	50	18.0	1.1	0.2	0.9	274	0.83
S-B-C0	61997	3-4'	9/6/02	39	8.0	0.9	5.5	1.3	2.8	1.4	0.61	3.5	1.0		0.7	<0.1	7	0.15	3.4	23	150	0.44	3.97	<0.01		233	19475	0.10	8.1	0.44	410	50	360	31.35	2.78	3507	156	65	17.5	1.3	0.3	0.9	282	0.78
S-B-C0	61997	4-5'	9/6/02	38	7.8	1.0	5.3	1.3	2.9	1.4	0.41	3.6	1.1		0.4	0.1	7	0.15	4.0	15	160	0.15	1.30	<0.01		339	22885	0.07	8.1	0.46	440	40	400	39.68	2.25	2937	174	75	14.7	1.4	0.3	1.0	296	0.74
S-B-C0	62758	0-1'	10/3/02	36	7.1	2.9	12	6.1	12	3.3	1.81	17.5	4.4		1.7	0.2	33	0.03	5.2	33	170	0.09	0.80	0.45	0.35	83	8520	0.03	7.5	1.18	920	120	800	54.6	1.64	830	137	279	4.1	1.1	1.2	0.9	756	0.95
S-B-C0	62758	1-2'	10/3/02	25	7.5	1.9	7.7	3.2	9.1	2.6	0.84	10.5	4.3		1.1	0.1	11	<0.01	2.2	38	110	0.05	0.30	0.65	<0.01	95	9550	0.04	7.9	0.57	420	30	390	26.6	1.49	1492	133	70	7.4	1.1	0.3	0.9	367	0.94
S-B-C0	62758	2-3'	10/3/02	26	7.7	1.6	7.0	2.9	7.9	3.1	0.70	9.6	3.8		0.8	0.1	7	0.04	44	30	130	0.03	0.44	2.22	<0.01	172	12265	0.05	8.0	0.51	440	50	390	25.2	1.55	3412	196	74	17.0	1.6	0.3	0.9	325	0.83
S-B-C0	62758	3-4'	10/3/02	27	7.8	1.5	6.2	2.6	7.1	3.2	0.69	9.0	3.6		0.4	0.1	5	0.03	1.2	11	170	0.02	0.25	1.35	<0.01	232	16430	0.07	8.1	0.48	560	40	520	20.8	1.46	2942	192	81	14.7	1.6	0.4	0.9	306	0.59
S-B-C0	62758	4-5'	10/3/02	26	7.8	1.5	6.9	2.8	6.8	3.6	0.62	9.5	3.2		0.3	0.1	5	0.03	1.2	7	83	0.01	0.09	NES		182	13195	0.06	8.0	0.50	450	20	430	18.1	1.03	922	100	51	4.6	0.8	0.2	0.9	317	0.74
S-B-C0	62758	5-6'	10/3/02	21	7.9	1.7	8.2	3.1	6.9	2.8	0.62	10.2	2.9		0.4	0.1	7	0.03	2.3	7	58	0.02	0.13	0.42	<0.01	121	10710	0.04	7.9	0.45	400	50	350	26.1	1.24	617	63	39	3.1	0.5	0.2	0.9	291	0.83
S-B-C3b	62872	0-1'	10/9/02	38	7.6	1.4	4.7	1.4	6.7	<0.1	1.5	5.69	4.2		2.4	0.1	8	0.1	3.3	44	260	0.071	0.85	2.92	<0.01	167	13450	0.06	7.9	0.57	870	120	750	61.3	2.15	3533	176	116	17.6	1.4	0.5	1.0	362	0.48
S-B-C3b	62872	1-2'	10/9/02	38	7.7	1.8	8.9	2.4	7.6	6.0	1.4	7.68	3.3		2.5	0.1	14	0.1	0.1	90	250	0.031	1.37	9.19	<0.01	268	16140	0.10	7.9	0.71	570	80	490	52.9	2.66	4203	221	123	21.0	1.8	0.5	0.9	451	0.92
S-B-C3b	62872	2-3'	10/9/02	31	7.8	0.9	3.6	1.1	4.1	2.0	0.61	2.64	2.6		2.7	0.1	5	0.1	<0.1	35	150	0.012	0.31	2.32	<0.01	178	15360	0.06	8.0	0.36	610	60	550	24.4	1.73	3793	199	70	18.9	1.6	0.3	1.0	230	0.42
S-B-C3b	62872	3-4'	10/9/02	32	7.7	1.0	3.8	1.3	3.8	1.7	0.34	3.98	2.2		0.6	0.1	5	0.1	<0.1	17	83	0.017	0.06	0.50	<0.01	203	16650	0.06	7.9	0.35	480	50	430	17.0	1.37	1533	167	65	7.6	1.4	0.3	1.0	221	0.51
S-B-C3b	62872	4-5'	10/9/02	29	7.8	0.9	3.3	1.2	4.3	1.9	0.18	4.21	2.9		0.3	0.1	3	0.1	<0.1	15	62	0.014	0.07	0.80	<0.01	207	18420	0.06	8.0	0.33	490	30	460	17.7	1.70	1443	160	84	7.2	1.3	0.4	1.0	214	0.46
S-B-C3c	63015	0-1'	10/16/02	34	7.8	1.8	6.5	2	8.3	3.6	1.33	9.49	4.4		2.4	0.1	9	<0.1	0.2	38	190	0.08	0.76	1.07	<0.01	112	9846	0.04	7.8	0.72	760	150	610	60.8	1.49	2146	140	117	10.7	1.2	0.5	1.0	461	0.76
S-B-C3c	63015	1-2'	10/16/02	31	7.8	1.9	9.6	3.4	6.5	2.9	0.81	9.84	2.4		1.15	0.1	19	<0.1	0.3	39	170	0.04	0.62	3.74	<0.01	172	14508	0.06	8	0.73	550	80	470	15	1.55	4156	211	100	20.7	1.7	0.4	0.9	467	0.99
S-B-C3c	63015	2-3'	10/16/02	29	8.0	1.0	3.1	1.3	4.9	2.2	0.45	4.32	3.5		1.4	0.2	3	<0.1	0.2	34	140	<0.01	0.23	2.95	<0.01	204	17611	0.06	8.2	0.38	750	80	670	25.1	2.70	4126	243	92	20.6	2	0.4	1.0	243	0.36
S-B-C3c	63015	3-4'	10/16/02	29	8.1	1.1	3.9	1.5	5.6	3.2	0.25	5.67	3.6		0.2	0.1	2	<0.1	0.2	9	87	0.01	0.07	0.95	<0.01	201	17826	0.06	8.2	0.44	460	60	400	15.6	1.43	1616	162	97	8.1	1.3	0.4	1.0	282	0.70
S-B-C3c	63015	4-5'	10/16/02	24	8.0	1.2	4.2	1.5	5.6	3.3	0.09	6.28	3.5		0.13	0.1	1	<0.1	0.4	5	17	0.01	0.09	1.05	<0.01	188	1473	0.05	8.2	0.36	430	40	390	14.6	1.28	1146	127	92	5.7	1	0.4	1.0	230	0.59
S-B-rain	64586	0-1'	1/20/03	36	7.5	1.0	3.8	1.1	5.1	1.2	1.4	4.1	3.5		2.2	0.1	6	<0.1	0.4	56	280	0.07	0.81	2.61	0.5	158	12240	0.05	8	0.45	580	60	520	182.7	2.2	3545	173	90	17.7	1.4	0.4	0.9	289	0.56
S-B-rain	64586	1-2'	1/20/03	37	7.7	1.33	5.4	1.5	5.9	2.4	1.1	6.7	3.3		1.7	0.1	4	<0.1	<0.1	89	300	0.02	0.99	7.03	0.15	262	17280	0.11	8.2	0.59	470	50	420	33	2.3	3935	226	151	19.6	1.9	0.7	1.0	380	0.91
S-B-rain	64586	2-3'	1/20/03	31	7.8	1.26	5.0	1.4	6.2	2.7	0.86	5.4	3.8		2.1	0.1	3	<0.1	0.7	50	200	0.01	0.52	4.16	0.02	190	13800	0.07	8.1	0.44	400	20	380	25.6	1.8	3955	181	105	19.7	1.5	0.5	0.9	282	0.74
S-B-rain	64586	3-4'	1/20/03	33	7.8	1.21	5.6	1.8	4.6	2.6	0.44	5.4	2.2		1	0.1	6	<0.1	0.3	29	110	0.01	0.11	0.96	<0.01	202	15430	0.06	8	0.45	350	30	320	51	1.1	2195	155	85	11	1.3	0.4	1.0	291	0.91
S-B-rain	64586	4-5'	1/20/03	29	7.6	1.08	4.7	1.8	4.1	2.1	0.33	4.2	2.1		0.4	0.1	8	<0.1	0.2	21	82	0.01	0.10	0.66	0.02	205	16720	0.05	8.1	0.4	300	<0.1	300	41.1	1.4	1425	141	65	7.1	1.2	0.3	1.0	253	0.84

*Est. IDS= EC x 640

***Note - Some of the 1:1 extracts have finely suspended colloid particles (mineral clay) which will effect TDS and IDS results.

**Ratio = EST IDS/ IDS

Non-Stillage 08/27/03

Non-Stillage Site Soil Test Results: 8/27/03

Sample ID	Sample Date	Fe	Mn	EC	ESP	NO3-N	NO2-N	NH4-N	Ca	Mg	Na	K	SO4-S	Cl	PO4-P	SP	pH
B-PW-0/12	8/27/2003	387	4.7	100	2.2	<4	<4	21	649	288	14	61	0.46	0.59	<5	29	8.2
B-PW-12/24	8/27/2003	422	5.8	170	2.3	<4	<4	16	998	329	17	67	0.69	0.56	<5	29	8.2
B-PW-24/36	8/27/2003	493	7.6	160	1.8	<4	<4	7.4	469	354	20	84	0.83	0.79	<5	31	8.2
B-PW-36/48	8/27/2003	528	7.6	190	1.8	<4	<4	7.7	409	354	21	84	0.75	0.76	<5	12	8.2
B-PW-48/60	8/27/2003	528	7.3	170	2.0	<4	<4	8.5	359	337	20	79	0.75	0.76	<5	32	8.2

Notes: K/J COC # KJ-B1a&b, TL COC # 7030-4525

MM/DD/YYYY = month/day/year of report
Sample ID = field sample identification
Sample Date = date of soil sample

mg/kg = milligrams per kilogram
meq/l = milliequivalents per liter

Sample Amounts:

ESP = 300 g
SP = 200 g
pH = 20 g
Ca, Mg, Mn, Fe, Na, K = 10 g
NO_3, NO_2, SO_4, PO_4, Cl = 20 g

SP = saturation percentage
EC = electrical conductivity (mmho/cm)
ESP = exchangeable sodium percentage
Ca = calcium (meq/kg)
Mg = magnesium (meq/kg)
Fe = iron (meq/kg)
Mn = manganese (meq/kg)
Na = sodium (meq/kg)
K = potassium (meq/kg)
SO_4-S = sulfate (meq/kg)
Cl = chloride (meq/kg)
NO_3-N = nitrate as nitrogen (mg/kg)
NO_2-N = nitrite as nitrogen (mg/kg)
NH_4-N = ammonia as nitrogen (mg/kg)
PO_4-P = phosphate (mg/kg)

mg/kg	Ca	Mg	Na	K	Fe	Mn	Cl	SO4-S
B-PW-0/12	13000	3500	330	2400	11000	130	21	22
B-PW-12/24	20000	4000	400	2600	12000	160	20	33
B-PW-24/36	9400	4300	470	3300	14000	210	28	40
B-PW-36/48	8200	4300	480	3300	15000	210	27	36
B-PW-48/60	7200	4100	470	3100	15000	200	27	36

Non-Stillage 09/24/03

Non-Stillage Site Soil Test Results: 9/24/03

Sample ID	Sample Date	Fe	Mn	EC	ESP	NO3-N	NO2-N	NH4-N	Ca	Mg	Na	K	SO4-S	Cl	PO4-P	SP	pH
B-C2-0/12	9/24/2003	387	4.7	230	3.0	<0.4	<0.4	31	294	255	13	72	0.56	1.81	<5	30.8	7.8
B-C2-12/24	9/24/2003	387	4.7	260	3.2	2.7	<0.4	12	1098	288	16	69	0.35	0.96	<5	28.1	8.0
B-C2-24/36	9/24/2003	387	5.5	420	2.5	8.4	<10	7.4	250	263	15	59	0.97	1.07	<5	27.8	7.7
B-C2-36/48	9/24/2003	563	8.4	370	1.7	7.4	<0.4	5.7	205	370	23	105	0.70	0.68	<5	8.9	7.7
B-C2-48/60	9/24/2003	563	8.0	240	2.1	<20	<10	4.5	200	354	20	92	0.55	0.71	<5	30.0	7.4

Notes: K/J COC # KJ-B-C3a, TL COC # 7030-5147

mg/kg	Ca	Mg	Na	K	Fe	Mn	Cl	SO4	
B-C2-0/12	5900	3100	290	2800	11000	130	64	81	26.973
B-C2-12/24	22000	3500	360	2700	11000	130	34	51	16.983
B-C2-24/36	5000	3200	340	2300	11000	150	38	140	46.62
B-C2-36/48	4100	4500	530	4100	16000	230	24	100	33.3
B-C2-48/60	4000	4300	450	3600	16000	220	25	79	26.307

MM/DD/YYYY = month/day/year of report
Sample ID = field sample identification
Sample Date = date of soil sample

mg/kg = milligrams per kilogram
meq/l = milliequivalents per liter

Sample Amounts:

ESP = 300 g
SP = 200 g
pH = 20 g
Ca, Mg, Mn, Fe, Na, K = 10 g
NO_3, NO_2, SO_4, PO_4, Cl = 20 g

SP = saturation percentage
EC = electrical conductivity (mmho/cm)
ESP = exchangeable sodium percentage
Ca = calcium (meq/kg)
Mg = magnesium (meq/kg)
Fe = iron (meq/kg)
Mn = manganese (meq/kg)
Na = sodium (meq/kg)
K = potassium (meq/kg)
SO_4-S = sulfate (meq/kg)
Cl = chloride (meq/kg)
NO_3-N = nitrate as nitrogen (mg/kg)
NO_2-N = nitrite as nitrogen (mg/kg)
NH_4-N = ammonia as nitrogen (mg/kg)
PO_4-P = phosphate (mg/kg)

Non-Stillage 10/21/03

Non-Stillage Site Soil Test Results: 10/21/03

Sample ID	Sample Date	Fe	Mn	EC	ESP	NO3-N	NO2-N	NH4-N	Ca	Mg	Na	K	SO4-S	Cl	PO4-P	SP	pH
B-C4-0/12	10/21/2003	422	5.8	210	5.4	<4.5	<3.0	24	898	329	20	72	0.43	0.96	7.5	12.6	8.3
B-C4-12/24*	10/21/2003	387	6.2	260	3.9	<4.5	<3.0	25	1297	321	20	64	0.33	0.76	6.3	100*	8.1
B-C4-24/36*	10/21/2003	422	5.8	400	3.1	<4.5	<3.0	7.8	1297	321	20	69	0.59	0.76	<5	100*	7.8
B-C4-36/48*	10/21/2003	493	7.3	340	1.9	<4.5	<3.0	<5	404	346	20	82	0.70	0.76	<5	100*	7.9
B-C4-48/60	10/21/2003	563	10.2	300	2.4	<4.5	<3.0	<5	314	395	23	90	0.65	0.76	<5	9.5	8.1

Notes: COC # 7030-5697, KJ-B-C4b

***NOTE: Sample was saturated with water upon receipt (melted cooler ice seeped into soil bags.)**

mg/kg	Ca	Mg	Na	K	Fe	Mn	Cl	SO4	SO4-S	
B-C4-0/12	18000	4000	460	2800	12000	160	34	62	21	0.333
B-C4-12/24*	26000	3900	450	2500	11000	170	27	47	16	0.333
B-C4-24/36*	26000	3900	450	2700	12000	160	27	85	28	0.333
B-C4-36/48*	8100	4200	460	3200	14000	200	27	100	33	0.333
B-C4-48/60	6300	4800	530	3500	16000	280	27	94	31	0.333

MM/DD/YYYY = month/day/year of report
Sample ID = field sample identification
Sample Date = date of soil sample

mg/kg = milligrams per kilogram
meq/l = milliequivalents per liter

Sample Amounts:

ESP = 300 g
SP = 200 g
pH = 20 g
Ca, Mg, Mn, Fe, Na, K = 10 g
NO_3, NO_2, SO_4, PO_4, Cl = 20 g

SP = saturation percentage
EC = electrical conductivity (mmho/cm)
ESP = exchangeable sodium percentage
Ca = calcium (meq/kg)
Mg = magnesium (meq/kg)
Fe = iron (meq/kg)
Mn = manganese (meq/kg)
Na = sodium (meq/kg)
K = potassium (meq/kg)

SO_4-S = sulfate (meq/kg)
Cl = chloride (meq/kg)
NO_3-N = nitrate as nitrogen (mg/kg)
NO_2-N = nitrite as nitrogen (mg/kg)
NH_4-N = ammonia as nitrogen (mg/kg)
PO_4-P = phosphate (mg/kg)

Non-Stillage 11/18/03

Non-Stillage Site Soil Test Results: 11/18/03

Sample ID	Sample Date	Fe	Mn	EC	ESP	NO3-N	NO2-N	NH4-N	Ca	Mg	Na	K	SO4-S	Cl	PO4-P	SP	pH
B-C6-0/12	11/18/2003	387	4.7	290	6.1	<4.5	<3.0	44	259	263	14	67	0.23	1.2	<5	12.0	8.2
B-C6-12/24	11/18/2003	422	5.8	330	3.6	<4.5	<3.0	22	469	346	19	77	0.41	0.87	<5	11.2	8.0
B-C6-24/36	11/18/2003	422	5.1	380	4.8	<4.5	<3.0	18	998	313	17	59	0.62	1.1	6.4	10.3	8.0
B-C6-36/48	11/18/2003	457	6.6	410	3.7	5.9	<3.0	10	1148	370	23	74	0.76	0.96	<5	10.9	7.8
B-C6-48/60	11/18/2003	598	8.7	400	2.4	6.1	<3.0	<10	289	387	20	90	0.83	0.79	<5	18.5	7.5

Notes: COC # 7030-6226, KJ-B-C6

MM/DD/YYYY = month/day/year of report
Sample ID = field sample identification
Sample Date = date of soil sample

mg/kg = milligrams per kilogram
meq/l = milliequivalents per liter

Sample Amounts:

ESP = 300 g
SP = 200 g
pH = 20 g
Ca, Mg, Mn, Fe, Na, K = 10 g
NO_3, NO_2, SO_4, PO_4, Cl = 20 g

SP = saturation percentage
EC = electrical conductivity (mmho/cm)
ESP = exchangeable sodium percentage
Ca = calcium (meq/kg)
Mg = magnesium (meq/kg)
Fe = iron (meq/kg)
Mn = manganese (meq/kg)
Na = sodium (meq/kg)
K = potassium (meq/kg)
SO_4-S = sulfate (meq/kg)
Cl = chloride (meq/kg)
NO_3-N = nitrate as nitrogen (mg/kg)
NO_2-N = nitrite as nitrogen (mg/kg)
NH_4-N = ammonia as nitrogen (mg/kg)
PO_4-P = phosphate (mg/kg)

mg/kg	Ca	Mg	Na	K	Fe	Mn	Cl	SO4	SO4-S
B-C6-0/12	5200	3200	320	2600	11000	130	44	33	11
B-C6-12/24	9400	4200	440	3000	12000	160	31	59	20
B-C6-24/36	20000	3800	400	2300	12000	140	39	89	30
B-C6-36/48	23000	4500	520	2900	13000	180	34	110	37
B-C6-48/60	5800	4700	470	3500	17000	240	28	120	40
to meq/l, mult by:	0.05	0.083	0.043	0.026			0.029	0.021	0.006993

Non-Stillage 12/16/03

Non-Stillage Site Soil Test Results: 12/16/03

	Sample Date	Fe	Mn	EC*	ESP	NO3-N	NO2-N	NH4-N	Ca	Mg	Na	K	SO4-S	Cl	PO4-P	SP	pH
B-C6B-0/12	12/16/2003	387	4.4	0.28	3.9	<4.5	<3.0	37	120	255	13	61	0.24	1.2	9.3	9.8	8.4
B-C6B-12/24	12/16/2003	387	4.7	0.30	5.1	<4.5	<3.0	17	898	288	16	61	0.24	1.44	9.6	11.0	8.4
B-C6B-24/36	12/16/2003	387	4.7	0.28	4.0	<4.5	<3.0	16	848	272	15	61	0.38	0.9	11	9.7	8.4
B-C6B-36/48	12/16/2003	528	7.3	0.34	3.2	<4.5	<3.0	<10	259	337	20	84	0.60	1.10	9.3	11.5	8.1
B-C6B-48/60	12/16/2003	563	9.1	0.33	1.7	<4.5	<3.0	<10	210	379	20	90	0.70	0.82	5.8	12.2	7.7

Notes: COC # 7030-6734 *Note: These EC units are in mmho/cm.

MM/DD/YYYY = month/day/year of report
Sample ID = field sample identification
Sample Date = date of soil sample

mg/kg = milligrams per kilogram
meq/l = milliequivalents per liter

Sample Amounts:

ESP = 300 g
SP = 200 g
pH = 20 g
Ca, Mg, Mn, Fe, Na, K = 10 g
NO_3, NO_2, SO_4, PO_4, Cl = 20 g

SP = saturation percentage
EC = electrical conductivity (**mmho/cm**)
ESP = exchangeable sodium percentage
Ca = calcium (meq/kg)
Mg = magnesium (meq/kg)
Fe = iron (meq/kg)
Mn = manganese (meq/kg)
Na = sodium (meq/kg)
K = potassium (meq/kg)
SO_4-S = sulfate (meq/kg)
Cl = chloride (meq/kg)
NO_3-N = nitrate as nitrogen (mg/kg)
NO_2-N = nitrite as nitrogen (mg/kg)
NH_4-N = ammonia as nitrogen (mg/kg)
PO_4-P = phosphate (mg/kg)

mg/kg	Ca	Mg	Na	K	Fe	Mn	Cl	SO4	SO4-S
B-C6B-0/12	2400	3100	310	2400	11000	120	44	34	11
B-C6B-12/24	18000	3500	360	2400	11000	130	51	34	11
B-C6B-24/36	17000	3300	350	2400	11000	130	33	54	18
B-C6B-36/48	5200	4100	470	3300	15000	200	39	86	29
B-C6B-48/60	4200	4600	460	3500	16000	250	29	100	33

Stillage Site Soil Test Data 2002

No.	Lab #	DEPTH	Date	SP	pHs	EC mmho/cm	meq/l Ca	meq/l Mg	meq/l Na	meq/l Cl	meq/l K	meq/l SO_4-S	ESP	Lime	mg/l P	mg/l B	mg/kg NO_3-N	mg/kg NO_2-N	mg/kg NH_4-N*	mg/kg PO_4-P	mg/kg K
S-G-C0	61807	0-1'	8/28/02	25	7.1	2.0	2.2	1.6	3.3	1.2	12.8	7.6	2.2		9.5	0.9	6	0.15	37	94	1050
S-G-C0	61807	1-2'	8/28/02	24	7.5	1.3	1.4	0.8	3.7	1.1	5.9	5.8	3.7		2.7	0.4	3	0.15	9.9	62	930
S-G-C0	61807	2-3'	8/28/02	24	7.6	1.5	1.5	0.9	4.9	1.1	6.7	7.6	5.0		0.6	0.2	5	0.15	6.2	22	690
S-G-C0	61807	3-4'	8/28/02	23	7.8	1.3	1.9	0.9	3.8	0.7	5.7	6.1	3.3		0.3	0.2	5	0.15	5.4	11	610
S-G-C0	61807	4-5'	8/28/02	24	7.7	1.6	2.7	1.4	4.6	0.8	6.1	7.3	3.3		0.3	0.1	8	0.15	4.8	10	590
S-G-C0	61807	5-6'	8/28/02	26	7.6	1.3	3.2	1.7	4.9	0.7	3.6	6.4	3.3		0.4	0.1	9	0.20	5.4	8	520
S-G-C1	62325	0-1'	9/18/02	26	6.8	1.0	1.5	0.8	1.5	0.8	5.2	3.8	<1.0		4.7	0.6	6	0.15	31	89	830
S-G-C1	62325	1-2'	9/18/02	22	7.5	1.3	1.5	0.8	4.4	1.2	5.3	7.1	4.6		1.8	0.5	3	0.15	7.5	55	870
S-G-C1	62325	2-3'	9/18/02	23	7.6	1.0	1.0	0.6	3.8	1.1	4.2	5.5	4.7		1.4	0.4	2	0.15	4.4	31	770
S-G-C1	62325	3-4'	9/18/02	24	7.8	0.9	0.9	0.5	4.3	0.8	3.3	4.2	6.1		1.2	0.3	2	0.15	2.7	21	730
S-G-C1	62325	4-5'	9/18/02	23	7.8	1.3	1.2	0.6	6.9	1.3	4.5	7.0	8.5		1.0	0.2	3	0.15	3.5	16	650
S-G-C2	62534	2.5'	9/26/02	25	6.8	0.9	0.6	0.3	2.5	1.3	4.0	5.0	3.8		0.79	0.5	1.5	0.15	5.8	25	760
S-G-C2	62534	5.0'	9/26/02	29	7.6	1.2	1.6	0.9	4.4	0.6	4.3	4.4	4.4		0.60	0.3	7.7	0.25	1.3	11	850
S-G-C3b	62872	0-1'	10/9/02	23	6.5	1.3	1.4	0.9	1.7	1.8	9.5	5.6	1.2		6.7	1.1	10	0.1	41.6	74	950
S-G-C3b	62872	1-2'	10/9/02	23	7.4	1.0	1.6	0.7	2.3	2.1	5.0	6.3	1.9		1.6	0.6	2	<0.1	13.5	38	820
S-G-C3b	62872	2-3'	10/9/02	21	7.7	1.0	1.4	0.6	3.7	1.8	4.1	8.1	4.0		1.2	0.4	1	<0.1	5.9	25	850
S-G-C3b	62872	3-4'	10/9/02	22	7.6	0.9	1.3	0.6	3.6	0.9	3.3	4.7	4.1		1.2	0.4	1	<0.1	3.9	18	680
S-G-C3b	62872	4-5'	10/9/02	22	7.5	1.1	1.7	0.8	5.3	1.1	3.5	6.6	5.4		1.0	0.3	2	<0.1	3.1	17	680
S-G-C4	63080	0-1'	10/21/02	25	6.7	1.2	1.2	0.7	1.1	1.4	7.0	4.6	0.5		5.50	1	9	0.1	30.9	93	1070
S-G-C4	63080	1-2'	10/21/02	23	7.2	1.1	1.1	0.9	2	1.3	6.6	8.6	1.7		1.90	0.6	2	<0.1	15	45	1050
S-G-C4	63080	2-3'	10/21/02	23	7.4	0.9	0.7	0.4	2.3	1.5	4.6	7.4	3.2		0.90	0.5	1	<0.1	7.4	27	860
S-G-C4	63080	3-4'	10/21/02	22	7.8	0.7	0.7	0.5	2.5	0.9	2.9	2.7	3.2		1.10	0.5	1	<0.1	4.2	24	720
S-G-C4	63080	4-5'	10/21/02	25	7.7	0.7	0.8	0.9	3	0.8	2.8	3.2	3.4		1.10	0.4	1	<0.1	2.1	14	740
S-G-C5	63305	0-1'	10/30/02	25	6.9	1.2	1.1	0.7	1.8	1.6	7.3	5.3	1.4		3.7	0.8	6	<0.1	23.9	76	980
S-G-C5	63305	1-2'	10/30/02	23	7.5	0.8	1.1	0.6	2.1	1.5	4.3	6.6	2		1.4	0.4	2	0.2	13.2	34	790
S-G-C5	63305	2-3'	10/30/02	23	7.7	0.7	1.0	0.5	1.4	1.0	3.5	6.1	1.2		0.9	0.4	2	<0.1	8.2	24	680
S-G-C5	63305	3-4'	10/30/02	22	7.8	0.6	0.8	0.5	1.9	0.7	2.6	4.0	2.2		0.7	0.3	1	<0.1	4.4	15	810
S-G-C5	63305	4-5'	10/30/02	24	8	0.6	0.8	0.5	2.3	0.7	2.6	3.8	2.8		0.6	0.3	1	<0.1	0.9	14	630
S-G-C7a	63950	0-1'	12/4/02	27	6.5	1.67	1.5	1.3	2	1.7	10	4.3	1.2		376	1	1.1	<0.1	39.4	68	960
S-G-C7a	63950	1-2'	12/4/02	22	7.3	0.92	0.9	0.5	2.9	1.6	4.8	4.9	3.7		462	0.5	1	0.1	21.6	37	930
S-G-C7a	63950	2-3'	12/4/02	23	7.1	0.98	1.3	0.6	4.1	1.6	3.7	6	4.8		439	0.6	1.1	0.2	16.7	20	800
S-G-C7a	63950	3-4'	12/4/02	22	7.2	0.8	0.8	0.4	3.2	1.1	3.2	6.1	4.7		451	0.5	0.9	<0.1	8.1	15	710
S-G-C7a	63950	4-5'	12/4/02	24	7.5	1.1	1.1	0.5	5.1	1.4	3.9	6.6	6.5		413	0.5	1.8	0.4	3.7	13	790
S-G-C7b	64084	0-1'	12/9/02	23	6.8	1.52	1.6	1.2	2.3	1.9	8.2	4.76	1.6		5	1	1.4	<0.1	7.7	75	910
S-G-C7b	64084	1-2'	12/9/02	21	7.3	1.14	1.8	0.9	4	2.2	5	8.89	3.7		2	0.5	1	<0.1	11.7	42	920
S-G-C7b	64084	2-3'	12/9/02	19	7.4	0.98	1.5	0.7	4.6	1.9	3.7	7.8	4.9		1.3	0.5	1.2	<0.1	7.6	25	690
S-G-C7b	64084	3-4'	12/9/02	21	7.6	0.78	0.8	0.4	2.8	1.2	3.1	4.84	3.9		0.9	0.5	1	<0.1	4.8	20	600
S-G-C7b	64084	4-5'	12/9/02	21	7.9	0.88	1.4	0.7	3.2	1.2	3.5	4.6	3.3		1.3	0.5	1.4	<0.1	2.5	19	710
S-G-rain	64575	0-1'	1/20/03	24	6.6	1.2	1.3	1.2	1.8	1.3	8.2	3.3	1.0		7	0.8	1	<0.1	22	74	870
S-G-rain	64575	1-2'	1/20/03	22	7.2	0.9	0.9	0.5	1.9	2.2	5.4	6.5	2.0		1.2	0.5	1	<0.1	15.4	34	990
S-G-rain	64575	2-3'	1/20/03	21	7.2	0.68	0.5	0.3	1.6	0.9	3.8	4.9	2.6		0.6	0.5	1	<0.1	14.7	20	950
S-G-rain	64575	3-4'	1/20/03	23	7.5	0.61	0.5	0.3	2.2	0.7	3.0	3.1	3.8		0.6	0.4	1	<0.1	6.8	15	750
S-G-rain	64575	4-5'	1/20/03	24	7.6	0.74	0.7	0.4	3.1	0.8	3.2	3.8	4.6		0.7	0.4	1	<0.1	5.1	13	790

No.	DEPTH	% TN combust	% TC combus	$CaCO_3$ equiv	TOC calc	mg/kg Mn	mg/kg Fe	% P	1:1 pH	1:1 EC	***1:1 TDS	1:1 VDS	1:1 IDS	1:1 TC	1:1 HCO_3	Ammonium Acetate Extraction, ppm Ca	ppm Mg	ppm Na	Ammonium Acetate Extraction, meq/100g Ca	meq/100g Mg	meq/100g Na	Sat paste EC* 10/ Sum Cat.	1:1 extract *Est. IDS	1:1 extract **Ratio EST IDS/IDS
S-G-C0	0-1'	0.47	0.07	0.40		44	4413	0.02	6.8	0.66	8230	660	7570	358	2.81	249	76	36	1.2	0.6	0.2	1.0	419.84	0.06
S-G-C0	1-2'	0.13	0.15	<0.01		122	11230	0.03	7.5	0.42	16920	1330	15590	177	3.38	240	92	82	1.2	0.8	0.4	1.1	267.52	0.02
S-G-C0	2-3'	0.07	0.12	<0.01		231	12795	0.02	7.6	0.41	17020	1200	15820	98.47	2.81	245	73	53	1.2	0.6	0.2	1.1	264.96	0.02
S-G-C0	3-4'	0.05	0.10	<0.01		208	10785	0.01	7.8	0.39	12030	910	11120	51.46	2.56	323	70	41	1.6	0.6	0.2	1.1	250.88	0.02
S-G-C0	4-5'	0.04	0.15	<0.01		79	5745	0.01	7.8	0.45	17410	1280	16130	52.62	2.95	398	103	42	2.0	0.8	0.2	1.1	284.8	0.02
S-G-C0	5-6'	0.04	0.12	<0.01		226	15035	0.02	7.6	0.45	12120	770	11350	35.70	2.07	722	177	76	3.6	1.5	0.3	1.0	289.28	0.03
S-G-C1	0-1'	0.35	0.10	0.25		103	10790	0.05	6.8	0.40	8620	740	7880	226	2.32	226	83	24	1.1	0.7	0.1	1.1	257.28	0.03
S-G-C1	1-2'	0.11	0.15	<0.01		145	12435	0.03	7.6	0.39	17900	930	16970	148	2.95	330	83	67	1.6	0.7	0.3	1.1	250.24	0.01
S-G-C1	2-3'	0.07	0.17	<0.01		181	12260	0.02	7.8	0.32	18680	900	17780	109	3.04	219	71	105	1.1	0.6	0.5	1.0	201.6	0.01
S-G-C1	3-4'	0.05	0.15	<0.01		188	12390	0.02	8.0	0.31	21360	1260	20100	72.74	3.19	338	79	105	1.7	0.7	0.5	1.0	195.2	0.01
S-G-C1	4-5'	0.05	0.10	<0.01		134	11815	0.01	8.0	0.38	19640	1580	18060	60.28	3.28	411	90	125	2.1	0.7	0.5	1.0	240.64	0.01
S-G-C2	2.5'	0.08	0.10	<0.01		112	11365	0.02	7.4	0.29	16480	1170	15310	119	2.42	161	57	49	0.8	0.5	0.2	1.1	186.88	0.01
S-G-C2	5.0'	0.05	0.12	<0.01		293	17220	0.02	8.0	0.46	21620	1600	20020	54.01	3.28	698	147	92	3.5	1.2	0.4	1.1	291.84	0.01
S-G-C3b	0-1'	0.075	0.527	0.22	0.307	83	8215	0.05	7.1	0.47	6000	310	5690	218	1.83	255	79	24	1.3	0.7	0.1	1.0	297.6	0.05
S-G-C3b	1-2'	0.029	0.196	0.30	<0.01	97	9440	0.04	7.9	0.33	12540	750	11790	145	2.81	276	94	39	1.4	0.8	0.2	1.1	209.92	0.02
S-G-C3b	2-3'	0.014	0.067	0.20	<0.01	145	10265	0.02	8.2	0.27	15590	990	14600	99.3	2.81	305	99	94	1.5	0.8	0.4	1.0	170.24	0.01
S-G-C3b	3-4'	0.013	0.057	0.20	<0.01	233	11170	0.02	8.2	0.25	14690	480	14210	72.2	2.81	301	87	68	1.5	0.7	0.3	1.0	160	0.01
S-G-C3b	4-5'	0.013	0.050	0.15	<0.01	161	10325	0.01	8.0	0.30	21320	940	20380	62.4	2.81	417	112	93	2.1	0.9	0.4	0.9	192.64	0.01
S-G-C4	0-1'	0.06	0.41	0.10	0.31	90	9687	0.05	7	0.43	9880	990	8890	275	1.83	227	86	19	1.1	0.7	0.1	1.2	275.2	0.03
S-G-C4	1-2'	0.02	0.13	0.15	<0.01	112	10619	0.04	7.7	0.33	17320	1400	15920	203	2.32	258	101	39	1.3	0.8	0.2	1.0	211.2	0.01
S-G-C4	2-3'	0.02	0.07	0.05	0.02	157	10179	0.02	8.1	0.24	19850	1470	18380	119	2.56	204	74	44	1.0	0.6	0.2	1.1	153.6	0.01
S-G-C4	3-4'	0.01	0.08	0.07	0.01	143	9127	0.02	8.3	0.19	13260	1030	12230	73.5	2.07	274	73	58	1.4	0.6	0.3	1.0	121.6	0.01
S-G-C4	4-5'	0.01	0.06	0.10	<0.01	171	10331	0.01	8.2	0.22	18160	1090	17070	64	2.07	391	79	72	2.0	0.6	0.3	0.9	140.8	0.01
S-G-C5	0-1'	0.071	0.549	0.17	0.53	87	8715	0.05	7.1	0.38	6530	210	6320	215	1.57	261	85	47	1.3	0.7	0.2	1.1	243.2	0.04
S-G-C5	1-2'	0.021	0.021	0.15	0.1	94	9735	0.03	7.8	0.27	12410	390	12020	138	2.21	238	82	49	1.2	0.7	0.2	1.0	172.8	0.01
S-G-C5	2-3'	0.015	0.069	0.1	0.06	95	7540	0.02	7.9	0.23	13290	320	12970	92.7	2.29	399	107	53	2	0.9	0.2	1.1	147.2	0.01
S-G-C5	3-4'	0.012	0.055	0.3	0.02	134	7575	0.02	7.9	0.17	12000	270	11730	62.8	2.00	227	82	28	1.1	0.7	0.1	1.0	108.8	0.01
S-G-C5	4-5'	0.009	0.039	0.22	0.01	150	7885	0.01	8.1	0.22	17290	440	16850	53.3	2.81	183	73	43	0.9	0.6	0.2	1.0	140.8	0.01
S-G-C7a	0-1'	0.069	0.521	0.22	0.49	92	9595	0.06	7.12	0.49	8200	950	7250	372	2.3	223	82	18	1.1	0.7	0.1	1.1	313.6	0.04
S-G-C7a	1-2'	0.025	0.123	0.3	0.09	100	10305	0.03	7.68	0.29	18510	1570	16940	263	2.4	215	86	48	1.1	0.7	0.2	1.0	185.6	0.01
S-G-C7a	2-3'	0.012	0.076	0.18	0.05	183	10545	0.02	7.71	0.21	19840	1730	18110	129	1.9	171	69	68	0.9	0.6	0.3	1.0	134.4	0.01
S-G-C7a	3-4'	0.011	0.074	0.1	0.06	204	9695	0.02	7.72	0.21	16170	1440	14730	91.6	1.9	182	71	61	0.9	0.6	0.3	1.1	134.4	0.01
S-G-C7a	4-5'	0.013	0.061	0.27	0.03	193	11495	0.02	7.91	0.29	25240	2020	23220	81.7	2.3	375	95	87	1.9	0.8	0.4	1.0	185.6	0.01
S-G-C7b	0-1'	0.052	0.403	0.17	0.38	98	10424	0.05	7.06	0.38	8810	440	8370	291.7	1.7	250	88	-1	1.2	0.7	0			
S-G-C7b	1-2'	0.017	0.127	0.14	0.11	92	9566	0.03	7.70	0.28	22250	730	21520	208.4	2.7	246	91	41	1.2	0.7	0.2			
S-G-C7b	2-3'	0.012	0.08	0.14	0.06	151	10090	0.02	7.87	0.22	23880	1260	22620	132.7	2.3	226	69	46	1.1	0.6	0.2			
S-G-C7b	3-4'	0.01	0.067	0.34	0.03	258	11103	0.02	7.91	0.2	15590	490	15100	88.74	2.3	281	78	30	1.4	0.6	0.1	*Est. IDS= EC x 640		
S-G-C7b	4-5'	0.015	0.061	0.22	0.03	201	13390	0.02	8.22	0.22	26240	1300	24940	87.53	3.68	491	110	95	2.5	0.9	0.4	**Ratio = EST IDS/ IDS		
S-G-rain	0-1'	0.064	0.472	0.08	0.46	105	10250	0.06	7.15	0.37	5310	420	4890	265.5	2	250	77	26	1.2	0.6	0.1	1.0	236.8	0.05
S-G-rain	1-2'	0.022	0.108	<0.01	0.11	127	10750	0.03	7.67	0.26	12300	1030	11270	134.8	1.9	238	86	39	1.2	0.7	0.2	1.0	165.76	0.01
S-G-rain	2-3'	0.013	0.074	0.06	0.07	252	11750	0.03	7.75	0.18	10870	800	10070	83.5	1.6	205	82	38	1	0.6	0.2	1.1	116.48	0.01
S-G-rain	3-4'	0.012	0.047	0.08	0.04	161	8840	0.02	7.98	0.17	9300	790	8510	50.3	1.4	251	68	54	1.3	0.6	0.2	1.0	107.52	0.01
S-G-rain	4-5'	0.010	0.060	0.03	0.06	167	11480	0.02	8.15	0.21	12110	1010	11100	84.2	1.9	371	83	73	1.9	0.7	0.3	1.0	134.4	0.01

Stillage 09/15/03

Stillage Site Soil Test Results: 09/15/03

Sample ID	Sample Date	Fe	Mn	EC	ESP	NO_3-N	NO_2-N	NH_4-N	Ca	Mg	Na	K	SO_4-S	Cl	PO_4-P	SP	pH
G-PW 0-12	9/15/2003	9800	120	210	1.4	25	<4	94	1100	2100	130	3100	13	<50	41	27.7	5.8
G-PW 12-24	9/15/2003	12000	140	180	1.6	21	<4	38	1000	2300	140	3800	16	<50	31	26.6	5.9
G-PW 24-36	9/15/2003	13000	160	210	2.1	23	<4	24	1000	2700	180	4300	22	<50	17	28	5.9
G-PW 36-48	9/15/2003	12000	270	210	<1.0	24	<4	56	1100	2600	160	3800	28	<20	9.9	30.8	6.6
G-PW 48-20	9/15/2003	16000	340	120	2.0	5.2	<4	22	1800	4300	290	5300	17	<20	6.5	9.4	7.8

Notes: K/J COC # KJ-G-C1, TL # 7030-4908

MM/DD/YYYY = month/day/year of report
Sample ID = field sample identification
Sample Date = date of soil sample

mg/kg = milligrams per kilogram
meq/l = milliequivalents per liter

Sample Amounts:
ESP = 300 g
SP = 200 g
pH = 20 g
Ca, Mg, Mn, Fe, Na, K = 10 g
NO_3, NO_2, SO_4, PO_4, Cl = 20 g

SP = saturation percentage
EC = electrical conductivity (mmho/cm)
ESP = exchangeable sodium percentage
Ca = calcium (mg/kg)
Mg = magnesium (mg/kg)
Fe = iron (mg/kg)
Mn = manganese (mg/kg)
Na = sodium (mg/kg)
K = potassium (mg/kg)
SO_4-S = sulfate (mg/kg)
Cl = chloride (mg/kg)
NO_3-N = nitrate as nitrogen (mg/kg)
NO_2-N = nitrite as nitrogen (mg/kg)
NH_4-N = ammonia as nitrogen (mg/kg)
PO_4-P = phosphate (mg/kg)

Stillage 10/10/03

Stillage Site Soil Test Results: 10/10/03

Sample ID	Sample Date	Fe	Mn	EC	ESP	NO3-N	NO2-N	NH4-N	Ca	Mg	Na	K	SO4-S	Cl	PO4-P	SP	pH
G-C2-0/12	10/10/2003	352	4.4	510	2.2	32	<4	150	49	165	6.1	87	0.58	0.71	130	14.9	6.2
G-C2-12/24	10/10/2003	387	5.8	340	2.8	13	<20	33	44	181	6.5	97	0.36	<0.56	90	11.2	6.5
G-C2-24/36	10/10/2003	387	5.8	340	1.0	17	<20	27	38	165	5.7	82	0.40	<0.56	72	14.0	6.2
G-C2-36/48	10/10/2003	493	9.8	440	0.7	12	<20	36	65	247	8.3	113	0.68	<0.56	24	16.4	7.6
G-C2-48/60	10/10/2003	352	6.2	260	0.7	<20	<20	49	60	173	7.4	69	0.28	<0.56	14	12.2	7.8

Notes: COC # KJ-G-C2, TL # 7030-5500

mg/kg	Ca	Mg	Na	K	Fe	Mn	Cl	SO4	
G-C2-0/12	990	2000	140	3400	10000	120	25	84	27.972
G-C2-12/24	880	2200	150	3800	11000	160	<20	52	17.316
G-C2-24/36	770	2000	130	3200	11000	160	<20	58	19.314
G-C2-36/48	1300	3000	190	4400	14000	270	<20	98	32.634
G-C2-48/60	1200	2100	170	2700	10000	170	<20	41	13.653

MM/DD/YYYY = month/day/year of report
Sample ID = field sample identification
Sample Date = date of soil sample

mg/kg = milligrams per kilogram
meq/l = milliequivalents per liter

Sample Amounts:

ESP = 300 g
SP = 200 g
pH = 20 g
Ca, Mg, Mn, Fe, Na, K = 10 g
NO_3, NO_2, SO_4, PO_4, Cl = 20 g

NO_3, NO_2, SO_4, PO_4, Cl = 20 g

SP = saturation percentage
EC = electrical conductivity (mmho/cm)
ESP = exchangeable sodium percentage
Ca = calcium (meq/kg)
Mg = magnesium (meq/kg)
Fe = iron (meq/kg)
Mn = manganese (meq/kg)
Na = sodium (meq/kg)
K = potassium (meq/kg)
SO_4-S = sulfate (meq/kg)
Cl = chloride (meq/kg)
NO_3-N = nitrate as nitrogen (mg/kg)
NO_2-N = nitrite as nitrogen (mg/kg)
NH_4-N = ammonia as nitrogen (mg/kg)
PO_4-P = phosphate (mg/kg)

Stillage 10/29/03

Stillage Site Soil Test Results: 10/29/03

Sample ID	Sample Date	Fe	Mn	EC	ESP	NO3-N	NO2-N	NH4-N	Ca	Mg	Na	K	SO4-S	Cl	PO4-P	SP	pH
G-C4-0/12	10/29/2003	327	4.0	490	1.8	23	<3.0	220	48	165	5.7	87	0.70	0.62	47	11.9	6.1
G-C4-12/24	10/29/2003	387	5.1	300	3.2	8.4	<3.0	21	47	189	7.0	102	0.33	1.33	38	6.6	7.7
G-C4-24/36	10/29/2003	387	5.8	270	1.6	<4.5	<3.0	14	38	181	6.1	95	0.57	0.56	6.2	10.4	7.7
G-C4-36/48	10/29/2003	493	8.0	460	1.7	5.2	<3.0	16	60	18	8.3	113	0.58	<0.56	10	17.8	8.2
G-C4-48/60	10/29/2003	528	8.0	480	1.3	8.4	<3.0	20	75	288	10.4	123	0.38	<0.56	15	14.4	8.3

Notes: COC # KJ-G-C4b, TL COC # 7030-5860

mg/kg	Ca	Mg	Na	K	Fe	Mn	Cl	SO4	SO4-S
G-C4-0/12	960	2000	130	3400	9300	110	22	100	33
G-C4-12/24	940	2300	160	4000	11000	140	47	47	16
G-C4-24/36	770	2200	140	3700	11000	160	20	82	27
G-C4-36/48	1200	220	190	4400	14000	220	<20	83	28
G-C4-48/60	1500	3500	240	4800	15000	220	<20	55	18

MM/DD/YYYY = month/day/year of report
Sample ID = field sample identification
Sample Date = date of soil sample

mg/kg = milligrams per kilogram
meq/l = milliequivalents per liter

Sample Amounts:

ESP = 300 g
SP = 200 g
pH = 20 g
Ca, Mg, Mn, Fe, Na, K = 10 g
NO_3, NO_2, SO_4, PO_4, Cl = 20 g

NO_3, NO_2, SO_4, PO_4, Cl = 20 g

SP = saturation percentage
EC = electrical conductivity (mmho/cm)
ESP = exchangeable sodium percentage
Ca = calcium (meq/kg)
Mg = magnesium (meq/kg)
Fe = iron (meq/kg)
Mn = manganese (meq/kg)
Na = sodium (meq/kg)
K = potassium (meq/kg)
SO_4-S = sulfate (meq/kg)
Cl = chloride (meq/kg)
NO_3-N = nitrate as nitrogen (mg/kg)
NO_2-N = nitrite as nitrogen (mg/kg)
NH_4-N = ammonia as nitrogen (mg/kg)
PO_4-P = phosphate (mg/kg)

Appendix D

Regional Water Quality Control Board (RWQCB) Comments on First Year of Study and Kennedy/Jenks Response to RWQCB Comments

WINE INSTITUTE

ROBERT P. KOCH
PRESIDENT AND CHIEF EXECUTIVE OFFICER

May 10, 2004

Mr. Bert E. Van Voris
Supervising Engineer
California Regional Water Quality Control Board
Central Valley Region, Fresno Branch Office
1685 E. Street
Fresno, CA 93706-2020

Subject: Response to CRWQCB Review Comments on Wine Institute Final Draft Land Application of Winery Stillage and Non-Stillage Process Water Study Results and Proposed Guidelines

Dear Mr. Van Voris:

Thank you for your letter of 23 December 2003 providing the Central Valley RWQCB staff's comments on our Final Draft Land Application of Winery Stillage and Non-Stillage Process Water Study Results and Proposed Guidelines dated 2 May 2003. We appreciate the staff's input as part of a continued collaboration between the RWQCB staff and the Wine Institute to develop updated guidelines for land application of these winery process waters.

2002 Field Studies

Kennedy/Jenks Consultants prepared the May 2003 Final Draft Report for the Wine Institute to document a 2002 field study at two volunteer wineries to address key technical, scientific, and operational issues associated with minimizing environmental impacts of winery process water land application. To develop the updated draft guidelines, a range of loading rates was examined during the 2002 field studies to determine rate-limiting constituents. To properly assess a potential range of loading rates, some individual applications were designed to exceed loadings in the existing Metcalf and Eddy Guidelines and the draft recommended guidance while other applications were designed to be much lower than recommended guidance. Thus, some of the data gathered during 2002 are not representative of applications that comply with the guidelines.

In 2003, field studies were performed using the draft guidelines. The results of the second year testing will be used to refine the guidelines and will be incorporated into the final report.

Response to General Comments

Your letter raised several general comments concerning the draft report and proposed guidelines. A report covering the two years of study will be issued later this year. Responses to general comments are discussed below.

Avoidance of Nuisance Conditions

RWQCB staff questioned the proposed guidelines that suggested that up to 5 days of process water application would be appropriate so long as odor generation did not occur. It appears that staff interpreted this guideline to mean standing discharge for five days. The recommended guideline is not intended to mean standing discharge for 5 days, but rather application for 5 days without free standing process water and with adequate infiltration and percolation. We feel that discharge up to 5 days is appropriate under certain conditions and odor generation does not occur. There are existing wineries with land application systems that discharge over 5 days without odors.

Free-draining Depth

RWQCB staff objected to the proposed guidelines that suggested a free draining depth of 15 feet because it is greater than the generally accepted root zone depth of 5 feet. We believe that it is inappropriate to dismiss additional treatment and attenuation at depths greater than 5 feet in the soil profile based on the first year study. The first year study was not designed to provide field data on this issue. The revised report will include a state-of-the-literature review of the science of land application and soil aquifer treatment, including available information on treatment and attenuation below 5 feet. This will enable the development of science and cost/effectiveness-based operational guidelines for land application areas in the future to achieve balanced treatment and removal of constituents in the entire soil profile to minimize the potential for impacts to underlying groundwater.

Field Testing at New Land Application Sites

RWQCB staff suggested field testing at new land application sites to evaluate the guidelines so that there would be less difficulty in evaluating impacts from historical practices. This was not practical to implement in the second year of study. Although such a study would yield interesting results, the fate and transport time associated with land application and constituents of concern potentially migrating to groundwater means that it could take decades to observe any results. This is also the case with historical operations, where changing past practices that may have been different than the proposed guidelines and perhaps not as sustainable, would not be expected to change impacts to groundwater overnight. There would be a lengthy fate and transport time associated with any change in practices.

Best Practical Treatment and Control (BPTC) and Compliance with Non-Degradation Policy

The RWQCB letter states "...the guidelines must define the parameters under which land application of waste can be performed and ensure compliance with water quality control plans, including the State Antidegradation Policy..." Specifically, "...degradation of groundwater that results from land treatment of winery waste can be no greater than degradation that results from BPTC applied directly to waste streams *prior* to release (such as biological treatment to render waste nonputrescible prior to discharge)."

Although this is an important consideration, it is beyond the scope of this report, but has been identified as a future study need. On the basis of our understanding of soil and water chemistry, we believe that such an analysis would demonstrate that the two approaches would be equivalent in most situations.

Response to Specific Comments

The enclosure to this letter provides responses to the RWQCB staff's "Table of Specific Comments on Report," enclosed with your 23 December 2003 letter. We have repeated each comment and provided a separate response to each comment. Where appropriate, we describe how comments are being addressed in the 2003 field study.

The interaction of process water percolating through soil is quite complex. Throughout the report, the RWQCB staff raised questions several times concerning water quality issues (pH, nitrogen control, and iron/manganese and calcium carbonate release) that demonstrate the need for providing a better overall description of the interactions between soil and process water chemistry. These interactions are quite complex as inorganic constituents can be transported back and forth between the soil and water phases. For example, calcium and alkalinity can be released from the soil to maintain pH due to carbon dioxide in the biodegraded process water (whether biodegradation occurs before or after land application) and calcium carbonate can reprecipitate under reaerated conditions. A state-of-the-literature description will be provided in an appendix to the final report.

We look forward to our next meeting to continue to discuss and develop sustainable land application guidelines for winery process water. Please contact Wendell Lee at 415-356-7534 or Robert S. Chrobak at 415-243-2524 if you have any questions or need additional information.

Very truly yours,

Robert P. Koch

RPK:kc
Enclosure: Response to Comments from Central Valley RWQCB

Response to Comments 10 May 2004

Item	Page		RWQCB's Comment/Recommendation
1.	Glossary	C(1)	Commendable overview of current terminology, especially as it pertains to loading rate definitions.
	Wine Institute response		*Thank you for your comment.*
2.	Glossary II	R	Disking/Tilling – identify potential need to implement management practices to minimize PM-10 production (especially in San Joaquin Valley).
	Wine Institute response		*The potential need to implement best management practices for disking/tilling to minimize PM-10 emissions is an issue unrelated to this land application study. The wine industry is addressing the issue by participating in a response to the Air District's Rule 4550/3190 Fee.*
3.	Glossary II	R	Leveling – identify optimum slope to ensure discharge flows quickly and uniformly across disposal surface.
	Wine Institute response		*Additional details regarding leveling and slope of land application areas will be included In the revised report.*
4.	Glossary II	R	Process Water – identify potential to contain high IDS wastestreams (e.g., ion exchange regenerant, boiler blowdown, etc.)
	Wine Institute response		*Identification and discussion of the potential need to control higher IDS streams will be included in the revised report.*
5.	Glossary III	R	Spreading Basin – entry reference to "larger infiltration ponds" identify maximum pond depth.
	Wine Institute response		*Maximum depth is not identified for any of the types of spreading basins described. Including a maximum depth for larger infiltration ponds is not necessary.*
6.	Executive Summary 2, 2002 Study Results - pH	C	Study results have not ruled out that soil buffering is not accomplished without the excessive dissolution of soil minerals (e.g., calcium carbonate). Evidence of Ca+Mg dissolution from lysimeter and soil monitoring data is consistent with a hypothesis that acidity buffering is causing the release of IDS from soil and potentially into groundwater.
	Wine Institute response		*Study results indicate that biological activity and decomposition of organics in process water occur at depth and byproducts of these processes and activities result in carbon dioxide and water. Some carbon dioxide may remain trapped in the subsurface and cause some movement of ions and reprecipitation. Release of carbon dioxide and available soil buffering capacity control the movement of the ions. The revised report will summarize the state-of-the-literature on ion dissolution and reprecipitation in the subsurface throughout the entire soil profile.*

Item	Page		RWQCB's Comment/Recommendation
7.	Executive Summary 2, 2002 Study Results - BOD	C	Soil oxidation of 85% BOD at 5' means [BOD] in percolate/leachate released from treatment zone was stronger than domestic waste (around 300 mg/L for Bronco, and 700 mg/L for Gallo).
	Wine Institute response		*The purpose of the first year study was to challenge the existing guidelines for land application of stillage and develop the science behind it. There was no attempt to manage and optimize the BOD removal at any depth and yet an average of 85% removal was achieved. The purpose of the second year study is to test the proposed guideline, observe the results, and then optimize and refine the proposed guideline. This will enable the development of science and cost/effectiveness-based operational guidelines for land application areas in the future to achieve balanced treatment and removal of constituents in the entire soil profile to minimize the potential for impacts to underlying groundwater.*
8.	Executive Summary 2-3, 2002 Study Results - Fe+Mn	C	Data show lowest BOD loadings cause percolate [Fe] and [Mn] to exceed water quality objectives (WQOs) (i.e., 0.3 and 0.05 mg/L, respectively, from California State secondary drinking water standards). Due to the uncertainty concerning precipitation in the lower soil, BOD loadings should not be based on operating at the threshold of pollution.
	Wine Institute response		*The proposed guidelines were developed on the basis of experimental process water applications designed to challenge the existing guidelines during the first year. The revised guidelines will be developed on the basis of the second year of study and will discuss optimization of treatment and removal of constituents, including BOD, in the entire soil profile to minimize the potential for impacts to underlying groundwater.*
9.	Executive Summary 3, 2002 Study Results - N	C	Proper cycling is identified as critical for N removal. Identifying proper cycling is site-specific and will likely require dischargers to increase data collection efforts and optimize waste minimization and disposal practices.
	Wine Institute response		*The proposed guideline includes the concept of site characterization and monitoring.*
10.	Executive Summary 3, 2002 Study Results - TDS	C	The data suggest a possible stochiometric relationship between the organic fractions of applied TDS with the concentrations of organic decomposition byproducts (alkalinity, Ca, Mg). Long-term and continuous field testing should be performed to test the likelihood of assumed reaeration. Evidence of Ca and alkalinity degradation in groundwater passing under organically overloaded sites (e.g., unlined sludge drying beds, food-processing waste discharges) suggests that reaeration, if it occurs at all during the year, is insufficient to adequately attenuate these constituents in the vadose zone.

Item	Page		RWQCB's Comment/Recommendation
	Wine Institute response		*The cycling (dissolution/precipitation) of calcium carbonate in the vadose zone will be site specific and depend on the organic loading. Because the source of the calcium carbonate is the soil matrix, it would be self-sustaining if loadings are properly controlled.*
11.	Executive Summary 3, 2002 Study Results - Per-Application Loading Rage	C	Important recommendation to establish hydraulic loading not simply to percolate in time for the next application but to enhance control by maximizing treatment in the upper soil profile.
	Wine Institute response		*Thank you for your comment.*
12.	Executive Summary 3, 2002 Study Results - Duration of Resting Cycle	C	How did initial test period loadings compare with historic loadings? Identifying the correct sequence of aerobic/anaerobic conditions may require sophisticated monitoring, which will require considerable commitment by the regulated community. Due to uncertain reaeration in the lower vadose zone, it is risky to optimize N removal by operating on the threshold of releasing Fe+Mn to percolate in concentrating magnitudes higher than WQOs.
	Wine Institute response		*Comparing initial test period loadings to historic loadings at the two sites that volunteered their land application basins and process water would not be relevant to the study's design goals. The study was designed to assess guidelines intended to optimize treatment during land application. The starting points for that evaluation of treatment efficacy were the application rates and resting periods defined in the 1980 M&E report, not historic loadings at the two volunteer sites. The study's first year tests were designed to challenge the existing guidelines for land application of stillage and develop the science behind them. There was no attempt to manage or optimize for nitrogen removal at any particular depth, and yet for some cycles of application, effective treatment was achieved. The second year study will test the proposed guidelines developed from the first year data, observe the results, and then optimize and refine the guidelines. This process enables the development of science and cost-effectiveness-based operational guidelines for land application in the future to achieve balanced treatment and removal of constituents in the entire soil profile to minimize potential impacts on underlying groundwater.*

Item	Page		RWQCB's Comment/Recommendation
13.	Executive Summary 3, 2002 Study - closing paragraph, last sentence	C	Report identifies need for proper discharge management (i.e., to identify suitable discharge rates and properly managed resting periods). The test data reveal that treatment was anything but a success, for it resulted in the release to percolate (and potentially to groundwater) of IDS and TDS constituents in concentrations exceeding WQOs and, in many cases, that in the discharge.
	Wine Institute response		*We respectfully disagree with the statement that "The test data reveal that treatment was anything but a success..." because the purpose of the first year study was to challenge, in some cases exceed, the existing guidelines for land application of stillage and develop the science behind them. There was no attempt to manage or optimize for specific constituent removal at any depth, and yet for some cycles of application very effective treatment was achieved. The report clearly documents successful removal of various constituents for various cycles of application and treatment. The purpose of the second year study is to test the proposed guideline, observe the results, and then optimize and refine the proposed guideline. This will enable the development of science and cost/effectiveness-based operational guidelines for land application in the future to achieve balanced treatment and removal of constituents in the entire soil profile to minimize the potential for impacts to underlying groundwater. It is our opinion that comparison of percolate quality data at the 5 foot depth to Water Quality Objectives (WQOs) under the assumption that no further attenuation or treatment is occurring in the remainder of the soil profile below 5 feet is inappropriate and inconsistent with what is actually observed at operating sites. Our experience and the available data indicate that treatment and further attenuation has occurred at these historical operations.*
14.	Executive Summary 4, 2002 Study - Conclusions		Report concludes that pH is not a critical process factor. However, test results have yet to demonstrate that soil buffering does not cause excessive dissolution of soil minerals (e.g., calcium carbonate). Evidence of Ca+Mg dissolution from lysimeter and soil monitoring data is consistent with a hypothesis that acidity buffering is causing IDS to be released from soil and potentially into groundwater. Report indicates operating the discharge to maximize nitrogen attenuation is complex. Assumed reliance on soil below 5' for additional treatment is not consistent with State Board or Regional Board plans and policies. Approval of such reliance must be substantiated by evidence indicating attenuation occurs into perpetuity and will not cause or contribute to exceedances of WQOs in groundwater. Basin plan amendments are the vehicles for revising WQOs for waters within the region.
	Wine Institute response		*The report states that pH is not a critical process factor because the soil and pore water pH are within acceptable limits. The low pH in winery process water is due to organic acids that are a food source for microorganisms in the soil profile. The study results*

Item	Page		RWQCB's Comment/Recommendation
			indicate that biological activity and decomposition of those organic acids in process water occur at depth and byproducts of these processes and activities result in alkalinity (for the ionized portion of the organic acids to maintain charge balance), carbon dioxide, and water. Some carbon dioxide may remain trapped in the subsurface and cause movement of ions and reprecipitation. Resting cycles result in the release of carbon dioxide from the soil pores, and this also impacts the dissolution and reprecipitation of ions that interact with available soil buffering capacity to adjust the pH naturally and to control the movement of the ions. We believe that this cycling of alkalinity can be managed with proper cycling of application and treatment. The revised report will summarize the state-of-the-literature regarding ion dissolution and reprecipitation in the subsurface throughout the entire soil profile. *The report states that operating the land application process to maximize nitrogen removal is complex. The purpose of the first year study was to challenge the existing guidelines for land application of stillage and develop the science behind them. There was no attempt to manage or optimize for Nitrogen removal at any depth, and yet for some cycles of application effective treatment was achieved. The purpose of the second year study is to test the proposed guideline and observe the results and then to optimize and refine the proposed guideline. This will enable the development of science and cost/effectiveness-based operational guidelines for land application areas in the future to achieve balanced treatment and removal of constituents in the entire soil profile to minimize the potential for impacts to underlying groundwater.* *It is inappropriate to dismiss additional treatment and attenuation at depths greater than 5 feet in the soil profile because the first year study was not designed to provide data below 5 feet. The revised report will include a state-of-the-literature review of the science of land application and soil aquifer treatment. That review will include available information on treatment and attenuation below 5 feet. The comment that attenuation must occur in perpetuity is inappropriate and premature based on the available study data.*
15.	Page 1-2, on Alkalinity measurements	C	Evidence is required to support conclusion that Ca+Mg and alkalinity impacts from winery wastewater discharges are comparable to that occurring naturally in arid-land soils as a result of irrigated agriculture with respect to type, magnitude, and impact rate.

Item	Page		RWQCB's Comment/Recommendation
	Wine Institute response		*The authority used to address the precipitation and dissolution of calcium in connection with carbonate carbon dioxide, and alkalinity is a soil chemistry text, Bohn, McNeal, and O'Connor, page 109. This text presents a sensible treatment of this very common "weathering" reaction in soils.*
16.	Page 1-2, on general water treatment process	C	Good overview of the biochemical and physical reactions in the soil treatment process. Conclusion that properly managed discharges generally show no effect on soil pH should be substantiated by long-term data and field testing to determine the extent to which soil buffering causes the release of VDS and IDS constituents from soil to percolate.
	Wine Institute response		*Thank you for the comment. See responses in 6 and 14 also.*
17.	Page 1-2, on general water treatment	Q	Could Kennedy/Jenks provide copies of cited articles by Enfield 1977 and Gilbert et al. 1979?
	Wine Institute response		*Kennedy/Jenks will provide copies of the cited articles.*
18.	Page 2-1, Table 1	R	What are the time frames for the cited ranges of BOD, N, TDS? Do data reflect grab samples? What is the frequency of sampling? Stating Bronco Winery's typical application operation parameters are variable is not informative. If possible, cite what Bronco considers low and high application depths and short and long cycles. Also, cite years of active discharge.
	Wine Institute response		*The final report will address the recommendation in greater detail than was presented in the Final Draft report.*
19.	Page 2-2, Table 2, on Water Samples	Q	Was soil moisture data utilized to time sample collection, and if so, how?
	Wine Institute response		*Soil moisture data were not used to time sample collection in the first year of study. Cycle length determined by experimental design and visual observation of surficial moisture as well as regularly scheduled maintenance were used to determine sample collection.*
20.	Page 2-3, §2.4.1 Lysimeter Event Loggers	Q	What was the data output for the tipping cups?
	Wine Institute response		*The data output is number of events or tips. Tipping cups were calibrated prior to installation. The data presented are a result of events multiplied by calibrated volume for an event.*
21.	Page 2-3, §2.4.2 Soil Moisture Sensors	Q	What was the data output for the soil moisture sensors?
	Wine Institute response		*Data output for the soil sensors is soil water potential as a function of time and depth. The units used are kilopascals (See Figure 5).*

Item	Page		RWQCB's Comment/Recommendation
22.	Page 2-3, §2.4.3 Soil Gas Probes	R	More detail on the soil gas probes (manufacturer, model, sensitivity, installation) should be provided.
	Wine Institute response		*Additional explanation and detail related to the soil gas investigation during the first year of study will be included in the revised report.*
23.	Page 3-1, §3.1 Hydraulic Loading	Q	Were approximations for percolate quantities based on water balance or lysimeter sample collection volumes? Were the test site soils ever evaluated for porosity and, if so, what are the ranges? If the approximated volume of percolate reached groundwater, how much vertical depth would the discharge's contribution occupy? What is that depth compared to perforation intervals in groundwater monitoring wells for the two test sites?
	Wine Institute response		*Approximations for percolate quantities were based on both water balances and sample collection volumes. Figure 4 of the report provides the dataset used for analysis. Test soils were not tested for porosity as part of this study. Instead, available data for the site from other investigations and Soil Conservation Service mapping were used. Porosity was not explicitly used in the study. Available water holding capacity and soil texture information were used.*
24.	Page 3-2, §3.1.2 Stillage Site	C	The extreme variability in discharge quality should be avoided in future field tests, perhaps by equalizing flow prior to discharge (essentially discharge a very large daily composite sample to the test basin).
	Wine Institute response		*The variability is a realistic representation of actual winery operations during the first year of study. The revised report will include second year data also.*
25.	Page 3-2, §3.1.4 Infiltration Rates...	Q	Is disking at the end of each cycle or just prior to the next application standard operating procedure at both sites? Cited Figure 5 of soil moisture with time shows all 7 cycles in the Stillage Site, but only cycle 4 in the Non-Stillage Site. Also, were the field capacities determined for each test basin and, if so, what are they?
	Wine Institute response		*Basin maintenance was not altered for the study. Disking was performed in the same manner at both sites during both regular operation and during the study. Soil moisture sensor wires were severed during a disking event at the Non-Stillage site yielding incomplete data at this loction.*
26.	Page 3-3, §3,2 pH effects	C	Field tests should be performed to determine whether or not soil buffering causes IDS and VDS to be released from the soil in excessive concentrations (e.g., by operating a control plot with receiving the same wastewater except for being pH neutralized with ammonia). Is there information on both sites as to the fluctuations of pH through the processing day?

Item	Page		RWQCB's Comment/Recommendation
	Wine Institute response		*Neutralization with salts or ammonia prior to land application is inappropriate because both additions contribute to the loading of the soil at the land application area either with salt or nitrogen. In addition, nitritification-denitrification processes will consume more alkalinity than the ammonia provides, thus allowing more dissolution of calcium carbonate than would occur if none were added at all. The biological decomposition of the organic constituents in the winery process water within the soil profile provides alkalinity for pH neutralization by natural processes. See responses to comments in 6 and 14. (Gallo and Bronco input needed here for pH variability observed during the daily operations.)*
27.	Page 3-4, §3,3.1 IDS Concentration Changes ...	C	Data for both sites show substantial IDS impacts from the discharge that cannot be explained by just concentration effects. If increase due solely to evaporation, [C1] increases in percolate would be more pronounced and proportional to [IDS] increases.
	Wine Institute response		*When IDS constituent loading and recovery are reviewed on a load basis (Table 6) that incorporates the water balance, [Cl] remains relatively constant for both sites (93% and 86% for Non-Stillage and Stillage, respectively).*
28.	Page 3-5, Role of Alkalinity	Q	Explain the statement, "Although there were increases or no change in IDS loads between the soil surface and 5' at both test sites, individual ion analysis indicates that the majority of this increase is due to alkalinity increases." Is "IDS load" meant only from the discharge and not also from mineral releases from soil from organic decomposition? If alkalinity impacts can be reversed by adequate reaeration, then evidence of alkalinity degradation in groundwater passing under winery waste disposal sites is evidence of inadequate aeration (and, by extension, organic overloading). Also, what is the scientific rationale for the presumed reaeration of percolate in the deeper zones when it contains relatively high concentrations of total organic carbon?

Item	Page		RWQCB's Comment/Recommendation
	Wine Institute response		*The general outcome of 2002 IDS species concentration changes was that, while total IDS changed a relatively small amount, the species composition did change. This is commonly observed in the literature of soil science (e.g., Bower, 1974) and is the result of both a) the existing ratios of salt ions in the soil solution and on cation exchange sites; and b) the interaction with calcium carbonate, carbon dioxide, and water in the soil. This geochemical reaction is the most common chemical reaction in soils (Bohn, McNeal, and O'Connor, 1979). In arid regions such as the California Central Valley, calcium is often the most prevalent cation in the soil. Regarding the direct relationship between organic loading and changes in groundwater solution composition, the geochemical system will change whether there are organics present or not. This presumed direct relationship is an unnecessary oversimplification. Deeper zone TOC is relatively non-biodegradable and possesses little to no BOD_5*
29.	Page 3-5, §3.4 BOD Reduction	C	Another management practice is to not load BOD at rates that will cause excessive IDS and TDS releases to percolate. (Percolate IDS and TDS will figure significantly in evaluating (a) the extent to which land application is equivalent to best practicable treatment and control and (b) the discharge's potential to degrade or pollute groundwater.
	Wine Institute response		*The purpose of the second year study is to test the proposed guideline, observe the results, and then optimize and refine the proposed guideline. This will enable the development of science and cost/effectiveness-based operational guidelines for land application areas in the future to achieve balanced treatment and removal of constituents in the entire soil profile to minimize the potential for impacts to underlying groundwater.*
30.	Page 3-7, §3.5.1 Nitrogen Transformation, Non-Stillage Test Site	C	Extremely high percolate [N] in initial cycles demonstrates evidence of excessive N accumulation in Non-Stillage Test Site soils.
	Wine Institute response		*Test basins were not cropped prior to the study season. It appears that nitrogen from the previous application season remained in the soil and flushed during initial test application cycles.*

Item	Page		RWQCB's Comment/Recommendation
31.	Page 3-7 through 3-8, §3.5.2 Nitrogen Transformation, Stillage Test Site	C	Cycles 2 and 3 were within Stillage Guidelines, yet prolonged saturated soil conditions occurred and total nitrogen removal was not efficient. This suggests that loadings and rest cycles recommended in the Stillage Guidelines, which focused on nuisance condition control, are not conducive for optimal soil treatment. The report's suggested solution of applying 'relatively large loads with longer resting periods' to achieve efficient nitrogen removal would result in conditions that have long been recognized as conducive to the creation of odor and vector nuisances.
	Wine Institute response		*Odor nuisances were controlled at the Stillage site throughout the 2002 study season except for a 48 hour period during the rest period of cycle 4 (pg 3-3 of Final Draft Report). Cycles 2 through 5 challenged the treatment system, as sufficient drying periods were not allowed. Odors may appear after prolonged anaerobic organic decomposition (usually in the presence or organic or inorganic sulfur) at or near the soil surface. The proposed guidelines indicate that sufficient reaeration is needed in the surface soils (i.e. two feet BGS) prior to reapplication to control odors. The data gathered in the 2002 crush season suggest that if surficial aeration occurs, relatively large loads provide a better subsurface (non-odor causing) anaerobic zone to more efficiently denitrify.*
32.	Page 3-8, §3.6 DO Levels & Fe+Mn Mobilizations	C	Good control of soil treatment environment would be evidenced by [Fe] and [Mn] at or below WQOs. Invariably, percolate [Fe] and [Mn] at both sites exceeded WQOs by orders of magnitude. Report notes that low [N] in percolate at the Non-Stillage Site is "only achieved" when [Fe] + [Mn] < 10 mg/L. Aerobic conditions, if they occurred to any extent in the Stillage Site, was still insufficient to decrease concentrations of mobilized Fe and Mn to < WQOs.
	Wine Institute response		*The purpose of the first year study was to challenge the existing guidelines for land application of stillage and develop the science behind them. There was no attempt to manage or optimize the Fe and Mn level during the first year of study. It is clear and discussed in the report that during cycles 2 through 5 at the Stillage site, prolonged periods of anaerobic conditions existed. The purpose of the second year study is to test the proposed guideline, observe the results, and then optimize and refine the proposed guideline.*
33.	Page 3-9, §3.6.3 Special Soil Gas Study	Q	If both sites were equipped with soil gas probes, why does the report only present results from the Stillage Site?
	Wine Institute response		*Originally purchased soil gas monitoring equipment proved unreliable. New equipment was rented to determine oxygen content and a limited period of analysis was undertaken due to availability.*

Item	Page		RWQCB's Comment/Recommendation
34.	Page 3-9, §3.7.1 Soil Sampling Results	C	Soil results suggest major mobilization of Ca is occurring in the upper soil profile. Additional evidence is necessary to justify the report's dismissal of discharge pH as a major operational parameter. This evidence includes an evaluation of the extent to which the buffering of low pH wastewater causes IDS and TDS constituents to be released to percolate in concentrations that threaten to cause groundwater to exceed WQOs.
	Wine Institute response		*The soil results in Figures 9 and 10 do not show "major mobilization" of calcium. All soil measurements at the Stillage test site range between 0.3 and 3 meq/l. That is, soil calcium levels vary in a small range. At the Non-Stillage test site, soil calcium levels ranged between 3 and 12 meq/l (except for a single outlier value at the soil surface). This is expected in soils of arid regions. The soils have abundant calcium and are, as a result, highly buffered against pH change outside a range near neutral. On the basis of change in either soil calcium or soil pH, process water pH cannot be regarded as a "major operational factor".*
35.	Page 4-1, §4.1, Approach 2nd paragraph	C	While EPA 1977 presented BOD load in terms of pounds per acre per day, the publication never explicitly defined "day" as meaning as the load averaged over the entire application/rest cycle.
	Wine Institute response		*Actually, Table IV-3 of "Pollution Abatement" gives data for the average summer season in pounds per acre per day. The same is true for some of the citations and technical studies that the EPA summary is based upon. It is our opinion that it is obvious that the land application treatment includes periods of application and resting and that some portion of the land application area is in each phase of the cycle, therefore the total land area used and the total number of days of the complete cycle must be used in assessing the loading on a per acre per day basis. Regardless, our study defines the basis for our terminology and the proposed guidelines will be based on the results of this study.*

Item	Page		RWQCB's Comment/Recommendation
36.	Page 4-2, §4.2 Review of Experimental Results	C	Cannot rule out pH control as an important management factor until scientific data presented that demonstrates soil buffering is accomplished without excessive release to percolate of IDS and VDS constituents. Cannot rule out simple BOD removal as a design constraint in light of scientific evidence of substantial Ca+Mg mobilization and alkalinity production caused by BOD_5 attenuation. Fe+Mn mobilization as a basis for BOD loading limits means the discharge will always be operated at the threshold of Fe+Mn pollution, which is not adequately conservative until scientific evidence is presented showing mobilized Fe+Mn precipitates in the lower soil before percolate reaches groundwater. The report's summary of N removal should mention cropping could have lessened the flushing of stored N during initial cycles at the Non-Stillage Site. Conclusion that the Stillage Site percolate and discharge IDS load was the same is not supported by evidence of leaching of Na and Cl and mobilization of Fe+Mn and of Ca+Mg. Per application loading rate cites data that was not presented in report (i.e., soil water storage capacity). Resting time needs must be established not only for N attenuation and Fe+Mn mobilization control, but also to minimize Ca+Mg mobilization and alkalinity production.
	Wine Institute response		*See responses to comments 6, 10, 14, and 46.*
37.	Page 4-2, §4.3 Draft Guidelines	C	Commendable approach to developing discharge guidelines based on examining crucial operational factors such as site specific properties, discharge quality, and application methods.
	Wine Institute response		*Thank you for the comment.*
38.	Page 4-3, §4.3.1 Spreading basin site characterization & instrumentation	R	1st paragraph – Recommend measurement item 6, "groundwater quality assessment beneath the application basins" include assessment of groundwater upgradient, beneath, and downgradient of discharge site. 2nd paragraph – Recommend additional scientific justification be presented for the proposed soil permeability limit of 0.6 in/hr. Also, indicate if permeability reflects optimum (before discharge season) or worst case (end of discharge season) conditions.

Item	Page		RWQCB's Comment/Recommendation
	Wine Institute response		*1st paragraph – The discussion is not meant to address the optimal method of determining the groundwater quality beneath the application basin, which is beyond the scope of the document.* *2nd paragraph – The use of 0.6 inches per hour in this section addressing site characterization is simply a trigger for more detailed analysis. The value was selected because a.) it correlates with soils of moderate clay content and b.) this value is used in most soil survey reports as the end of a range of permeabilities provided for each soil. The value is good for initial screening of a given site because it can be quickly determined from a soil survey report. Because there are numerous factors that affect soil infiltration rate, it is not appropriate to tightly specify permeability. If a soil has a low permeability, site management practices can be implemented to make it suitable for use as a spreading basin.*
39.	Page 4-3, §4.3.1 Spreading basin site characterization & instrumentation	C	3rd paragraph – Proposed free draining depth of 15' to "allow for good spreading basin performance" assumes use of deeper vadose zone for constituent attenuation. To propose using depths below the active rooting zone for waste constituent attenuation requires scientific evidence demonstrating complete removal of applied waste constituents within the upper 15'. 4th paragraph – Excellent suggestion to limit discharge quantities to not exceed soil's field capacity water storage volume. Prolonged discharge of high organic waste may decrease soil's field capacity water storage volume, since BOD removal achieved by conversion of organic to biomass. Soil drainage to below field capacity may not always correlate with soil reaeration. Soil gas monitoring is a cost-effective means to determine soil reaeration.
	Wine Institute response		*The revised report will include a state-of-the-literature review of the science of land application and soil aquifer treatment.*
40.	Pages 4-4, §4.3.2 Limiting constituent analysis	C	A proposed hydraulic loading that allows standing discharge for up to 5 days is not consistent with tried-and-true management practices (rapid infiltration within 24 hours) that has been effective at precluding odor and vector nuisance conditions. This proposal recommends the discharge be conducted at the threshold of nuisance creation.
	Wine Institute response		*The recommendation is not intended to mean standing water for 5 days, but rather application for 5 days. There are existing wineries with land application systems that discharge over 5 days without odors.*

Item	Page		RWQCB's Comment/Recommendation
41.	Pages 4-4, §4.3.2 Limiting constituent analysis	R	Before expanding pH ranges, scientific data should be collected to demonstrate soil buffering is not accomplished at the expense of releasing IDS and VDS constituents to percolate. Dosing low pH discharge with ammonia, a biodegradable IDS, could achieve neutralization with no or little IDS impacts.
	Wine Institute response		*Neutralization with salts or ammonia prior to land application would not be appropriate because both additions contribute to the loading of the soil at the land application area with either salt or nitrogen. In addition, nitritification-denitrification processes will consume more alkalinity than the ammonia provides, thus allowing more dissolution of calcium carbonate than would occur if no ammonia was added. The biological decomposition of the organic constituents in the winery process water within the soil profile provides alkalinity for pH neutralization by natural processes. See responses to comments in 6 and 14.*
42.	Pages 4-4, §4.3.2 Limiting constituent analysis	C	To ensure groundwater protection, maximum BOD loading should correspond to loadings that do not result in excessive Ca+Mg mobilization or alkalinity production in percolate released from the 5' depth. The proposed BOD loading means the discharge would be conducted at the threshold of Fe+Mn pollution (and likely TDS pollution). Data show Fe+Mn mobilization at all BOD loadings. The proposed BOD upper loading of 7,000 lb/ac was not tested at the Non-Stillage Site, where lesser loadings resulted in percolate [Fe+Mn] to exceed WQOs by orders of magnitude. At the Stillage Site, substantial Fe+Mn mobilization occurred at BOD loadings less than 2,000 lb/ac.
	Wine Institute response		*The purpose of the second year study is to test the proposed guideline, observe the results, and then optimize and refine the proposed guideline. This will enable the development of science and cost/effectiveness-based operational guidelines for land application areas in the future to achieve balanced treatment and removal of constituents in the entire soil profile to minimize the potential for impacts to underlying groundwater.*

Item	Page		RWQCB's Comment/Recommendation
43.	Pages 4-5, §4.3.2 Limiting constituent	C	There are two components of IDS loading to groundwater: the IDS in the discharge itself, and the IDS released from the soil as a result of treatment. Stating that there will be no negative impacts to groundwater if the discharge IDS is < groundwater IDS does not take into consideration the release of IDS from soil treatment. Further, groundwater WQOs for salinity are expressed as EC and TDS. If VDS forms a significant component of percolate TDS, then VDS minimization is necessary to ensure TDS/EC WQOs are not exceeded. To minimize discharge IDS, high-TDS wastestreams (e.g., ion exchange regenerant and boiler blowdown) must not be mixed with high-organic wastestreams but separated for proper disposal (e.g., Title 27 ponds) or re-use as an agricultural soil amendment. Assumed reliance on the lower soil profile to further attenuate IDS (especially Fe, Mn, and Ca) requires site-specific scientific evidence demonstrating the extent to which, if any, such attenuation is occurring. Reliance on vadose zone for waste constituent storage is inconsistent with State Board guidance (Title 27 Statement of Reasons, or SOR).
	Wine Institute response		*Biological conversion will result in conversion of organics to alkalinity, carbon dioxide, and water, and nitrification-denitrification. Also, some constituents in the process water may exchange with minerals in the soil column, as would other irrigation waters. This does not necessarily indicate that such changes will adversely impact groundwater.* *From a scientific standpoint, it is incorrect to include VDS as a measure of salinity. "Standard Methods" recognizes that TDS is a surrogate for the mineral content of water and suggests that it is less useful for this purpose when the measured value is more than 20 greater than the sum of the cations and anions, especially when that difference is due to organic matter. For example, the organic matter (dissolved volatile matter) in a food processors' process wastewater represented about 40 percent of the residual solids measured by the TDS analysis. In such cases, the recommended practice is to characterize the organic matter by a more meaningful parameter such as BOD_5.* *The report does not and is not intended to address Title 27 interpretations.*
44.	Pages 4-6, §4.3.2 Timing of Analytical Measurements	C	If quality data from the previous discharge season is employed, there should be sufficient water quality analyses to demonstrate that sampling frequency (e.g., 2/month) is representative of the discharge. This can be accomplished by a short period of intensive monitoring. Waste characterization should be determined from flow-weighted composite samples, not grab samples (except for pH).

Item	Page		RWQCB's Comment/Recommendation
	Wine Institute response		*The characterization evaluation should be based on the specifics of the stream and site under study using the optimum sampling method that provides a representative sample. It may, in some cases, be a grab sample depending upon the stream.*
45.	Pages 4-6, §4.3.3 Crush Season Management Practices	C	What constitutes acceptable percolate quality is a critical factor in the identification of the rate-limiting constituent. The proposed criterion for resting cycle duration - unsaturated soil conditions at 1' - means for most of the discharge season, depths lower than 1' may be chronically anoxic or anaerobic, which decreases organic removal efficiency. Resting intervals should be as long as necessary to re-aerate the upper 5', which can be determined by soil gas probes and percolate quality ([Fe] & [Mn] < WQOs).
	Wine Institute response		*Resting intervals will be further addressed in the revised report.*
46.	Pages 4-7, §4.3.4 Example of Flowchart Analysis	C	Flowchart is a good approach, but the proposed guidelines operate on the threshold of pollution and nuisance and, as such, constitute recommendations that preclude regulatory approval. The report should describe the scientific evidence that supports the conclusion that the IDS loading from the maximum hydraulic loading "is adequate at both sites regarding the overall groundwater basin management plan." What about the non-crush season? Monitoring data shows that this can be higher strength than crush wastewater (although lower volume). What about the fact that the report says that spreading basins must be rested between crush seasons? That doesn't happen at many wineries, does it? Does the report indicate non-crush water can't be applied to the crush water spreading basins?

Item	Page		RWQCB's Comment/Recommendation
	Wine Institute response		*The purpose of the first year study was to challenge the existing guidelines for land application of stillage and develop the science behind them. There was no attempt to manage or optimize constituent removal at any depth, and yet effective removal of constituents was achieved. The purpose of the second year study is to test the proposed guideline, observe the results, and then optimize and refine the proposed guideline. This will enable the development of science and cost/effectiveness-based operational guidelines for land application areas in the future to achieve balanced treatment and removal of constituents in the entire soil profile to minimize the potential for impacts to underlying groundwater.* *Guidelines are included in the flowchart for the non-crush season even though the field study occurred during the crush season. During the crush season total loadings are higher than non-crush season. It is not uncommon for some concentrations of constituents in process water to range as high as the crush season, but it is not sustained and the non-crush flows are much lower so the total load is less, particularly at Non-Stillage wineries. Resting can be accomplished by taking a portion of the land application area out of service for a portion of the year or by reducing the loading, or by some combination of these measures depending upon the site specific characteristics and the land that is available. Non-crush season process water can be applied to the crush season land application areas.*
47.	Other comments	C	The proposed guidelines are complicated and require considerable monitoring (pre-application, during application, post-application) to ensure effectiveness. This does not equate to a low management, low maintenance, and low risk process suitable for a waiver of WDRs. Discharges following the guidelines improve the likelihood of authorization for continued discharge to land.
	Wine Institute response		*Although more complex than the current guidelines, the proposed guidelines are being developed with the assistance of the wine industry so that they can be practically implemented at working wineries.*

Item	Page		RWQCB's Comment/Recommendation
48.	Recommendations for 2003 study	C	The 2003 study should include lysimeters at least to 15' bgs to show whether or not waste constituents detected in the 5' lysimeters are treated in the remaining soil column, or whether they would move into groundwater. Tested hydraulic loading rates should result in all applied wastewater infiltrating within 72 hours (fly cycle). Odor generating potential should be monitored. Control plots should be operated at similar hydraulic loadings but with fresh irrigation water (e.g., groundwater or surface water) to determine the extent to which stored waste constituents and decomposition byproducts are released from disposal site soils in concentrations that threatened groundwater. Test plots to evaluate the effect of soil buffering on percolate TDS quality should be operated at same hydraulic and BOD loadings and have pH neutralized by ammonia. The quality of discharge to control plots should be representative of the entire daily discharge. Collecting flow-weighted composite samples in a tanker track and discharging from the truck instead of the discharge delivery pipelines can accomplish this. Hydraulic and BOD loading rates should be varied to determine which rates result in minimizing Ca+Mg mobilization and alkalinity production.
	Wine Institute response		*The 2003 study was not able to include lysimeter installation at 15 feet below ground surface. However, the revised report will include a state-of-the-literature review of the science of land application and soil aquifer treatment. This will provide information at depths greater than 5 feet at other operating land application systems where extensive research has been completed and is ongoing.* *During the first year study, any observable odor at the test basins was recorded.* *Control plots were not part of the 2003 study protocols.* *Neutralization with ammonia is not recommended because of the addition of nitrogen, which consumes more alkalinity than it provides when it undergoes nitrification-denitrification.* *The quality of the applied water should be representative of the operating facility to the extent practical.* *Application rates and results were monitored to assess the proposed guideline so that it can be optimized for balanced constituent removal.*

(1) C = Comment, R = Recommendation, Q = Question/Request for Information, blank = other

Appendix E

Pertinent Chemical Reactions During Land Application of Winery Process Water

Appendix E: Impacts of Land Application of Winery Process Water on Inorganic Dissolved Solids

The following interactions of winery process water applied to soil will impact the quality of the water as it moves through the soil column:

- Degradation of organic matter ($BOD_5 = \{CH_2O\}$):
    - Organic Acid Oxidation (e.g., lactic acid):
        - $CH_3CHOHCO\text{-}OH + 1.5\ O_2 \rightarrow 3\ H_2CO_3$ (unionized)
        - $CH_3CHOHCO\text{-}O^- + 1.5\ O_2 \rightarrow 2\ H_2CO_3 + HCO_3^-$ (partially ionized)
    - Alcohol Oxidation (e.g., Ethanol):
        - $CH_3CH_2COH + 4\ O_2 \rightarrow 3\ H_2CO_3$
- Nitrogen Transformations:
    - Conversion of organic nitrogen to inorganic nitrogen:
        - $R\text{-}CO\text{-}NH_2 + H_2CO_3 + H_2O \rightarrow R\text{-}CO\text{-}OH + NH_4^+ + HCO_3^-$
    - Ammonium adsorption on soil:
        - $NH_4^+ + X\text{-}Na^+ \rightarrow X\text{-}NH_4^+ + Na^+$
    - Conversion of ammonia nitrogen to nitrate (nitrification):
        - $NH_4^+ + 1.5\ O_2 + 2\ HCO_3^- \rightarrow NO_2^- + 2\ H_2CO_3 + H_2O$ (nitrosomonas oxidation)
        - $NO_2^- + 0.5\ O_2 \rightarrow NO_3^-$ (nitrobacter oxidation)
        - $NH_4^+ + 2\ O_2 + 2\ HCO_3^- \rightarrow NO_3^- + 2\ H_2CO_3 + H_2O$ (overall reaction)
    - Conversion of nitrate nitrogen to nitrogen gas (denitrification):
        - $1.25\ \{CH_2O\} + NO_3^- \rightarrow 0.5\ N_2 + HCO_3^- + 0.25\ H_2CO_3 + 1.25\ H_2O$
    - Nitrate Reduction to ammonium ion:
        - $2\ \{CH_2O\} + NO_3^- + H_2O \rightarrow NH_4^+ + 2\ HCO_3^-$
- Dissolution of calcium and magnesium carbonates from soil:
    - $Ca_xMg_y(CO_3)_{x+y} + (x+y)\ H_2CO_3 \rightarrow x\ Ca^{2+} + y\ Mg^{2+} + 2*(x+y)\ HCO_3^-$

- Release of iron and manganese from soil:
  - $0.5 \{CH_2O\} + MnO_{2(s)} + 1.5\ H_2CO_3 \rightarrow Mn^{2+} + 2\ HCO_3^- + 0.25\ H_2O$
  - $0.25 \{CH_2O\} + FeOOH_{(s)} + 1.75\ H_2CO_3 \rightarrow Fe^{2+} + 2\ HCO_3^- + 1.75\ H_2O$
- Sulfate Reduction to Hydrogen Sulfide:
  - $2 \{CH_2O\} + SO_4^{2-} \rightarrow HS^- + HCO_3^- + H_2CO_3$
- Methane Fermentation (e.g., lactic acid):
  - $CH_3CHOHCO\text{-}OH \rightarrow 2\ CH_4 + H_2CO_3$
- Precipitation of calcium and magnesium carbonates from percolate:
  - $x\ Ca^{2+} + y\ Mg^{2+} + 2*(x+y)\ HCO_3^- \rightarrow Ca_xMg_y(CO_3)_{x+y} + (x+y)\ H_2CO_3$
- Precipitation of Iron and Manganese from percolate (Oxidation):
  - $Fe^{2+} + 0.25\ O_2 + 2\ HCO_3^- + 1.5\ H_2O \rightarrow FeOOH_{(s)} + 2\ H_2CO_3$
  - $Mn^{2+} + 0.5\ O_2 + 2\ HCO_3^- + H_2O \rightarrow MnO_{2(s)} + 1.5\ H_2CO_3 + H_2CO_3$

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1. INTRODUCTION

This introductory chapter describes the purpose of the manual, the target audience, and the organization and use of the manual. In addition, it notes the protocol for definition of key terms within the manual and provides a list of acknowledgments for development of the document.

1.1 Purpose, Goals and Objectives of the Manual

The purpose of the guidance manual, as originally produced in 2002, was to provide a state-of-the-knowledge resource for designing and operating a land application system for best management of food process/rinse water. Specifically, the manual was developed to establish and explain the scientific and engineering basis and methods for good practice, as necessary to achieve regulatory compliance and foster environmentally, economically, and socially sustainable operations.

This edition of the manual was revised in 2006 to address comments from regulatory agencies on the original manual and to incorporate new research findings. To ensure that the revised manual would meet the expectations of food processors, consultants and regulators alike, the California League of Food Processors (CLFP) convened a set of four working committees comprised of representatives from the various interests. Each committee focused on resolution of specific issues, and their findings and conclusions were incorporated in the revised manual. In addition, the revised manual reflects valuable comments from a number of CLFP members, regulators, and others. While some issues could not be as fully resolved as intended due to insufficient or inconclusive existing research or the absence of known alternatives, this manual provides the most complete compilation, available as of the date of publication. Ideally, the manual should be considered a living document which is updated as new information becomes available.

The focus of the manual is on slow rate land application systems, where hydraulic loading rates are generally similar to agricultural irrigation rates. The planning and design of soil aquifer treatment (rapid infiltration) systems is covered by other texts (USEPA, 2006; Crites, et al., 2000).

Several related research projects are currently underway and may provide additional information and guidance on best practices in the near future. These include (1) the State Water Resources Control Board (State Water Board) salinity study led by Dr. Karl Longley; (2) the Hilmar Cheese Company Supplemental Environmental Project (SEP) on salinity management; (3) the Stanislaus County study on food processing byproducts use; and (4) the studies on process water management conducted by the Wine Institute.

1.2 Target Audience

The guidance manual was prepared to serve as a reference for use by the CLFP community, including food processors, regulators and consulting engineers and scientists involved in planning, designing, evaluating, and operating land application systems. Although many of the topics and discussions of chemical and physical processes are technical in nature, the guidance elements of the manual were intended to be accessible and useful to a broad industry audience. The manual should also not be viewed as a regulatory document, as compliance with environmental regulations will still need to be achieved through the appropriate regulatory agencies.

1.3 Organization and Use of Manual

The manual is organized by chapter to address the full range of design and operational considerations that are pertinent to land application treatment systems. An overview of the benefits is presented in Chapter 2, and the regulatory framework is reviewed in Chapter 3. Characteristics of process/rinse water and the constituents of concern are discussed in Chapter 4. Chapters 5, 6 and 7 describe key facets of site selection and crop selection are described in Chapters 5 and 6. The basis for a tiered risk categorization is presented in Chapter 7 along with determination of appropriate rinse water loading rates, for a given site and process/rinse water to be applied. Chapter 8 presents an approach for evaluating best practicable treatment and control and identifying waste minimization opportunities. It also provides descriptions of various source reduction and pretreatment options.

Water distribution systems are described in Chapter 9, along with methods of irrigation scheduling. In Chapter 10, the basics of compliance and operational monitoring are described for discharged water and site soil, groundwater, and vadose zone. In Chapter 11 areas that have been identified for future research and demonstration are described. In Chapter 12, the approach to process design is presented, along with example calculations for different risk categories.

1.4 Definition of Terms

Technical terms will be defined in the text as they are introduced. A glossary of terms and a list of acronyms and abbreviations are presented in Appendix A.

1.5 Acknowledgments

Development of this revised document was led by Mr. Rob Neenan of the California League of Food Processors. His collaborative approach, leadership and perseverance are all greatly appreciated. The revised manual was prepared by a team from Brown and Caldwell and Kennedy and Jenks Consultants (K/J). Mr. Ron Crites was the project manager for the team and senior author from Brown and Caldwell. Authors included Mr. Robert Beggs and Mr. Jeff Bold of Brown and Caldwell, and Ms. Sharon Melmon and Mr. Gary Carlton of K/J.

Members of four subcommittees that participated in prioritizing and defining the manual revisions in 2006 are noted below. We appreciate the contributions of each member.

Subcommittee #1—Development of a Waiver

- Rob Beggs
- Dan Burgard
- Bob Chrobak
- Wendy Wyels

Subcommittee #2—BOD Loading Rate

- Bob Chrobak
- Ron Crites
- Troy Elliott
- Jo Anne Kipps
- Tim Ruby

- Wayne Verrill

Subcommittee #3—Point of Compliance

- Rob Beggs
- Dan Burgard
- Gary Carlton
- Tim Durham
- Burt Fleischer
- Bill Jennings
- Bert Van Voris
- Matt Wheeler

Subcommittee #4—Soil Monitoring

- Rob Beggs
- Dan Burgard
- Wayne Verrill

1.6 References

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US EPA . 2006. Process Design Manual: Land Treatment of Municipal Wastewater Effluents. EPA 625/R-06/016, ORD, Cincinnati, OH.

2. BENEFICIAL USE OF FOOD PROCESSING/RINSE WATER

California is the largest agricultural state in the nation, and food processing employment was 190,600 workers in 2005 (California Employment Development Department, 2005). With a large variety of crops and great growing conditions, California ships $50 billion worth of food products per year (CLFP, 2002). Regionally, the processing of fruits and vegetables is especially significant in the San Joaquin Valley, Sacramento Valley and Central Coast area. The San Joaquin Valley, particularly Fresno County, leads the state and the nation in food production. Clearly, this industry is vital to the state's economy as well as the nation's food supply and food security. To ensure that food production and processing operations continue in a sustainable manner within the state, implementation of appropriate and beneficial process/rinse water management practices is imperative.

This chapter provides an introduction to the volumes of food process/rinse water available for beneficial reuse, existing and potential beneficial reuse of process/rinse water, key constituents in process/rinse water, mechanisms for treatment of the applied water in the soil, and the reliability of land treatment systems.

2.1 Process/Rinse Water Generation Rates in California

The food processing industry requires a significant amount of potable water for cleaning, fluming, processing, and rinsing operations. The amount of water needed depends on the food type. A summary of water usage is presented in Table 2-1.

Table 2-1. Estimates of Water Usage by Selected Food Processing Commodities in 1999 (CLFP, 1999)

Food type	Tons/yr	Gal/ton	Flow, mgy	Flow, acre-ft/yr
Apricots	101,500	2,300	233	701
Brussel sprouts	11,291	800	9	27
Cherries	17,600	11,900	209	628
Garlic	40,405	2,800	113	339
Olives	103,500	8,000	828	2,484
Onions	97,107	1,000	97	291
Pears	312,000	4,170	1,301	3,903
Peaches	525,000	2,800	1,470	4,221
Prunes	615,000	52	32	96
Raisins	2,602,000	2,000	5,204	15,612
Tomatoes	8,892,754	920	8,181	24,543
Wine grapes	2,895,000	1,120	3,242	9,726
TOTAL	16,213,157		20,919	62,571

Note: mgy = million gallons/year; 1 million gallons = 3.069 acre-ft

The process/rinse water generated is a function of the type of food processed, the amount of product generated, and the type of peeling that may be required. Process/rinse water is used in this manual to characterize the combined sources of water that are to be treated via land application.

2.2 Reuse of Process/Rinse Water in California

Land application of food process/rinse water has a long and successful history (Crites, et al., 2000). Overviews of the practice and case studies have been published from the 1940s through the present (Monson, 1958; Bruner, et al., 1999; Crites et al., 2000; Crites, 2001). A 1964 national survey identified 844 systems applying food process/rinse water to the land (Hill et al., 1964).

The reuse of process/rinse water includes irrigation of field and forage crops, replacement of potable supplies for dust control, soil reclamation, and wildlife habitat enhancement. Typical crops grown with food process/rinse water include eucalyptus trees, corn, cotton, sudan grass, wheat, oats, barley, alfalfa, and pasture grass. It is estimated by the CLFP that 70 percent of the process/rinse water generated each year is applied to the land for treatment and reuse.

2.3 Reuse Benefits

The potential benefits of land application include crop irrigation, replacement of or supplement to fresh water irrigation supplies, reclamation of soils, avoidance of surface water discharge, replacement of commercial fertilizers, maintenance of soil organic matter, improvement of soil water holding capacity and tilth, and habitat for wildlife in constructed wetlands. Crop irrigation is the most widely practiced form of land application and results in both water and nutrient reuse benefits. The process/rinse water provides valuable moisture, nutrients, and organic matter required to sustain and produce profitable crops. The organic nitrogen in process/rinse water can slowly become available to crops so that summertime application can often provide nitrogen for crop uptake the following winter and spring. At Oakdale, process/rinse water is replacing the fresh water used for irrigation of a 1,200-acre pasture. In turn, the farmer who has contracted for the process water has released some of the fresh water he would normally use to augment water supplies for wildlife habitat in the San Joaquin Delta.

The potential for water reuse through constructed wetlands has been investigated recently by Sustainable Conservation (O'Brien, 2002). Constructed wetlands have the potential for both treatment and reuse of food process/rinse water given appropriate organic loading rates. Potato process/rinse water at Connell, Washington has been treated and reused using a two-stage constructed wetlands in conjunction with land application (O'Brien, 2002).

The objectives of land application include:

- Provide cost-effective treatment of process/rinse water constituents in compliance with environmental standards.
- Provide beneficial use of applied constituents by producing a harvestable crop for sale/reuse.
- Conserve limited water resources by substituting fresh water with process/rinse water to meet crop consumptive needs.
- Preserve community enjoyment of life and property.

2.4 Overview of Process/Rinse Water Characteristics

Food process/rinse water is usually characterized by its biochemical oxygen demand (BOD) and total suspended solids (TSS). Typical loadings, in terms of pound/ton of product, are presented in Table 2-2. Other characteristics of importance are the nitrogen content, pH, fixed dissolved solids (FDS), sodium adsorption ratio (SAR), sodium, chloride, phosphorus, potassium, and boron concentrations. Characteristics of process/rinse water are described in Chapter 4.

Table 2-2. Typical Unit Flows and Loads from Various Products (USEPA, 1977)

Product	Industry-typical flows, 1,000 gal/ton	Industry-typical BOD, lb/ton	Industry-typical TSS, lb/ton
Apples	2.4	18	4.5
Apricots	5.6	40	9.9
Asparagus	8.5	4.9	7.5
Beans, lima	7.7	48	39
Beans, snap	4.2	15	6.1
Beets	2.7	53	22
Carrots	3.3	30	17
Cherries	3.9	38	2.0
Corn	1.8	27	10
Peaches	3.0	35	8.6
Pears	3.6	50	12.0
Peas	5.4	38	11
Potatoes, white	3.6	84	128
Spinach	8.8	14	6.1
Tomatoes, peeled	2.2	9.3	12.0
Tomatoes, product	1.6	4.7	10.0

2.5 Overview of Land Treatment Mechanisms

Food process/rinse water is well suited to land application because the BOD and TSS can be readily converted into soil organic matter. The applied BOD is filtered and adsorbed by the soil and biologically oxidized by the soil bacteria. TSS is filtered by the soil and converted to topsoil. The land treatment mechanisms are described in more detail in Chapter 7.

The four elements of a land treatment system are:

- Removal of decomposable constituents from the site – This includes nutrient and dissolved solids uptake by crops and subsequent removal by harvest. It also includes CO_2 and NH_3 volatilization or nitrogen gas loss from denitrification and loss of applied water by evapotranspiration.
- Permanent storage in the soil – The most important form of P storage is through fixation by reaction with Ca, Fe, and Al.
- Vadose Zone Retention – Some calcium and magnesium minerals with lower solubility precipitate in the vadose zone. In addition, a portion of the positively charged ions such as ammonium are retained by clay and organic matter particles, displacing other positively charged ions on clay platelet and organic matter adsorption sites.
- Groundwater System – Dilution and dispersion of percolate constituents. (Note - Use of groundwater dilution and dispersion factors in process/rinse water system planning may be limited by applicable Regional Water Board policy.)

Nutrients in process/rinse water are adsorbed, used by crops, and used by the soil bacteria, which serve to keep them from percolating through the soil. The nitrogen cycle, described in Chapter 7, illustrates how the applied organic nitrogen is converted into plant-available nitrogen, lost to denitrification, immobilized by soil bacteria and converted into stable soil humus. Phosphorus is quickly retained in the soil by chemical adsorption and precipitation, with some subsequent plant uptake. Potassium is also readily taken up by plants as a major plant nutrient. Dissolved mineral solids are removed by precipitation and crop uptake. However, some leaching of dissolved minerals to groundwater is generally required to maintain appropriate chemical balances for good soil structure and crop production. Groundwater provides dilution and dispersion of percolate constituents.

2.6 Reliability of Land Application Treatment

Land treatment systems can accommodate wide variations in the applied water content of BOD, TSS, organic nitrogen, and other nutrients (i.e. phosphorus, potassium, sulfate, etc.). The mechanisms for removal of organics and nutrients are robust so that the receiving groundwater is well protected. The buffering capacity of the soil can tolerate swings in applied pH without adverse effects on the soil, crop, or groundwater. Well-designed land application systems can intensively treat BOD, TSS, and nitrogen as effectively as advanced mechanical/biological treatment plants (Crites and Tchobanoglous, 1998).

Land application relies on simple and reliable methods of distribution (see Chapter 9) that are rarely subject to breakdown. Routine monitoring of the process/rinse water and the loading rates (see Chapter 10) allows for the careful management of the process/rinse water constituent loadings.

2.7 References

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3. REGULATORY OVERVIEW

This chapter provides an overview of federal, state, and local regulatory programs that are relevant to establishing, permitting, and operating a land application system. Note that these regulations and policies have been condensed and summarized for the purposes of this overview. For the most current, comprehensive information on applicable regulatory programs and site-specific requirements, it is incumbent upon the discharger to contact the applicable regulatory agencies directly. Regulations and policies presented in this chapter may be subject to change, pending passage of new legislation, further interpretation of existing laws or changes in regulatory agency leadership. For example, the evolving policies and limits surrounding the development of total maximum daily loads (TMDL) for impaired California water bodies will likely affect the practice and regulation of land application. In California, application of process/rinse water to land is regulated primarily at the state level; this includes authority to implement some federal programs, as delegated by the US Environmental Protection Agency (USEPA) to the State Federal Laws and Regulations.

The basis for water policy on discharges to surface water nationwide is the federal Clean Water Act (CWA) (33 U.S.C., 1251 et seq.; 40 C.F.R. Part 122 et seq. and Part 400 et seq.), enacted in 1972. The CWA is intended to restore and maintain the integrity of the country's surface waters. The CWA encourages water reuse and recycling, and this has led to an increase in the number of manufacturing facilities designed to operate as "zero discharge" facilities. It also directs states to establish water quality standards for all "waters of the United States" and to review and update these standards at least every three years under a Triennial Review. The USEPA has delegated the implementation of the CWA to most states, and this became the responsibility of the State Water Board and Regional Water Boards in California. The Code of Federal Regulations (Title 40, CFR) and USEPA guidance documents provide direction for implementation.

3.1 State Statutes and Regulations

Along with implementing the CWA for discharges to surface waters, the State regulates discharges that could affect beneficial uses of groundwater via the Porter-Cologne Water Quality Control Act. Porter-Cologne directed the state to prepare basin plans to ensure protection of waters in each region of the state. In addition, the state's "anti-degradation policy" was intended to further protect both surface water and groundwater. The impact of these laws and policies on the regulation of land application systems is further detailed below, including an overview of the state's waste classification scheme and specific permitting procedures and issues.

3.1.1 Porter-Cologne Water Quality Control Act

Application of food process/rinse water to land, which has the potential to affect groundwater, is regulated in California under the Porter-Cologne Water Quality Control Act, also referred to as the California Water Code (Division 1, Chapter 2, Article 3, sections 13000 et seq.). The Porter-Cologne Act was enacted by the state of California in 1969 and took effect on January 1, 1970. It authorizes the State Water Board to adopt, review, and revise policies for all waters of the state, including groundwater, and directs the nine Regional Water Boards to develop regional basin plans for water quality protection. Protection of water quality in California is the responsibility of the State Water Board, which develops statewide policies and regulations, and the Regional Water Boards, which implement water quality policies on a regional basis. Figure 3-1 provides contact information for the State Water Board and each of the nine Regional Water Boards, and includes a map showing the boundaries of the regions.

In accordance with the Water Code, most discharges to land require a permit because they have potential to impact groundwater underlying state lands. Permits regulating the discharge of food process/rinse water to land are issued in the form of Waste Discharge Requirements (WDRs), granted by the applicable Regional Water Board following submission of the permit application known as a Report of Waste Discharge (RWD). Further information on RWD contents and the permitting process is provided in Section 3.2.5 below.

3.1.2 Basin Plans

Section 13263 of the California Water Code requires that discharge permits provide for implementation of any relevant water quality control plans that have been adopted. These plans include by reference any "statewide plans and policies" formulated by the State Water Board, and "basin plans" formulated by the Regional Water Boards as prescribed in Water Code Section 13240. Each of the nine Regional Water Boards was responsible for adopting a basin plan for the area in its region. Copies of the basin plans may be obtained by contacting the State Water Board office in Sacramento or the appropriate Regional Water Board office, or from the State Water Board's website (http://www.swrcb.ca.gov).

Basin plans contain California's administrative policies and procedures for protecting state waters, including preservation and enhancement of groundwater and surface water quality for the designated beneficial uses of water bodies. The basin plans designate beneficial uses, such as agricultural supply, drinking water supply, water contact recreation, and/or habitat of various types. They also define "water quality objectives" for some water bodies and beneficial uses. Water quality objectives are threshold levels of chemicals and water quality characteristics that are considered necessary for reasonable protection of beneficial uses of water and prevention of nuisance conditions within a specific area. The water quality objectives may apply region-wide or be specific to individual water bodies or portions of water bodies.

The California Water Code and the different regional basin plans give the Regional Water Boards some discretion in interpreting the law and developing WDRs for individual dischargers. In recent individual permits, the Regional Water Boards have tended to require dischargers to meet water quality objectives that are protective of all potential beneficial uses of groundwater, as opposed to focusing on the existing and probable anticipated beneficial uses of the groundwater body in question. The practical result of this approach is issuance of permit requirements developed to be protective of the "best and highest use" of groundwater, which is as a drinking water supply or an agricultural water supply suitable for the most salt-sensitive crops. In the cases where basin plans do not dictate specific numerical objective values for particular beneficial uses or water bodies, permits have included limitations based on external references. For certain constituents, beneficial uses other than

Water Boards

STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

Office of Public Affairs: (916) 341-5254
Office of Legislative Affairs: (916) 341-5251

State Water Resources Control Board
Location: 1001 I Street, Sacramento, CA 95814
Mail: P.O. Box 100, Sacramento, CA 95812-0100
www.waterboards.ca.gov • info@waterboards.ca.gov

Financial Assistance information: (916) 341-5700
Water Quality information: (916) 341-5455
Water Rights information: (916) 341-5300

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARDS

NORTH COAST REGION (1)
www.waterboards.ca.gov/northcoast
5550 Skylane Blvd., Suite A
Santa Rosa, CA 95403
info1@waterboards.ca.gov
(707) 576-2220 TEL • (707) 523-0135 FAX

SAN FRANCISCO BAY REGION (2)
www.waterboards.ca.gov/sanfranciscobay
1515 Clay Street, Suite 1400
Oakland, CA 94612
info2@waterboards.ca.gov
(510) 622-2300 TEL • (510) 622-2460 FAX

CENTRAL COAST REGION (3)
www.waterboards.ca.gov/centralcoast
895 Aerovista Place, Suite 101
San Luis Obispo, CA 93401
info3@waterboards.ca.gov
(805) 549-3147 TEL • (805) 543-0397 FAX

LOS ANGELES REGION (4)
www.waterboards.ca.gov/losangeles
320 W. 4th Street, Suite 200
Los Angeles, CA 90013
info4@waterboards.ca.gov
(213) 576-6600 TEL • (213) 576-6640 FAX

CENTRAL VALLEY REGION (5)
www.waterboards.ca.gov/centralvalley
11020 Sun Center Drive, Suite 200
Rancho Cordova, CA 95670
info5@waterboards.ca.gov
(916) 464-3291 TEL • (916) 464-4645 FAX

Fresno branch office
1685 E Street, Suite 200
Fresno, CA 93706
(559) 445-5116 TEL • (559) 445-5910 FAX

Redding branch office
415 Knollcrest Drive
Redding, CA 96002
(530) 224-4845 TEL • (530) 224-4857 FAX

LAHONTAN REGION (6)
www.waterboards.ca.gov/lahontan
2501 Lake Tahoe Blvd.
South Lake Tahoe, CA 96150
info6@waterboards.ca.gov
(530) 542-5400 TEL • (530) 544-2271 FAX

Victorville branch office
14440 Civic Drive, Suite 200
Victorville, CA 92392
(760) 241-6583 TEL • (760) 241-7308 FAX

COLORADO RIVER BASIN REGION (7)
www.waterboards.ca.gov/coloradoriver
73-720 Fred Waring Dr., Suite 100
Palm Desert, CA 92260
info7@waterboards.ca.gov
(760) 346-7491 TEL • (760) 341-6820 FAX

SANTA ANA REGION (8)
www.waterboards.ca.gov/santaana
California Tower
3737 Main Street, Suite 500
Riverside, CA 92501-3339
info8@waterboards.ca.gov
(951) 782-4130 TEL • (951) 781-6288 FAX

SAN DIEGO REGION (9)
www.waterboards.ca.gov/sandiego
9174 Sky Park Court, Suite 100
San Diego, CA 92123
info9@waterboards.ca.gov
(858) 467-2952 TEL • (858) 571-6972 FAX

State of California
Arnold Schwarzenegger, Governor

California Environmental Protection Agency

State Water Resources Control Board
Tam M. Doduc, Chair
Celeste Cantú, Executive Director

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Figure 3-1. State Water Resources Control Board drinking water can trigger more stringent permit requirements. Protection of groundwater considered a drinking water supply generally requires that discharges be managed to meet primary and/or secondary drinking water standards. The primary standards, known as primary maximum contaminant levels (MCLs), are maximum concentrations for certain constituents that drinking water is allowed to contain. The MCLs are established by the Department of Health Services (DHS) and can be found in Title 22, California Code of Regulations, for a number of organic and inorganic constituents. The secondary standards are not established based on human health, but set limits that address water taste, odor, and appearance considerations. Information on current MCLs may be obtained from the DHS website (http://www.dhs.ca.gov).

In cases where the natural background concentration of a particular constituent exceeds an applicable water quality objective in the basin plan, the background concentration must not be exceeded; the water quality objectives do not require dischargers to meet standards that constitute higher quality than background concentrations.

Groundwater quality exemptions for some beneficial uses can be specified in a basin plan for situations where natural conditions make that particular beneficial use highly unlikely, such as for an aquifer with excessive natural salinity or low groundwater production capacity. In practice, this is difficult as it requires documentation to justify amendment to a basin plan. In such situations, the person seeking the exception has the burden of providing the documentation. Both the Regional Water Boards and State Water Board must conduct public hearings, and then the Office of Administrative Law must approve it.

3.1.3 Antidegradation Policy and Best Practicable Treatment and Control

A key element of California's water quality regulatory framework is the state's Antidegradation Policy, adopted by the State Water Board as Resolution 68-16 (Statement of Policy with Respect to Maintaining High Quality Waters in California) (Appendix B). This policy applies to water bodies with water quality characteristics that are better than the basin plan requires for protection of beneficial uses. It establishes a goal to preserve that level of quality to the maximum extent possible. However, the policy is not a zero-discharge policy. Where the existing water quality is better than the water quality objectives, reduction of water quality can be allowed if the Regional Water Board determines it will not unreasonably affect present and probable beneficial uses, will be consistent with the maximum benefit to the people of the state, and is consistent with other factors listed in the California Water Code.

Water Code Section 13241 recognizes that it may be possible for the quality of water to be changed to some degree without unreasonably affecting beneficial uses, and requires a Regional Water Board to consider a range of factors including past, present and probable future uses of water; environmental characteristics of the hydrographic unit; water quality conditions reasonably achievable through coordinated control of all factors; economic considerations; and the need for housing in the region. Section 13000 mandates that activities which may affect water quality shall be regulated to attain the highest water quality which is reasonable, considering all demands being made and to be made on those waters and the total values involved.

To comply with the policy, a processor planning to discharger process water to land in an area where it could have an affect on high quality groundwater must demonstrate use of best management practices and best practicable treatment and control (BPTC) for process/rinse water. Although neither the Water Code nor the Antidegradation policy defines BPTC explicitly, in their rationale for decisions on several WDR applications the State Water Board has described this (sometimes along with recognition of Section 13241 factors) as the level of treatment and control technically achievable using "best efforts". In these decisions, the State Water Board has established that, to provide evidence of BPTC, dischargers need to compare proposed methods with existing proven technology, evaluate performance data, compare alternative methods of treatment and control, consider methods used by similarly situated dischargers, and evaluate the potential impact of the discharge as well as the mitigating effects of BPTC on groundwater. For food processors, at a minimum BPTC should include source reduction and segregation of high-strength wastes. Accordingly, Chapter 8 of the manual describes an approach for evaluating facility operations and identifying appropriate methods to reduce process/rinse water generation and strength.

3.1.4 State Wastewater Classifications

Wastes, including wastewater, discharged to land are classified according to the risks they pose to water quality and to determine the appropriate waste management option(s). The waste classification is central to the permit conditions and requirements assigned to dischargers by the Regional Water Boards. Flowcharts summarizing the State Water Board's framework for waste classification and management are shown in Figure 3-2 and Figure 3-3. Wastes are either classified as hazardous or non-hazardous, based on criteria outlined in Title 22 of the California Code of Regulations (Title 22, CCR).

Wastes classified as hazardous based on criteria outlined in Title 22 are also regulated under that title. Non-hazardous wastes that are discharged to land with constituent concentrations greater than groundwater quality objectives or which could impact beneficial uses may be classified and regulated by the Water Boards as "designated" wastes under Title 27, CCR (refer to Figure 3-3). However, process/rinse water generated by food processing facilities is typically not classified as hazardous waste, and discharges have historically not been classified and regulated as a designated waste under Title 27. Accordingly, the non-hazardous classification is applicable.

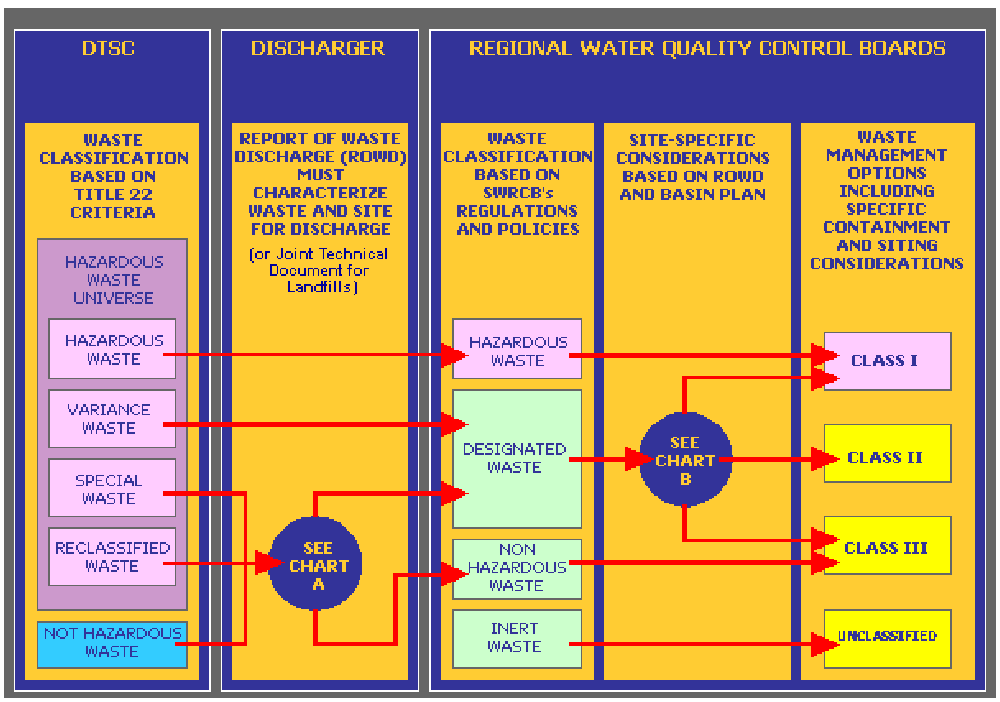

Figure 3-2. State Water Board's Flowchart for Waste Classification and Management

Title 27 represents a relatively recent consolidation of existing waste disposal to land regulations of the State Water Board and the California Integrated Waste Management Board. The State Water Board's portion of the Title 27 regulations was previously contained in Title 23, Division 3, Subchapter 15. Title 27 CCR Section 20090 provides several exemptions from regulation under Title 27. For example, California Water Code

Subsection 20090(b) provides an exemption for the discharge of wastewater to land. This exemption includes, but is not limited to, evaporation ponds, percolation ponds, or subsurface leachfields, if the following conditions are met on an ongoing basis:

- The applicable Regional Water Board has issued WDRs, reclamation requirements, or waived such issuance,
- The discharge is in compliance with the applicable water quality control plan (basin plan), and
- The wastewater does not need to be managed according to Chapter 11, Division 4.5 Title 22 of this code as a hazardous waste.

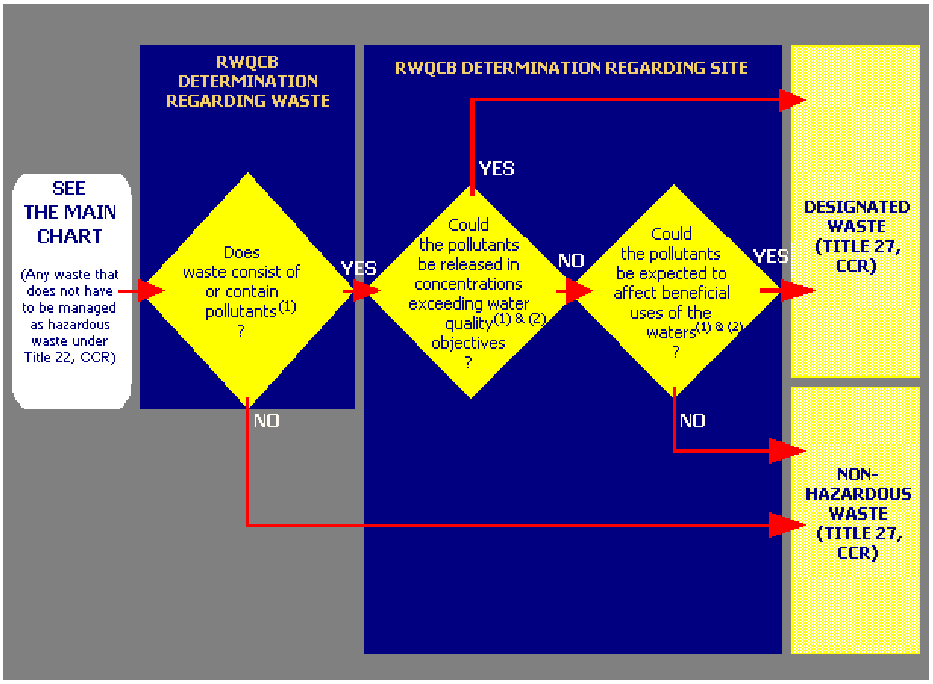

Figure 3-3. State Water Board's Flowchart for Waste Classification and Management

The principal underlying the exemptions, and Title 27 as a whole, is the protection of groundwater resources, as provided by the applicable water quality control plan (basin plans) and ensured through WDR permits issued pursuant to the Porter Cologne Water Quality Control Act.

3.1.5 State Waste Discharge Requirements Permits

WDR permits for discharge of process/rinse water to land, incorporating conditions and requirements designed to protect the underlying groundwater and nearby surface water bodies, are issued by the applicable Regional Water Board. Typically WDRs for discharge to land are issued for the life of the activity, provided there is no substantial change in the activity; however, WDRs are subject to review at a regular interval based on the relative threat to water quality. There is no vested right in the permit. Permits may be transferred in the event of a change in ownership of the facility at the discretion of the Regional Water Board. The Regional Water Board must be notified of the change in facility ownership. Waivers from WDRs are issues under specific circumstances, as detailed in Section 3.2.6 below.

To obtain new or updated WDRs, the discharger must submit a permit application to the appropriate Regional Water Board office (Figure 3-1). The application must include both a completed Form 200

Application (Appendix C) and a technical report that thoroughly characterizes the discharge (the report of waste discharge (RWD)) prepared by an engineer registered in California. The Regional Water Board recommends submitting the RWD at least 6 to 9 months prior to the date of the proposed discharge to allow adequate time for staff review and preparation of WDRs. Because reviews are limited by staff availability and backlog, early submittal is considered imperative to avoid impacts on operations which are contingent on permitting.

Form 200 requires facility contact information, a summary of the CEQA information, description of the type of discharge, and a certification statement. To be considered complete, the accompanying RWD must contain a thorough characterization of the discharge, including flows and chemical analyses, a description of best management practices the facility has implemented or will implement, a description of any treatment performed prior to discharge, and a description of the disposal methods. If operations could pose a threat to groundwater, the RWD must also contain a groundwater monitoring plan.

Collection of information for the RWD requires process/rinse water sampling, flow measurement, and process documentation. The discharger must develop this information by monitoring the discharge volumes and constituent levels over time, so that representative information is submitted in the application. If the discharger does not yet have a complete set of information, they should provide plans in the RWD, including a time schedule to develop the information.

The general outline for the RWD may be based on the Central Valley Regional Water Quality Control Board's list of "Information Needs for Waste Disposal to Land"; however, specific content requirements may be modified by the Regional Water Board, depending on site conditions and planned operations. The Regional Water Board highly recommends that processors discuss their draft outline with staff in advance to ensure the compiled RWD will satisfy information needs. This planning step will also serve to minimize permitting delays due to requests for additional information. Typical RWD information includes the following (see also Appendix C):

- **Facility Description –** Provide information on the raw materials, how these are processed, and the products. The description should quantify what is produced (e.g., pounds of fruit on a daily basis) and provide the hours of operation including seasonal variations. Significant plant equipment and function in the process should be included here.
- **Discharge Characteristics –** Describe the quality of each component of the process/rinse water stream proposed to be discharged (process/rinse water, wash water, boiler blowdown, etc.) and any pretreatment received prior to discharge and the removal efficiencies. The description should include maximum and average flow and concentrations of BOD, suspended solids, standard minerals, and total nitrogen (TN) for the discharge following pretreatment. The inorganic, or salts, component of the process/rinse water discharge is currently receiving increased attention from the Regional Water Boards. This component is measured by the parameter FDS, which represents the inorganic fraction of the TDS. TDS has typically been used as a surrogate for dissolved inorganics or salinity and is not an appropriate measurement parameter for discharges containing a significant organic dissolved solids component.
- **Daily and Seasonal Discharge Variations –** Describe methods for monitoring the volume and quality of the discharge and measuring flow rate. This section should also identify hazardous wastes generated at the facility, management practices to avoid commingling them with the process/rinsewater, and disposal plans.
- **Process Flow Diagram –** Describe sources and volumes of intake water, operations contributing wastewater to the discharge, and treatment units.
- **Water Balance -** Provide a full water balance, including: (1) wastewater flows from all sources (e.g., process water, subsurface inflows, storm water run-on and any inflow and infiltration from any collection system); (2) local precipitation data; (3) local evaporation data; (4) site-specific measurements of

evaporation if an enhanced evaporation system is present; (5) projected percolation rates for any effluent storage reservoir; and (6) irrigation disposal rates. The water balance must be completed by a California Registered Engineer.

- **Chemical Usage Accounting –** Provide detailed accounting of the usage at the facility for all chemicals that enter the process stream, the purpose of using the chemical and a description of how and where they enter the process. Estimate chemical usage on an annual basis.
- **Vicinity Map –** Provide a scaled map based on the United States Geological Survey (USGS) 7 ½' Quadrangle map (or equivalent) showing the location and acreage of the process/rinse water application area. Indicate topographic features, the direction of groundwater flow, locations of domestic and irrigation wells within 500 feet of the site, prevailing wind direction, residences within ½ mile, and land use in the vicinity of the site.
- **Site Map –** Provide a scale map of the site showing the location and dimension of major buildings, roads and parking areas, process and wastewater treatment structures, drainage control structures, onsite wells, ponds, and process/rinse water application areas.
- **Treatment and Holding Pond Design, Maintenance, and Management –** Describe treatment and storage facilities in detail. WDRs generally require that each facility have sufficient treatment, storage, and disposal capacity to accommodate process/rinse water discharge and seasonal precipitation during the winter months. The integrated land application system, including ponds, should be designed to accommodate total annual precipitation using a rainfall return period of 100 years distributed monthly according to the average monthly precipitation patterns and the anticipated process/rinse water volumes. Typically, no less than two feet of freeboard is required to be maintained in ponds at design conditions. Provide a water balance, a description of the ponds including dimensions, separation between the pond bottom and groundwater, presence or absence of a liner, and holding capacity and describe how the ponds will be managed and maintained. If a liner will be used, describe the proposed materials and construction specifications. Provide design calculations demonstrating adequate freeboard.
- **Information on Soil Types Underlying the Ponds and Application Areas –** Provide soils information, including data from onsite borings. This may also include published reference data.
- **Groundwater Information –** Provide information on depth to first groundwater and gradient based on wells of known construction perforated in the upper aquifer. If such data is not available, estimates based on published sources may be used. Background groundwater quality is an important factor in evaluating the potential impact of any discharge. Regional Water Board personnel have indicated that if sufficient information to evaluate background water quality is not available, the assumptions made in issuing the WDR will be conservative in nature, leading to more stringent requirements intended to protect assumed groundwater quality.
- **Surface Water Information –** Provide slope and direction of surface drainage at the proposed facility and disposal area as well as annual precipitation and evaporation data, including 100 year precipitation distributed monthly where storage is used. Describe the nearby surface water bodies receiving storm water drainage from the facility.
- **Water Quality and Quantity for Facility Source Water –** Describe the source water and provide water quality and quantity information. The amount used may be tracked through water consumption records or invoices.
- **Process/Rinse Water Management Plan –** Describe how the system will be designed and operated to minimize nuisance odors and maximize attenuation of the decomposable organics within the aerobic soil profile. If features such as ponds, sumps, or ditches involving long-term contact of the process/rinse water with the soil are incorporated in the design of the land application system, describe the design, operation and maintenance of these features to be protective of underlying groundwater. Provide a plan

describing the acreage of proposed crops; water use; irrigation scheduling; nitrogen uptake of the crops; and wastewater hydraulic, BOD, nitrogen, and commercial fertilizer loading.

Regional Water Board personnel rely on the applicant to supply sufficient information concerning how the system will be operated, maintained and monitored. System performance parameters included in the RWD are often incorporated into the WDR as effluent limits.

- **Monitoring and Reporting –** Describe the proposed monitoring plan to verify the process/rinse water characterization information, to implement the process/rinse water management plan, including loadings, and to demonstrate that groundwater quality requirements are satisfied.

Additional site-specific information, such as a description of storm water and domestic wastewater management methods, may sometimes be requested for inclusion in the RWD by the Regional Water Board staff. Food processing facilities that have materials, machinery or products exposed to stormwater are required to obtain coverage under an individual or the General NPDES permit for discharges of stormwater and develop a Storm Water Pollution Prevention Plan (SWPPP). The Regional Water Board also encourages including an analysis and evaluation of reclamation and reuse of process/rinse water.

When a discharger submits the RWD to the Regional Water Board, a staff person is assigned to work directly with that applicant. Staff reviews the RWD and issues comments, which can include a request for more information, to the discharger prior to issuing tentative WDRs for the facility. The WDRs typically describe the discharge and applicable laws pertaining to the discharge; describe site-specific requirements for the discharge, including prohibitions, specifications, receiving water limitations and provisions; and include Standard Provisions, a monitoring and reporting program, information sheets outlining the regulatory and technical justification for the WDR terms and conditions, and various attachments such as process flow diagrams and guidelines for preparation of technical reports or monitoring well installation.

The discharger negotiates final permit conditions to be contained in the WDR with the Regional Water Board staff. If there are no adverse comments, WDRs are typically adopted by the Water Board as an uncontested item. If warranted, the discharger may request review by Regional Water Board supervisory staff, request modification of the proposed WDR terms in a public Regional Water Board meeting and/or appeal the final permit conditions to the State Water Board. If 140 days have elapsed since submittal of the RWD and any supplemental information requested, the discharge may begin if the waste discharged does not create or threaten to create a condition of pollution or nuisance, as long as certain CEQA conditions are met. As such, the Regional Board may adopt WDRs beyond the 140 day time limit.

Groundwater monitoring is typically required in permits for land application of process/rinse water to evaluate the effect on underlying groundwater. Current information concerning the procedure for submitting a monitoring well work plan is included in Appendix D. To obtain a permit for the installation of monitoring wells, the discharger must contact the applicable county Environmental Management or Health Department for a permit application. Permit requirements and fees vary from county to county, but typically, multiple wells can be covered by the same permit application and installation fees will not exceed several hundred dollars per well. The permit application is usually processed and approved by the county within several weeks.

3.1.6 State Waiver Process

The California Water Code makes provision for waiver of the permit requirement for some types of discharges (known as categorical waivers) or individual discharges. Granting of waivers is subject to the discharges meeting certain conditions, and the waivers may be terminated at any time. As of the year 2000, waivers are limited to a five-year term. Waivers can be renewed; categorical waiver renewal requires public hearing and evaluation. The conceptual framework for issuance of either a waiver or a WDR permit by the Regional Water Board is outlined in Figure 3-4.

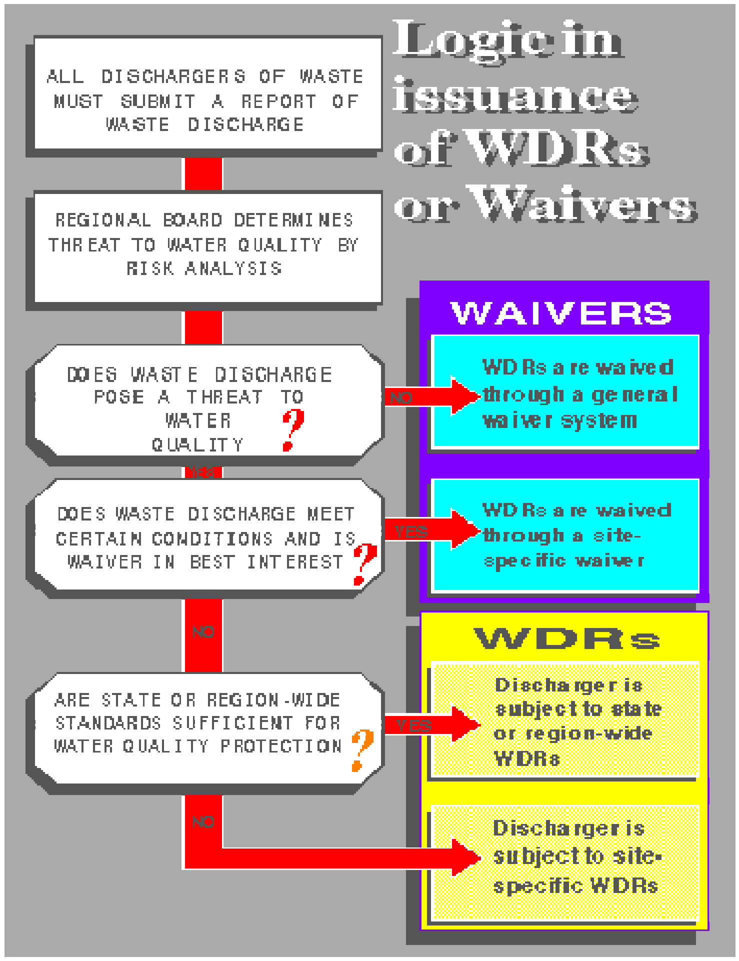

Figure 3-4. Logic in Issuance of WDRs or Waivers

General waivers currently in force for the Central Valley Regional Water Board (Region 5) include the following that are relevant to food processing operations:

- Industrial wastes utilized for soil amendments where industry certifies its nontoxic content and BMPs are used for application.
- Small food processors (generating less than 100,000 gallons of wastewater per year), including wineries (crushing less than 80 tons of grapes per year or generating less than 100,000 gallons of wastewater per year) that apply waste to cropland at an agronomic rate. Also applicable to small processors and wineries of any size that elect to store and haul all wastes offsite to a permitted treatment facility.
- Agricultural commodity wastes that require expedient disposal resulting from culls, spoils or contamination. Examples include unprocessed fruit, vegetables and raw milk that can not be salvaged. Processed food and processed food residuals are excluded from the waiver.

The waiver application process is similar to the application for waste discharge requirements, but has fewer procedural steps and involves a lesser level of detail. A completed Form 200 Application (Appendix C) is still required, and a waste management plan including waste characterization is also usually required. Best management practices may need to be described and implemented as a condition of the waiver. Soils data for constituents of concern may be required both prior to commencement of discharge and as part of ongoing monitoring. Groundwater monitoring is not usually required, but readily available groundwater information should be compiled as part of initial planning. Waivers often have annual reporting requirements for loading rates and other site parameters of interest. Fees for waivers are based on the threat to water quality and reporting complexity.

The Central Valley Regional Water Board staff is considering expanding the waiver process to address other types of low-risk rinse water discharges. These discharges are viewed by Central Valley Regional Water Board staff as posing a low level of environmental "threat" when appropriately managed to protect water quality and prevent nuisance conditions. The current concept is to preserve the existing small discharge waiver based on volume, but to also offer a waiver applicable to other low-threat situations based on constituent loading rates and concentrations coupled with appropriate management practices. If adopted, the new waiver should help to simplify permitting and compliance procedures for some dischargers, while allowing the Regional Water Board to focus their limited resources on the more significant water quality threats.

From best available research, a set of relative risk level categories for various land application loadings and site characteristics are defined in Chapter 7, Loading Rates and System Design Approach. The lowest level risk category is proposed to define the new low-threat waiver program, pending Central Valley Regional Water Board approval.

3.2 Enforcement

As part of their responsibilities to maintain and enhance waters of the state, the Water Code has authorized the Regional Water Boards to take enforcement actions against persons who do not comply with the Water Code or with actions directed by the Regional Water Board under authority of the Water Code. Failure to apply for a WDR permit, discharging before acquiring a WDR permit, and failure to submit a timely or complete technical or monitoring report can all result in a Regional Water Board assessing administrative civil liability. Failure to comply with terms in a WDR permit can result in a cease and desist order, referral to the attorney general, or assessment of administrative civil liability. Creation of an unreasonable, or a threatened unreasonable impact, on water quality or beneficial uses can result in a cleanup or abatement order. The State Water Board's Water Quality Enforcement Policy, adopted by Resolution 2002-0040, describes these alternative actions and under what circumstances they should be taken, and it's Cleanup and Abatement Policy, Resolution 92-49, describes procedures for required cleanup actions.

3.3 Local Regulations

Additional local regulations pertaining to land application programs are implemented through permits issued by the applicable county Planning Department. In some counties, including Fresno and Napa Counties, a Conditional Use Permit issued by the county planning department is required for new facility construction or expansions. The applicant must follow review procedures under the California Environmental Quality Act (CEQA). Under CEQA, a lead agency, such as the county, is identified to conduct an initial study with a preliminary assessment of potential environmental impacts of the proposed facilities. If no significant impacts are identified, the outcome is a negative declaration. If impacts are identified, the applicant must conduct a more extensive, in-depth CEQA analysis, including soliciting public participation, and establishing mitigation measures with the goal of reducing the impact of the facilities on the environment.

Measures routinely required by the county planning department or health departments to minimize potential nuisance conditions associated with the proposed land application system are then incorporated into the WDR. These additional measures may include items such as establishment of minimum set-back distances from the property lines, requiring flushing of the process/rinse water sumps periodically, and limiting noise levels or hours of operation.

Historically, county agencies have been responsible for regulating septic systems and leach fields used for disposal of domestic wastewater or "equivalent" waste, as delegated by the Regional Water Boards. Some counties consider food processing or winery wastes discharged to septic systems to be equivalent to domestic waste, therefore under their purview. In counties where the waste are not considered equivalent, the Regional Water Boards assume responsibility. When Counties take the lead, they ensure that Regional Water Board standards are met, and in some cases they also implement local requirements concerning operation of the septic systems and leach fields. For example, Monterey County adopted guidelines specifying hydraulic capacity limits for these systems in an effort to restrict the nitrate loading to the underlying aquifer.

4. FOOD PROCESS/RINSE WATER QUALITY CRITERIA

Food process/rinse water is generated in the processing of fruits, vegetables and other raw foodstuffs. This water typically does not contain domestic sewage or require chlorination/disinfection before land application. Rinse water typically does not contain limiting concentrations of regulated heavy metals, pesticides and/or other organic pollutants. Most process/rinse waters contain valuable organic matter and macro and micro plant nutrients that may be beneficial to both soils and plants. Nutrients in process/rinse water may allow up to a 20-30 percent reduction in fertilizer application to crops (Beardsell et al., 1995).

Like most commercial fertilizers and soil amendments routinely utilized on farms, food process/rinse waters may contain solids, salts, and other minerals that may be detrimental to plants or soil structure if their application is not properly managed. The following sections discuss the key chemical characteristics to evaluate when considering rinse water as a source of water for land application.

4.1 Water Quality Analyses

When assessing the quality of rinse water for land application, it is important to perform the following basic water quality analyses:

- Total nitrogen, major nitrogen compounds, and phosphorus;
- Total organics (measured as BOD, COD);
- Suspended solids (measured as TSS);
- Salinity (measured as FDS, EC);
- Cations and anions; and,
- pH and boron.

If undisinfected rinse water is to be used for sprinkler irrigation of a fresh market vegetable crop, the rinse water should also be checked for possible pathogens, such as the O157:H7 strain of e-coli bacteria.

4.1.1 Nitrogen and Phosphorus

Nitrogen (N) and phosphorus (P) are among the major nutrients found in rinse water. Both of these are essential nutrients required by plants.

N is a vitally important plant nutrient and is the most frequently deficient of all nutrients (Tisdale et al., 1993). N plays a major role in plant production. It helps in the formation of proteins, increases photosynthetic activity, speeds up maturity and can produce dark green color in plant leaves.

N is absorbed into plants as nitrate (NO_3^-), ammonium (NH_4^+) or urea. Nitrate is the most dominant available form of N in moist, well-aerated soils. The primary forms of N in food process/rinse water are organic N and ammonium. These are measured as total Kjeldahl nitrogen (TKN). Nitrate concentrations in food process/rinse water are usually low.

Nitrates may contaminate surface and groundwater sources because the nitrate ion is negatively charged and tends to be easily leached from soil. Sandy soils are generally more susceptible to nitrate leaching than are clayey soils.

In order to properly manage nitrogen to prevent or minimize groundwater degradation, it is important to analyze process/rinse water for nitrogen before applying it to crops. It is also important to measure the amount of nitrogen in the soil and plants to adequately assess the amount of N required. The most common way to assess the amount of nitrogen in water is by measuring the concentration of NO_3, TKN, and ammonia (NH_3-N). To determine how much of the TKN is in the organic form, the ammonium nitrogen is determined and subtracted from the TKN.

Phosphorus is also an important nutrient for plants. Phosphorus helps in energy storage and transfers within the plant, is essential for seed formation, increases root growth, improves the quality of certain fruits and vegetables, and can increase disease resistance in crops (Tisdale, et al., 1993).

Phosphorus is mainly absorbed into plants as orthophosphate ions ($H_2PO_4^-$ or HPO_4^{2-}), and may be derived from decaying plant and animal remains, rocks or other mineral deposits and fertilizers. Phosphates can also be found in process/rinse water.

Phosphates are negatively charged ions and are repelled by negative charges on clay minerals and other organic compounds in soils. Phosphates react with iron and aluminum in acid soils and calcium and magnesium in neutral to calcareous soils to form solid materials that are not readily leached (Johnson, 2002).

4.1.2 Total Organics

Organic material consists of decayed plant and animal residues. Organic matter is one of the major components contributing to increased soil productivity, increased soil fertility, and crop production. The soil productivity benefits from organic matter include increased water holding capacity, improved soil structure, increased micro-organism and macro-organism activity, and increased water infiltration. Upon decomposition, organic matter provides N, phosphorus, sulfur, and other nutrients to plants. Organic matter undergoing aerobic decomposition also uses oxygen, reducing the amount of soil oxygen available to plants. Depletion of soil oxygen can result in anaerobic conditions, which can cause a reduction in infiltration capacity due to the sealing effect of gels and slimes secreted by anaerobic microorganisms (King, 1986).

Food process/rinse water organic constituents that are easily biodegradable are traditionally measured using five-day BOD. COD results can be obtained more quickly than BOD and can provide a better estimate of total ultimate oxygen demand if potential chloride interferences are addressed. COD tends to somewhat overstate ultimate biological oxygen demand. TOC is rarely used to measure organics in food process/rinse water because of the high cost of the test and the fact that it is not specific to the biodegradable portion of the organics. Volatile dissolved solids (VDS) can provide an indication of organic levels in process/rinse water, but some inorganic compounds influence VDS results, and VDS does not directly translate into oxygen demand. Organics measurement parameters are discussed in detail in Appendix G. The effects of organic loading rates on soil oxygen availability are discussed in Chapter 7.

Water Quality Analysis Recommendation: Use BOD and (if needed) COD for measuring organics in process/rinse water.

4.1.3 Suspended Solids

Solids concentration measurements are some of the most important physical characteristics to consider when evaluating process/rinse water for land application. Solids in water are composed of floating matter, settleable matter, colloidal matter, and matter in solution. TSS is a measure of the solids that can be filtered out of the water column. Excessive TSS accumulation at the soil surface can adversely affect water intake rates, thereby causing prolonged ponding, odors, and crop suffocation.

4.1.4 Total Salinity

Salts from process/rinse water can affect the health of crops and groundwater quality. Process/rinse water often has high concentrations of non-ionized organics that are broken down in the upper soil layer to carbon dioxide and water. With adequate soil aeration, the carbon dioxide escapes to the atmosphere over time. Assuming essentially complete removal of organics in the soil profile, only the mineral salts in the process/rinse water are of interest in protecting groundwater salinity. Therefore, the TDS test is not appropriate for measuring salinity in process/rinse water because it measures both mineral and non-mineral dissolved solids.

The most accurate method for measuring total mineral salinity in process/rinse water is to measure and sum the concentrations of all the major mineral ions. However, this procedure is relatively expensive for frequent use. The best measure for salinity of process/rinse water on a routine or frequent basis is FDS. Mineral waters of hydration and a portion of the mass of original bicarbonate are lost in the FDS test, meaning that FDS slightly understates total mineral salinity. The relationship between FDS and the sum of major minerals can be derived from a few samples. Then FDS measurements can be multiplied by a correction factor to obtain a good estimate of total mineral salinity.

EC can be useful as a “quick” measure of total salinity for comparative operational monitoring purposes for food process/rinse water, and average relationships between EC and the sum of the major minerals and/or FDS can also be derived. EC is typically found to be on the order of 1.7 times FDS, although the relationship varies somewhat depending upon process/rinse water characteristics. The use of process/rinse water EC directly for comparison with water quality objectives can overstate mineral salinity because of the presence of organic acids in process/rinse water. EC typically provides a much better indication of mineral salinity of food process/rinse water than the TDS test. Salinity measurement parameters are discussed in detail in Appendix G. General agronomic guidelines for irrigation water EC are discussed later in this chapter.

Water Quality Analysis Recommendation: Use the sum of ions and FDS for permit compliance monitoring for process/rinse water salinity. Use EC for field measurements and for comparison with irrigation water salinity guidelines. Use TDS and EC for groundwater salinity compliance monitoring.

4.1.5 Cations and Anions

There are many cations and anions found in process/rinse water. The major individual cations generally present include: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and potassium (K^{+}). The major anions include: bicarbonate (HCO_3^{-}), carbonate (CO_3^{-}), chloride (Cl^{-}), and sulfate (SO_4^{2-}). These cations and anions can have a profound impact on the physical and chemical properties of soils (California Fertilizer Association, 1995) as well as affecting plant production. The following is a summary of the benefits and potential problems associated with these ions:

- Calcium improves the physical properties of soils and increases water penetration if high concentrations of sodium are present. Calcium is essential in plant cell wall structure and is necessary for the formation of new cells. Because calcium is a salt ion that contributes to EC, the previously mentioned problems associated with high salinity are similar to those associated with high calcium concentrations.
- Magnesium behaves in a very similar manner as calcium in soil. In plants it is essential for photosynthesis and helps in the growth process. Magnesium is also a salt ion that contributes to EC, and high concentrations may result in nutrient imbalances.

- Sodium salts are very soluble and can be easily leached. In clayey and sandy soils, high concentrations of sodium can result in unfavorable environments for plant growth. In addition, sodium can disperse the clays that are present. When it rains, the clay particles are dispersed and become very impervious to water. When the dispersed soils dry, hard layers may form that are difficult to cultivate and present other management problems. In plants, too much sodium along with other ions can cause osmotic effects that reduce the availability of water.
- Potassium is an essential cation required for plant growth. It helps in root growth, increases crop resistance to disease and increases the size and quality of fruits and vegetables. The potassium ion is positively charged and water-soluble. Negatively charged materials in the soils, such as clay and humus, attract potassium. Most soils have enough clay and humus to adsorb or fix all of the potassium added. As a result, potassium is one of many ions that may accumulate to potentially toxic levels in the soil. Too much potassium can manifest in root loss and cause the wilting of new growth. In addition, too much potassium may cause deficiencies in magnesium and sometimes calcium.
- Bicarbonate can increase soil pH. When soils dry, calcium and magnesium combine with bicarbonate to form calcium and magnesium bicarbonate. Waters with high concentrations of bicarbonate can cause the following to occur in plants: iron chlorosis symptoms and white precipitate on foliage. In addition, high levels of bicarbonates can increase the precipitation of calcium and magnesium carbonates, which may subsequently cause soil sodicity problems.
- Carbonate can be found in waters with a pH greater than 8.0. In dry clayey soils carbonate reacts with calcium and magnesium to cause problems similar to those occurring in soils with high concentrations of bicarbonate.
- Chlorides are also found in most process/rinse waters and assist in photosynthesis and disease resistance in plants. However, high chloride concentrations can have toxic effects on plants and cause leaf abscission, marginal scorch, and salt burn.
- Sulfate also contributes to the total salt content of process/rinse water. The types of sulfates found in water include: sodium, magnesium, potassium and calcium. Although sulfur is an essential micronutrient, it is the cause of much acidity in some soils and may result in the development of acid sulfate soils in certain environments.

The SAR is calculated from the concentrations of sodium, calcium, and magnesium in water. SAR is used to determine a wastewater's potential to create soil permeability problems and the possibility of sodium toxicity after long-term use of water (Farnham, et al.). The following equation is used to determine the SAR in solution:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \tag{4-1}$$

Where concentrations are expressed in milliequivalents per liter (meq/L).

Ca meq/L = Ca mg/L ÷ 20.04
Mg meq/L = Mg mg/L ÷ 12.15
Na meq/L = Na mg/L ÷ 22.99

An adjusted sodium adsorption ratio (adj R_{Na}) is a modification of the SAR that takes into account changes in calcium solubility in the soil water determined as a function of the ratio between HCO_3 to calcium and the EC of the wastewater (Metcalf and Eddy, 1991). The following is the equation used to determine the adj R_{Na} in solution:

$$\text{adj } R_{Na} = \frac{Na}{\sqrt{\frac{Ca_x + Mg}{2}}} \tag{4-2}$$

Where Na, Mg and Ca_x concentrations are expressed in meq/L per liter. For Ca_x values see Metcalf and Eddy (1991).

Soil dispersion is one result of sodium accumulation that causes soil to become impermeable to water, develop hard surface crusts or create "slick spots" on the surface. Salt accumulation can reduce crop yield and quality. Crop growth can also be affected by salinity through osmotic effects, which reduce the amount of water available to plants.

4.1.6 pH and Boron

When considering process/rinse water for land application, the boron (B) concentration and pH should also be evaluated.

Boron is an element required by all plants, but in very small amounts. Boron plays a significant role in plant growth processes and helps in the development and growth of new cells, nodule formation in legumes, and flowering and fruit development.

Boron is absorbed in plants most often in the form of boric acid (H_3BO_3). Other forms of boron include: $B_4O_7^{2-}$, $H_2BO_3^{-}$, HBO_3^{2-}, and BO_3^{3-}. However, these forms contribute little to plants, and too much boron may result in severe problems. For example, excess boron can cause leaf edges to die, leaves to lose chlorophyll, seeds to fail to sprout, and restriction of root growth.

The pH of process/rinse water has a major influence on crop production, weathering of soil minerals, functioning of soil microorganisms, and the fate and transport of waste constituents. The pH in water is expressed as the negative logarithm of the hydrogen-ion concentration given in moles per liter and ranges on a scale from 0 (most acidic) to 14 (most alkaline). A neutral pH is 7.

The ideal pH for many plants is slightly acidic, between 6.0 and 7.0. If the soil pH becomes too alkaline (pH>8.5), iron, manganese, zinc and other essential micronutrients are less available to plants. In contrast, if the soil pH is too low (pH<4.20), Al, Fe and Mn toxicity to plants may result.

Process/rinse waters with a low pH can affect the functioning of soil microorganisms and affect the fate and transport of waste constituents. In an environment characterized by a low pH, the bacterial population is lowered and does not fix nitrogen (when the pH is under 5.3) (Biomassters, Inc. 1999). In addition, many metals are more soluble in lower pH and thus can increase the fate and transport rate of waste constituents.

4.2 Irrigation Water Quality Ranges

Recommendations have been developed for major water quality parameters for irrigation water.

4.2.1 Salinity

Salinity measured as EC in units of millimhos per centimeter (mmhos/cm) or decisiemens per meter (dS/m) is often used as the basis for evaluating the acceptability of irrigation water. Most crops can use water with a concentration of 1 mmhos/cm or less. Only a few crops can tolerate water with an EC of 5 mmhos/cm without some yield loss (Oster et al., 1998). Soil salinity levels of between 0 and 2 mmhos/cm (saturation paste extract specific conductance) have negligible effects on most agronomic crops. Typically, soil salinity and resulting infiltration problems may occur in medium to fine textured soils when percentage of exchangeable sodium exceeds 15 or the SAR of a saturated paste exceeds 12.

4.2.2 Specific Ion Toxicity

Specific ion toxicity refers to the excessive concentration of specific ions, which may result in diminished soil quality and crop decline or toxicity. The ions of greatest concern are chloride, sodium, and boron, and their concentrations in process/rinse waters are usually expressed in meq/L, as parts per million (ppm), or mg/L.

Table 4-1. Irrigation Water Quality Guidelines

		Degree of Restriction[a]		
Type of problem	Units	Negligible	Increasing	Severe
Acidity				
pH		5.5-7.0	<5.5 or >7.0	<4.5 or >8.0
Salinity				
EC_{water}	(dS/m) or	<0.75	0.75-3.0	>3.0
TDS[b]	(mg/L)	<480	480-1,920	>1,920
Permeability[c]				
Low EC_{water}	(dS/m) or	>0.5	0.5-0	n.s.[d]
Low TDS[b]	(mg/L)	>320	320-0	n.s
SAR		<6.0	6.0-9.0	>9.0
Toxicity				
Root absorption				
Sodium (SAR)	Unitless	<3	3-9	>9
Chloride	(meq/L)	<2	2-10	>10
	(mg/L)	<70	70-345	>345
Boron	(mg/L)	1	1.0-2.0	>2.0-10.0
Foliar Absorption				
Sodium	(meq/L)	<3.0	>3.0	n.s
	(mg/L)	<70	>70	n.s
Chloride	(meq/L)	<3.0	>3.0	n.s
	(mg/L)	<100	>100	n.s
Boron	(mg/L)	<0.7	0.7-3.0	>3.0

Source: Ayers and Westcot (1985)

Notes:

[a] *Neglible: process rinse water which equals or is less than values shown will not cause soil or cropping problems under good irrigation practices and no restrictions are applicable. Increasing: process rinse water which equals or exceeds the values listed and will need to be carefully managed to avoid soil and cropping problems or reduced yields. Severe: process rinse water, which equals or exceeds values noted will require special irrigation management to avoid soil salinity problems and will restrict the type of crops that may be grown.*

[b] *Use FDS rather than TDS for process/rinse water*

[c] *Permeability restriction is affected by salinity and SAR together. See source text for additional information.*

[d] *n.s. means not specified.*

In production agriculture, chloride and sodium toxicity depends on the application and crop used. Most crops can tolerate surface applied waters with concentrations of chloride or sodium at less than 5 meq/L (Oster et al., 1998). However, at concentrations exceeding 15 meq/L, significant restrictions can apply.

Boron toxicity can occur in most crops. Crops can usually tolerate 1.0 ppm of boron in water. However, boron concentrations as low as 0.7 ppm can begin to cause toxicity resulting in leaf-margin necrosis or worse. Local irrigated crops that are sensitive to boron include among others: blackberry, lemon, grapefruit, avocado, apricot, peach, plum and orange.

Molybdenum (Mo) is an essential nutrient, but can also be toxic to plants at higher levels. In addition, molybdenum may be toxic to livestock if forage is grown in soil with high levels of available molybdenum. Irrigation water should not contain more than 0.010 mg/L of molybdenum (Metcalf & Eddy, 1991).

4.2.3 Nutrients

As discussed in the previous sections, the nutrients found in rinse water can provide many benefits to crops if applied effectively. However, if application is not monitored closely, soil quality may be negatively impacted, groundwater quality could be impacted, crop yields may be reduced, or imbalances may occur over time.

High levels of phosphorus may result in decreased availability of other metal micronutrients. As mentioned before, too much potassium can reduce calcium and magnesium availability to plants. Although rare, excess NH_4 can cause K deficiency.

4.2.4 Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

In terms of potential effects on crops and soil conditions, concentrations of total organics in irrigation water are not as important as loading rates. Appropriate loading rates for total organics (measured as BOD and/or COD) are discussed in Chapter 7.

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5. KEY LAND APPLICATION SITE CHARACTERISTICS

The land application site characteristics determine the potential for effective reuse of process/rinse water and its constituents. The site characteristics also directly influence the potential for the transport of constituents from the site surface to beneficial users of groundwater.

The key site features and characteristics include climate, topography, soils, geology, depth to groundwater, proximity to water supply wells, and proximity to surface water bodies. Interaction between these factors and their resultant influences on the effectiveness of land application processes are discussed in the following sections.

5.1 Climate

Climate is the average weather of an area, including seasonal variations and weather extremes (such as prolonged periods of droughts) averaged over a period of at least 30 years (Miller, 2000). The two main factors that determine climate in a given area are temperature, with its seasonal variations, and the amount and distribution of precipitation. Climate establishes many site characteristics because it:

- Affects the rates of physical, chemical and biological weathering processes over a large geographic area,
- Influences soil properties,
- Determines the types of vegetation or agricultural crops that may be grown,
- Determines the rates of evaporation and evapotranspiration, and
- Determines the amount of precipitation that must be accounted for during site and system design.

Temperature is important because the rates of assimilation and conversion of process/rinse water constituents by soil microbes are a function of temperature (Barker, 2000). The rate of microbial conversion of nitrogen compounds, in particular, decreases substantially with cool temperatures, which can be a consideration in loading rate design (Chapter 7). Plant assimilation of nutrients and organic matter increases with increasing temperature. Temperature also has a direct effect on evaporation and plant water use (Chapter 6).

The distribution and amount of precipitation is important to land application practices because of the potential implications for runoff, soil erosion and leaching. For example, if the average annual rainfall is 24 inches and is evenly distributed throughout the year (i.e., approximately 2 inches per month), less soil erosion and leaching will likely occur than the same annual amount of rainfall falling at a rate of 4 inches per month over a six month rainy season.

Climate is also considered by many soil scientists to be the most important factor in determining the properties of many soils. The main soil properties that correlate with climate are organic matter and nitrogen content, clay content, type of clay and iron minerals, the presence or absence of calcium carbonate ($CaCO_3$) and more soluble salts, and depth to the top of salt bearing horizons (Birkeland, 1984). For example, the organic matter and nitrogen content of comparable soils generally tends to increase as one moves from a warmer to a cooler climate. This occurs because organic matter production (i.e., plant growth) exceeds destruction or microbial decomposition of organic matter at temperatures less than approximately 75°F (Brady and Weil, 2002). Organic matter and nitrogen also tend to accumulate in soils with increasing moisture.

Clay content tends to be highest in soils developed under conditions of high temperature and moisture because of increased weathering rates. Land application areas with high clay contents require more intensive management, because clayey soils are more difficult to work than coarser textured soils. Additionally, infiltration and permeability rates decrease as the content of clay increases. Climate also influences the type of clay minerals present, with expansive (shrink-swell type) clays or smectites, such as montmorillonite, being more prevalent in drier environments. Non-expansive clays, such as kaolinite, are more common in warm, humid environments. Agricultural soils containing smectites require special irrigation practices because swelling and dispersion of smectites may significantly decrease infiltration rates, particularly if the soils contain large amounts of sodium.

The climate throughout much of California is well suited to both seasonal and year-round application of process/rinse waters. In contrast to agricultural areas in other regions of the country, prolonged freezing conditions that may limit the application of process/rinse waters do not occur in the central and southern agricultural regions of California. A long growing season is also characteristic throughout much of the state, allowing sites to be double or triple cropped, thus increasing annual consumptive water use and nutrient/salt recycling capacity. In particular, high evapotranspiration rates in the central and southern portions of the state result in process water being a valuable commodity that may be used to completely fulfill the water requirements for crop growth or serve as a supplemental water source.

Weather and climate data for a specific area can be obtained from a variety of sources including the National Oceanic and Atmospheric Association (NOAA), United States Department of Agriculture (USDA) offices, the California Department of Water Resources and County Agricultural Commissioner offices. Selected web addresses for California weather data are provided in the following table.

Organization	Web Address
NOAA	http://www.crh.noaa.gov
California Irrigation Management Information System (CIMIS)	http://www.cimis.water.ca.gov
Central Valley Water Education Center	http://www.cvwater.org

5.2 Topography

Topography refers to the configuration of the land surface and may be described in terms of elevation, slope, relief, aspect and landscape position (Birkeland, 1984; Brady and Weil, 1999). Site topography is also important in land application practices because:

- Topographic low positions accumulate water from higher adjacent areas and may have higher moisture contents, shallow groundwater, and/or greater salinity,
- The natural horizontal movement of groundwater usually follows the ground slope,
- Erosion and runoff potential increase with increasing slope; and

- Slope orientation or aspect affects the absorbance of solar energy.

The distribution and properties of soils in the landscape are strongly influenced by topography because of the resulting differences in microclimate, soil-forming processes and geological surficial processes. For example, steep slopes generally encourage surface erosion and allow less rainfall to enter the soil prior to runoff. Therefore, the depth of soil development on steep terrain is generally limited. The opposite condition is found in soils in flat flood basin areas, which tend to be deep and fine textured.

In general, the maximum slope recommended for cultivated agriculture is 12 to 15 percent (Pettygrove and Asano, 1985; USEPA 2006). It may be possible to adapt crops that do not require cultivation, such as grass-hay, or grapes, to slopes of 15 to 20 percent or more, depending on site-specific runoff constraints. A summary of limitations for crop cultivation with increasing slope is provided in Table 5-1.

Table 5-1. Influence of Slope on Limitations for Crop Cultivation

Percent Slope	**Limitations**
<2	Slight
2-6	Moderate
6-12	Severe
>12	Very Severe

Topography may also influence moisture content and the depth to groundwater tables. In wet or humid climates, topographic low positions may accumulate moisture from upland areas resulting in a high water table. In arid or semiarid climates, soluble salts derived from weathering in upland areas often naturally accumulate in low-lying areas.

5.3 Soils

Soils have four major roles to play in agricultural or other areas where land application of process/rinse waters occurs. The first is to function as a medium for plant growth. In this capacity, soils provide anchorage for vegetation, supply nutrients and water, and enable the exchange of gases between plant roots and the above ground atmosphere. The second role of soil is to provide habitat for a multitude of organisms. In fact, soils harbor much of the genetic diversity of the earth (Dubbin, 2001; Brady and Weil, 2002). A single handful of soil may contain billions of organisms that live and interact within a small space. Third, soils are important in the degradation and recycling of organic materials. Soils have the capacity to assimilate large quantities of organic wastes and convert the nutrients in the wastes to forms that may be utilized by plants and animals. Finally, soils play a major role in influencing the quality of water passing over or through them. Contaminated water passing through the soil may be cleansed of its impurities through a variety of soil processes, including microbial digestion and filtration. Conversely, clean water passing through a contaminated soil may itself become impacted.

As a result, detailed descriptions of the physical and chemical characteristics of the soil within the entire rooting zone (or upper five feet) should be made prior to land application of process/rinse waters. Initial information on soil types, characteristics, and depths can often be obtained from the Soil Survey published by the USDA Resource Conservation Service (RCS), available at http://websoilsurvey.nrcs.usda.gov/app/. Even if soil survey information is available, it should be supplemented by an investigation by a soil scientist to evaluate the suitability of the soil to adequately treat the process/rinse water. Hand-held soil auger boreholes and/or backhoe pits should be excavated and described. Soil characteristics that should be described include slope, aspect, effective depth, texture of different soil horizons, horizon thickness and boundaries, consistency, presence of rapidly draining materials, restrictive horizons or groundwater, mottling, drainage class, roots, estimated organic matter content, color, structure and pH. Additionally, descriptions of other parameters such as infiltration rate, cation exchange capacity (CEC), type of clay, available water capacity, type and amount of coarse fragments present, salinity, sodium adsorption ratio, flooding potential, soil erodibility, coatings of oxides and sesquioxides and horizons with carbonate or salt accumulations may be needed. Detailed descriptions of some of these characteristics are provided in the following sections.

5.3.1 Texture

Inorganic soil particles with diameters ranging from 2 to 0.05 millimeters (mm) are classified as sand; those with diameters ranging from 0.05 to 0.002 mm as silt; and those with diameters less than 0.002 mm as clay. Soil texture refers to the relative proportion of sand, silt and clay separates. The major soil textural classes as defined by the percentages of sand, silt and clay are shown in Figure 5-1. In some soils, coarse fragment modifiers, such as stony, gravelly or cobbly are included as part of the textural class name. Fragments ranging in size from 2 to 75 mm along their greatest diameter are termed gravel; those ranging from 75 to 250 mm are called cobbles; and those more than 250 mm across are called stones or boulders.

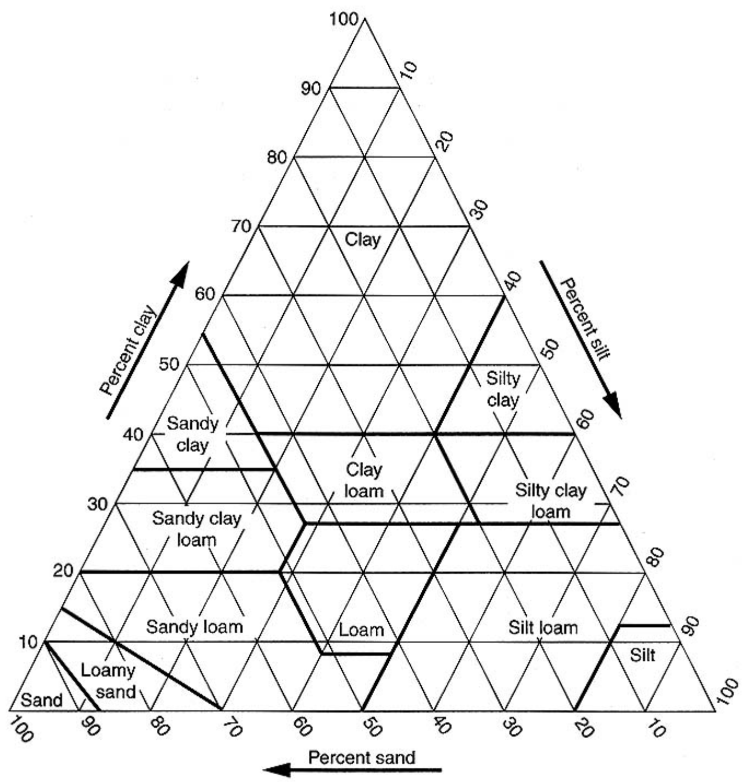

Figure 5-1. Textural Triangle. The Major Soil Textural Classes are Defined by the Percentages of Sand, Silt and Clay According to the Heavy Boundary Lines Shown.

Texture is one of the most important characteristics determining fundamental soil properties such as fertility, water-holding capacity and susceptibility to erosion (Dubbin, 2001; Brady and Weil, 2002). The typical influence of sand, silt and clay textures on some fundamental properties and behavior of soils are summarized in Table 5-2. In general, coarse-textured (sandy) soils can accept large volumes of water but do not retain much moisture. Fine-textured (clayey) soils can retain larger volumes of water but do not drain well. Overall, deep, medium-textured (loamy) soils exhibit the best characteristic for process/rinse water irrigated systems.

It should also be noted that limitations for land application of process/rinse waters may increase when the proportion of coarse fragments is high and the unsaturated soil depth is small. This is largely the result of the decrease in soil surface area for treatment of the applied waters.

Table 5-2. Influence of Texture on Soil Properties and Behavior

	Typical rating[a] associated with textural class		
Property and/or Behavior	Sand	Silt	Clay
Water-holding capacity	Low	Medium to high	High
Rate of drainage	High	Slow to medium	Very Slow
Soil organic matter content	Low	Medium to high	High to medium
Organic matter decomposition	Rapid	Medium	Slow
Susceptibility to wind erosion	Moderate	High	Low
	High if fine sand		
Susceptibility to water erosion	Low	High	Low if aggregated,
	Moderate if fine sand		High if not
Shrink-swell potential	Very low	Low	Moderate to very high (depending on clay mineralogy)
Ease of tillage after rain	Good	Medium	Poor
Inherent fertility	Low	Medium to high	High
Potential for leaching	High	Medium	Low (unless cracked)
Susceptibility to pH change	High	Medium	Low

[a] *Exceptions to these typical ratings may be observed and are often related to soil structure or clay mineralogy.*

5.3.2 Available Water Holding Capacity

Available water is defined as the portion of water in a soil that can be readily utilized by plant roots. The effective soil depth and texture have a significant impact on this soil property. Water in soils is held in pores ranging in size from large cracks or macropores to tiny interlayer spaces or micropores. When all of the macropores and micropores in a soil are filled with water, the soil is said to be saturated. Water is easily drained from a saturated soil because of gravitational forces. A soil is defined as being at *field capacity* when the soil is holding the maximum amount of water it can against the force of gravity. At this point, the water has drained from the macropores and is present only in micropores.

At field capacity, a plant will initially be able to extract water easily from the soil. However, soil water is held more tightly as the amount of water decreases and larger pores are drained. Eventually, plants are unable to extract sufficient water from the soil to survive, and the soil is said to be at its permanent wilting point. Although clay-textured soils may contain large amounts of water at the permanent wilting point, this water is held so tightly that it is unavailable to plants. As a result, the amount of water held between field capacity and the permanent wilting point, the available water, is more important for plant growth than the total soil water content. The presence of organic matter increases the amount of available water directly, because of its greater water supplying ability, and indirectly, through beneficial effects on soil structure and total pore space. The variation in field capacity, available water, permanent wilting point, and unavailable water with differing soil textures is illustrated in Figure 5-2.

Ranges in the available water holding capacity for different soil types are summarized in Table 5-3. Additional information concerning the water holding capacities of soils throughout California is available in the University of California publication titled: "Water-Holding Characteristics of California Soils" (University of California, Division of Agriculture and Natural Resources, Leaflet 21463). General information on available water holding capacity is also provided in the County Soil Surveys published by the USDA SCS.

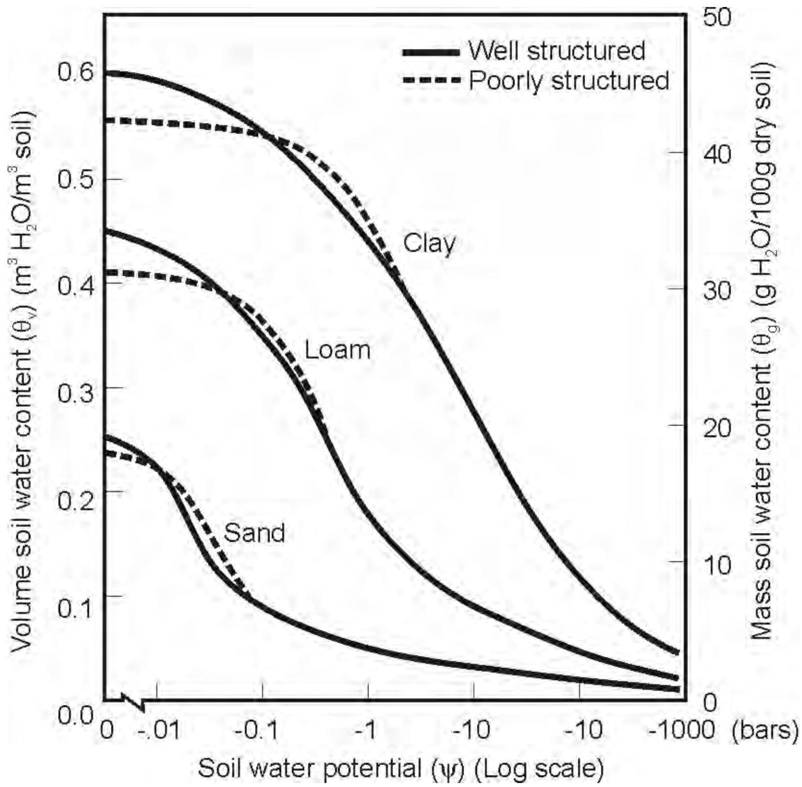

Figure 5-2. General Relationship between Soil Water Characteristics and Soil Texture

Table 5-3. Available Water Holding Capacity for Different Soil Types

Soil Type	Available Water Holding Capacity	
	Range (in/ft)	Average (in/ft)
Very coarse to coarse-textured – sand	0.5 to 1.00	0.75
Moderately coarse-textured – sandy loams and fine sandy loams	1.00 to 1.5	1.25
Medium-textured – very fine sandy loams to silty clay loam	1.25 to 1.75	1.50
Fine and very fine-textured – silty clay to clay	1.50 to 2.50	2.00
Peats and mucks	2.00 to 3.00	2.50

Source: University of California. 1981. Basic Irrigation Scheduling. Leaflet 21199.

5.3.3 Effective Depth

Effective depth refers to the depth of soil to seasonal groundwater and/or a restrictive soil horizon that limits rooting depth. Adequate soil depth is important for root development, retention of process/rinse water constituents on soil particles, and microbial action. Most plants, both annuals and perennials, have the bulk of their roots in the upper 10 to 12 inches of the soil as long as adequate moisture is available. Perennial plants, such as alfalfa and trees, have some roots that are capable of growing to depths greater than nine feet and are able to absorb a considerable portion of their moisture requirements from the subsoil. Retention of process/rinse water components is a function of their residence time in the soil and the degree of contact with soil particles. Except for very high permeability soils, a soil depth of two feet is generally adequate for process/rinse water treatment (Pettygrove and Asano, 1985; USEPA, 2006).

5.3.4 Infiltration and Percolation

The process by which water enters the soil pore spaces and becomes soil water is termed infiltration. The rate at which water enters the soil is termed the infiltration capacity *I*:

$$I = \frac{Q}{A * t} \tag{5-1}$$

Where Q is the volume of water (ft^3) infiltrating the soil, A is the soil surface area in (ft^2) exposed to infiltration, and t is time in seconds (s). The units of infiltration are generally simplified to inches per hour (in/hr). The infiltration capacity is not constant with time, and generally decreases during an irrigation or rainfall event (Brady and Weil, 1999). If the soil is dry at the onset of infiltration, all of the macropores open to the surface will be available to conduct water into the soil. In soils with expansive clays, the initial rate of infiltration may be quite high as water enters the network of shrinkage cracks formed during periods of drying or desiccation. As infiltration continues, many macropores become filled with water and the shrinkage cracks swell shut. Therefore, the infiltration capacity declines sharply initially, and then begins to level off, remaining fairly constant thereafter and is often called the saturated infiltration.

Once the water has infiltrated the soil, the water moves downward into the soil profile by the process of percolation. The rate of percolation is related to the hydraulic conductivity of the soil. Both saturated and unsaturated flow are involved in the percolation of water through the soil. Saturated flow occurs when the soil pores are completely filled (or saturated) with water, and unsaturated flow when the larger pores are filled with air, leaving only the smaller pores to hold and transmit water. As a result, macropores account for most of the water movement during saturated flow and micropores for movement during unsaturated flow. Thus, coarse-textured sandy soils have higher saturated permeability than fine-textured soils, because they typically have more macropore space. Medium-textured soils, such as loam or silt loam, tend to have moderate to slow saturated permeability. The influence of texture on soil permeability is summarized in Table 5-4. The conversion of percolation rates in the USDA Soil Survey to recommended design percolation rates is shown in Figure 5-3 (Crites, et al., 2000).

Table 5-4. Influence of Texture on Soil Permeability

Soil Texture	Permeability (in/hr)
Coarse-textured soils – sandy soils	Moderately rapid – 2.0 to 6.0 Rapid – 6.0 to 20 Very rapid - >20
Medium-textured soils – loamy soils	Slow – 0.06 to 0.20 Moderately slow – 0.2 to 0.6 Moderate – 0.6 to 2.0
Fine-textured soils – clayey soils	Very slow - <0.06 Slow – 0.06 to 0.20

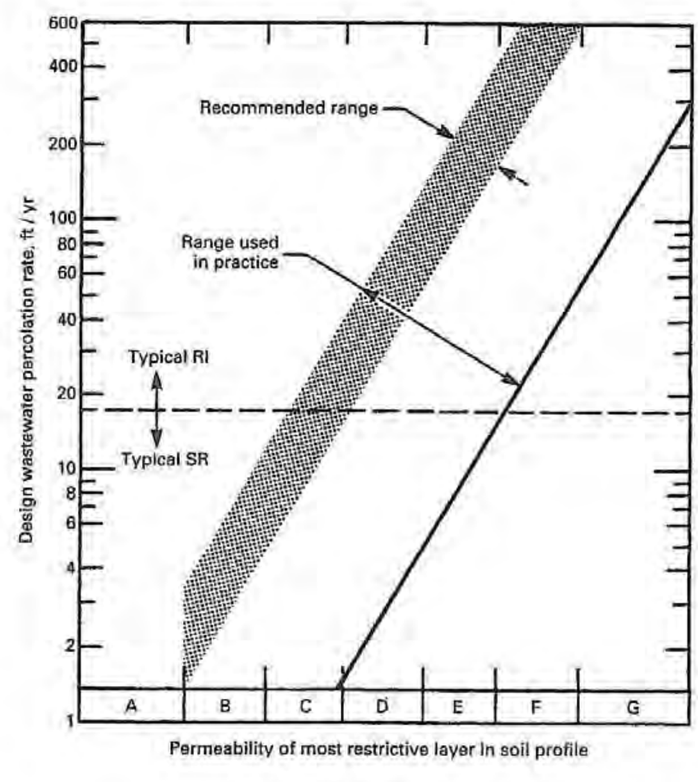

Figure 5-3. Design Percolation Rate Vs. NRCS Soil Permeability Classifications for Slow Rate and Rapid Infiltration Land Treatment (Crites, et al., 2000); A= very slow, G= very rapid.

5.3.5 Infiltration Rate Testing

If irrigation methods or application rates used on a site will be changing for the application of process/rinse water, infiltration rate testing may be warranted. This would be especially true for sites that could be prone to runoff, erosion, or extended ponding. Infiltration rate testing should also be performed if center pivot or linear move sprinklers are contemplated because of their very high instantaneous application rates. Infiltration tests can be performed using cylinder infiltrometers, basin infiltration tests, or other means described in USEPA, 2006. These tests can be a part of the site soils investigation described previously. The use of data from infiltration tests for system design is discussed in Chapter 7.

Irrigation systems should be designed to deliver water at a rate that is less than the infiltration capacity of the soil to minimize runoff or excessive percolation. Runoff and erosion may present problems if the soil infiltration capacity is low, the land is relatively steep, and/or too much water is applied in one place. Water may be lost to deep percolation or runoff because of uneven distribution of water. Uneven distribution and penetration of water may also result in yield losses in certain portions of the field. These and other factors important in irrigation system design are discussed in detail in Chapter 9.

5.3.6 Soil Chemical Characteristics

Process waters often contain nutrients and/or organic matter that can improve soil chemical, physical or biological properties of agricultural land. In fact, soil has a tremendous buffering capacity for receiving process water compared to air and water and may serve as the best choice for management of process waters with the least impact on the environment. However, there are several soil chemical characteristics that may need to be checked initially and/or monitored periodically during land application to ensure that soil quality is not degraded, and that toxicity to crops is prevented. These characteristics include:

- pH;
- Cation exchange capacity;
- Salinity; and
- Micronutrient and macronutrient concentrations.

The potential impact of land application of process/rinse waters on these soil characteristics are discussed in the following sections. The recommended frequency of monitoring for these parameters is discussed in more detail in Chapter 10.

pH. The pH scale, as discussed in Chapter 4, ranges from 0 (most acidic) to 14 (least acidic), and is logarithmic, meaning that each unit change in pH represents a ten-fold change in acidity. Of all soil chemical characteristics, pH is the most important and influences diverse properties including nutrient availability, functioning of microorganisms and fate and transport of many contaminants. For example, soils with pH less than five often contain soluble aluminum in concentrations that are toxic to plants, and show deficiencies of calcium, magnesium and molybdenum. Conversely, plants that require large amounts of iron, such as azaleas and rhododendrons, prefer acidic soil environments in which iron is most available.

Soils with pH greater than nine generally contain sodium at concentrations high enough to be detrimental to soil structure (Brady and Weil, 1999; Dubbin, 2001). Additionally, plants grown in high pH soils may exhibit micronutrient deficiencies. Typically, a soil pH between 5.5 and 7 is optimal for nutrient availability to plants. The ability of a soil to resist changes in pH as a result of land application of rinse waters or other activities is termed its buffering capacity. The buffering capacity of a given soil increases with increasing organic matter, calcium carbonate content and cation exchange capacity.

The activity of microorganisms is also reduced in acidic soils, resulting in a reduction in the rate of nitrogen and phosphorus mineralization. The decreased rate of microbial activity also adversely affects soil structure, because the production of organic materials required for the formation of stable aggregates is insufficient.

Cation Exchange Capacity (CEC). The CEC of a soil is the sum total of exchangeable cations that may be adsorbed, and therefore, represents the nutrient holding capacity of a soil. The CEC is primarily due to the clay minerals present and organic matter content. The contribution of organic matter to CEC, on a weight basis, is approximately four times as much as that from the clay fraction (Dubbin, 2001). Typically, the highest CEC and fertility occur in clayey soils high in organic matter.

The CEC is expressed in terms of moles of positive charge adsorbed per unit mass in terms of $cmol_c/kg$, which is equivalent to meq/100g. The CEC of most soils typically ranges from approximately 3 to 50 $cmol_c/kg$, and tends to increase with increasing pH (Brady and Weil, 1999). At pH values <6.0, the CEC is generally lower. The CEC is typically measured at a pH of 7.0 or above to evaluate the maximum retentive capacity. Checking the initial CEC of the soil is important in land application of process/rinse waters because leaching of cations from the applied water is more likely to occur in soils with low CEC (<5 $cmol_c/kg$). In contrast, leaching is reduced in soils with high CEC (>10 $cmol_c/kg$).

Salinity. Soluble salts are generally composed primarily of calcium (Ca^{+2}), magnesium (Mg^{+2}), sodium (Na^{+}), chloride (Cl^{-}), bicarbonate (HCO_3^{-}), and sulfate (SO_4^{-2}). Sodium is the most problematic of all the ions released by soluble salts. As discussed previously, sodium disperses clay and organic matter, thereby degrading soil structure and reducing macropore space. Soils high in sodium, therefore, are poorly aerated and have reduced permeability to water. Soluble salts alter osmotic forces in soils and impede the uptake of water by plants. Deleterious effects of salts on plants are also caused by toxic concentrations of sodium and chloride. Fruit crops are particularly susceptible to high concentrations of these elements. Additionally, the high pH caused by excess sodium may result in micronutrient deficiencies.

An indirect measure of soluble salt content in soils can be obtained by measuring the EC of saturation extract of the soil, designated as EC_e. An EC_e greater than 4 dS/m indicates a saline soil, and an EC_e of 2 to 4 dS/m indicates moderately high soil salinity. The threshold for yield effects for the most sensitive crops begins at about 1 dS/m. The EC_e of soil subject to land application of rinse waters should be checked periodically as part of the soil monitoring program to ensure that potentially harmful and/or toxic concentrations of soluble salts are not present. The ESP and the SAR, two measurements of the sodium content in soils, should also be monitored. The ESP indicates the extent to which the CEC of the soil is occupied by sodium; the SAR provides information on the comparative amounts of sodium, calcium and magnesium in soil solutions. Soils with an ESP greater than 15 are classified as sodic soils.

5.3.7 Geophysical Mapping of Site Soil Salinity

Discreet soil samples represent relatively very small volumes of soil from a site. Characterizing spatial salinity trends across a site using discrete soil samples is excessively expensive. Geophysical mapping using electromagnetic (EM) equipment can be cost effective for soil conductivity mapping. Using either a backpack or small trailer mounted unit, the site can be traversed to take hundreds of measurement points with a unit that measures electrical current eddies in the soil induced by an above-ground EM source. Measurement locations are recorded on the fly with a geographical positioning system (GPS) unit. Depending upon the dimensions of the inductive equipment, the results can provide an indication of soil salinity up to 15 feet deep. The EM results should be calibrated with results from discreet soil samples at a few select locations. EM surveys are useful for background surveys of sites where salinity will be a particular concern and for long term (5 or 10 year interval) checking of trends.

5.3.8 Soil Macronutrient and Micronutrient Concentrations

Concentrations of the macronutrients, nitrogen, phosphorus and potassium, and the micronutrients calcium, iron, magnesium, sulfur, manganese, molybdenum, zinc, copper, and boron should also be monitored in soils irrigated with rinse waters. The purpose of this monitoring is to ensure that hazardous, or potentially toxic, levels of nutrients do not accumulate and that sufficient concentrations are available for plant growth. Additionally, application of excess nitrogen can result in leaching of nitrate to groundwater. The recommended frequency of monitoring for these elements and compounds will vary depending on the characteristics of the soils and the chemistry of the rinse waters being applied.

5.4 Hydrogeology

The site specific geology and hydrogeology are critical components of the land application site. These factors determine the fate of water and constituents that have leached through the soil column. All readily available information on geologic and hydrogeologic factors should be compiled for a land application site, including:

- Existence, depth, and characteristics of hardpan,
- Depth and quality of the first-encountered groundwater,
- Depth, thickness, and characteristics of clay and sand/gravel layers down to and including the layers tapped by production wells in the area (This information may be obtained from well driller logs and e-logs of wells on or near the site),
- Publicly available regional hydrogeology reports,
- Groundwater levels, quality, and beneficial uses for monitoring and production wells on or near the site; and

- Where bedrock is a factor in production wells, the depth to, type and characteristics of bedrock, and underlying unconsolidated materials and sediments including fracturing, degree of weathering, density, tilt or slope.

Hardpan Characteristics. If a hardpan underlies the existing site, it could provide an impediment to the downward flow of percolate. This would provide additional protection for groundwater quality. The soil immediately above a hardpan will also tend to stay in a more saturated condition. This could limit hydraulic loading, but could enhance nitrogen removal. It will also affect the interpretation of soil and vadose zone monitoring.

First Encountered Groundwater. The depth and quality of first encountered groundwater is important in regulatory negotiations and in planning for site loading rates and site monitoring. Concentrations of constituents in groundwater prior to the effective date of water policies and to the application of process/rinse water are used when applying anti-degradation criteria (Chapter 3). A shallow depth to groundwater can limit the hydraulic loading rates and the soil zone treatment effectiveness. Depth to groundwater at several points on and near the site determine the shallow groundwater horizontal flow gradient, which is important for establishing upgradient and downgradient monitoring well locations (Chapter 10). Depth to groundwater is also a consideration for deciding where to screen monitoring wells.

Generally, a depth to groundwater of three feet or more is preferable. Shallower depths to groundwater will require subsurface drainage unless shallow groundwater occurs only during non-land application periods and permanent crops susceptible to damage from poor drainage are not grown.

Hydrogeologic Layers. The hydrogeologic layers and other subsurface structural information provides an indication of risk to existing beneficial uses of groundwater from constituents in percolate. Thick zones of low permeability beneath the site lessen the potential risk of groundwater quality impacts to the beneficial uses of water from below the zone. An understanding of the hydrologic structure also is important to consider when planning a groundwater monitoring program; i.e. should deeper sand/gravel zones be monitored and should existing production wells be incorporated into a groundwater monitoring program?

Regional Hydrogeology Reports. Regional hydrogeology reports can supplement local well logs and provide important information on natural (pre-modern) hydrogeologic conditions. An understanding of natural groundwater gradients and other conditions may help explain things like elevated shallow groundwater salinity at some sites. An average upward vertical gradient in groundwater may also lessen the risk to existing groundwater beneficial uses. Conversely, evidence of high hydraulic connectivity between shallow groundwater and aquifers tapped by water supply wells could indicate a greater risk to beneficial uses and the need for a more conservative system design.

Nearby Water Wells. The location, construction details and screened interval(s), depth, pumping rates, and hydrogeologic position (upgradient versus downgradient) of all water wells within ½ mile of sites should be determined to the extent that such data are available prior to initiating land application of rinse waters. This information can be useful in characterizing local geologic and hydrogeologic conditions and shallow or deep aquifers currently or previously utilized as a water source(s). Such data may also be used to assess baseline water quality and assist in the design of groundwater monitoring wells to be constructed on site. For example, if nearby wells are completed and screened within deeper aquifers, this may indicate that shallow groundwater is limited and/or of poor quality (i.e., high in iron, manganese and/or other potentially harmful constituents). Additionally, existing water well data may indicate that multiple aquifers are being utilized and may need to be monitored. Monitoring of multiple aquifers requires nested or cluster wells. In any case, installation of a network of monitoring wells is typically required at land application sites to monitor changes in groundwater levels and quality to ensure that beneficial uses of groundwater are not being significantly impacted. If possible, collection of groundwater samples for one to two years (eight quarterly sampling events) is recommended to establish baseline groundwater quality data prior to initiation of land application of rinse waters.

Data on groundwater levels in nearby wells can be used to help establish vertical groundwater flow gradients. Groundwater quality data in nearby wells can be used to establish a baseline for the evaluation of long term monitoring data. The beneficial uses of groundwater in nearby wells may be a factor in regulatory negotiations and the application of groundwater quality objectives. For example, increased water hardness (calcium and magnesium) may be beneficial for some agricultural water uses while it would be considered detrimental for municipal uses. If all the nearby production wells were for surface or undertree sprinkler irrigation, water hardness would be less of a regulatory concern.

Shallow Bedrock. Shallow bedrock can affect site planning and monitoring. Depth to bedrock, soil characteristics down to bedrock, and slope will determine hydraulic loading capacity of the site and the potential for percolate to resurface downhill from the site. Drilling logs and completion information for nearby production wells can provide information on fracture zones in the bedrock. Fracture zones that extend up to the process/rinse water application site can provide a more direct path for percolate to reach water supply wells, which could necessitate a more conservative system design.

5.4.1 Groundwater Transport

Understanding how groundwater moves under a land application site and transports dissolved constituents can be important when interpreting groundwater monitoring results (Chapter 10). While a detailed discussion of groundwater transport is beyond the scope of the Manual, this section presents the types of data that can be gathered and how the data can be used.

Groundwater flow direction and velocity is a direct function of the gradient (difference in groundwater surface elevation divided by the distance between monitoring wells) and the lateral hydraulic conductivity of saturated materials, particularly shallow sand and gravel layers. The velocity across the site is also a function of the specific yield of the shallow aquifer materials.

Very approximate estimates for hydraulic conductivity and specific yield can be based on aquifer material texture from driller's logs. Laboratory evaluation of drilling core samples for texture and hydraulic conductivity provide better results. The best hydraulic conductivity data is usually obtained from pumping and recovery tests of site monitoring wells.

Determining the average age of groundwater can be useful for estimating how quickly surface applications of water are likely to reach groundwater monitoring wells. High accuracy tritium, helium-3, and chlorofluorocarbon (CFC) analysis of groundwater samples can provide information on groundwater age for groundwater less than 60 years old, and can indicate whether a groundwater sample is more than 60 years old.

The mix of ions in water can provide a characteristic signature that can often be related to the recharge source of groundwater. This can be important for characterizing initial groundwater quality and for subsequently determining if applied process/rinse water is a main component of the groundwater from a given monitoring well. Stiff or Piper diagrams provide a visual method to help characterize and group water from monitoring wells.

Tracers can be used to see how quickly applied water reaches groundwater monitoring wells. An ideal tracer is something that is mobile, low in concentration in monitoring wells, and not a water quality concern at the concentrations needed for tracer use. Iodide, bromide, and boron have been used effectively as groundwater tracers, although bromide and boron can have water quality limit concerns. Tracers should only be used when there are significant apparent water quality impacts at a site and groundwater transport cannot be explained using the other tools described in previous paragraphs.

5.5 References

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6. WATER USE AND CROP SELECTION

In this chapter the characteristics of crops that impact their use in land treatment: water use, nutrient uptake, and tolerance for trace constituents, are described. Guidance on crop selection for a process/rinse water land application site is provided.

6.1 Crop Selection

The primary role of vegetation in a land treatment system is to recycle nutrients in the process/rinse water into a harvestable crop. Plant uptake is not the only form of nutrient transformation or removal from the soil-plant systems utilized in land treatment, but plant growth does impact all mechanisms either directly or indirectly. Plants also play a role in stabilization of the soil matrix and help maintain long-term infiltration rates. In slow rate systems designed for agricultural reuse, nitrogen generally is the limiting nutrient.

Varieties (cultivars) of major grain, food, and fiber crops are bred specifically for different regions of the United States because of differences in growing seasons, moisture availability, soil type, winter temperatures, and incidence of plant diseases. Other regional issues include infrastructure for post-harvest processing and demand for harvested by-product. A regional approach, therefore, is generally recommended for selection and management of vegetation at land treatment sites (Jensen et al., 1973). One of the easiest methods for determining regional compatibility of cropping for land treatment is to investigate the surrounding plant systems.

Once regional issues are considered, the final criteria should be based on specific system objectives including nutrient uptake, cultural practices, season of growth, compatibility with hydraulic loading (quantity and timing), and salt tolerance. Although plant uptake is not the only form of nutrient transformation that takes place in the soil-plant system, plants are often selected for their propensity for uptake of a certain nutrient or for use of large quantities of water.

6.2 Evapotranspiration (ET)

ET is the sum of plant transpiration and evaporation from plant and soil surfaces and is also known as crop water use. As commonly defined, ET does not include components of irrigation inefficiency or losses such as:

- Deep percolation
- Wind drift
- Droplet evaporation in the air
- Run-off

Sophisticated computer models can be used to estimate separate transpiration and evaporation components of ET. However, site-specific data for reference ET is often available. Crop ET based on reference ET adjusted for a specific crop is sufficiently accurate for water balances and irrigation scheduling.

6.2.1 Transpiration

Transpiration is the water that passes from the soil into the plant roots. Less than one percent of the water taken up by plants is actually consumed in the metabolic activity of the plant (Rosenberg, 1974). The remainder passes through the plant and leaves as vapor through the openings in the leaves known as stomata.

The drier and hotter the air, the higher the transpiration rate will be. The drier the soil, the slower the transpiration will be, because the water is held more tightly by the soil. A specific plant variety will have a genetic potential to transpire a certain quantity during the growing season. The transpiration on a given day depends on the plant growth stage, weather conditions, the availability of water, and general plant health. Non-plant based models used to calculate ET assume transpiration is not impacted by plant health or water stress.

6.2.2 Evaporation

Evaporation is water converted from liquid to vapor that does not pass through the plant. Evaporation may occur from wet soil or plant surfaces. When plants are young, a large portion of ET is evaporation from the soil surface. When plants achieve 70 to 80 percent canopy cover, soil evaporation will amount to only 10 to 25 percent of the ET. The ET due to soil evaporation primarily occurs immediately after irrigation when the soil surface is wet as illustrated in Figure 6-1.

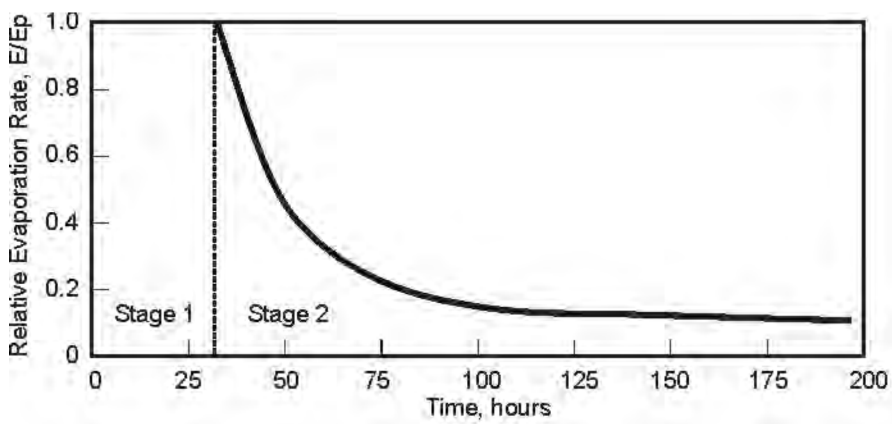


Figure 6-1. Evaporation from Bare Soil which was Initially Wet (Hanks and Retta, 1980)

Evaporation from the soil is increased by maintaining moist surface conditions. The extremes occur with sub-surface drip, which has very little evaporation, and small frequent sprinkler applications, which can evaporate a high percentage of the applied water.

6.2.3 Calculating ET

Crop evapotranspiration (ETc) is commonly calculated based on a rigorously defined reference crop evapotranspiration (ETo) and a crop coefficient (Kc) representing the specific crop and growth stage.

$$ETc = ETo \cdot Kc \tag{6-1}$$

Table 6-1 contains a range of expected ETc of a variety of crops. Further discussion of ETo and Kc is included in subsequent subsections.

Table 6-1. Range of Seasonal Crop Evapotranspiration

Crop	ET, in	Crop	ET, in
Alfalfa	24-74	Grass	18-45
Avocado	26-40	Oats	16-25
Barley	15-25	Potatoes	18-24
Beans	10-20	Rice	20-45
Clover	34-44	Sorghum	12-26
Corn	15-25	Soybeans	16-32
Cotton	22-37	Sugar beets	18-33
Deciduous trees	21-41	Sugarcane	39-59
Grains (small)	12-18	Vegetables	10-20
Grapes	16-35	Wheat	16-28

In areas such as the San Joaquin Valley of California monthly ET rarely varies more than 10 percent from the historical averages. Table 6-2 shows an example of alfalfa and grass ETo with the corresponding ET rates of various crops.

6.2.4 Reference ET

ETo is a term used to describe the ET rate from a known surface, such as closely cut grass or alfalfa (alfalfa ETo normally exceeds grass ETo by 0 to 30 percent). ETo is expressed in either inches or millimeters. The ETo for an average year is referred to as normal year ETo.

Rather than measuring the water consumption in the reference crop, ETo is often calculated from weather data or pan evaporation. Pan evaporation, as defined by the U.S. Weather Bureau's Class A pan, is commonly used for sizing pond systems and therefore, is often available to engineers designing land application systems. Pans store more heat than crops and consequently they cause more evaporation. The pan evaporation is normally higher than ET (15 percent for humid conditions and 25 percent for dry conditions). The coefficients in Table 6-3 can be used to convert pan evaporation to ETo using equation 6-2.

Table 6-2. Example ET Values for Southern San Joaquin Valley of California (Burt, 1995)

Month	Evapotranspiration Rate, inches/month								
	ETo, alfalfa	ETo, grass	Alfalfa* Hay	Cotton	Citrus	Deciduous orchard. w/o cover crop	Deciduous orchard. w/ cover crop	Grape Vines	Small Grains
January	0.88	0.69	0.73		0.85		0.68		0.41
February	2.41	1.97	1.99		1.52		1.98		1.99
March	3.75	3.13	3.11		2.32	1.49	3.33	0.05	3.92
April	6.19	5.24	5.11	0.48	3.75	3.63	5.89	1.16	6.37
May	7.98	6.78	6.71	2.06	4.85	5.58	8.10	4.13	6.24
June	9.03	7.65	7.32	6.68	5.06	6.83	9.08	6.00	0.63
July	9.32	7.92	7.80	10.03	5.27	7.59	9.58	6.72	
August	8.44	7.14	6.92	8.76	4.73	6.85	8.41	5.96	
Sept.	6.03	5.08	5.16	4.47	3.57	4.87	5.89	3.30	
October	4.55	3.75	3.63	0.77	2.69	3.02	3.90	1.22	
November	1.92	1.52	1.61		1.18	0.07	1.58	0.14	
December	0.71	0.55	0.60		0.38		0.50		0.09
TOTAL	61.2	51.4	50.7	33.3	35.9	40.8	58.9	28.7	19.8

Includes water use reduction during harvest periods.

$$ETo = K_{pan} \cdot E_{pan} \tag{6-2}$$

Where, ETo = reference evapotranspiration
K_{pan} = pan coefficient (Table 6-3)
E_{pan} = pan evaporation

Table 6-3. Pan Coefficient for Class A Evaporation Pans Placed in a Reference Crop Area (Doorenbos and Pruitt, 1977)

Wind, mi/h	Relative humidity, %		
	Low, <40	Medium, 40-70	High, >70
Light, < 4.5	0.75	0.85	0.85
Moderate, 4.5-11	0.70	0.80	0.80
Strong, 11-18	0.65	0.70	0.75
Very Strong, >18	0.55	0.60	0.65

Evaporation pans are difficult to maintain and numerous weather networks now gather ET data with empirical models that have been developed over the last 50 years. The ET models are based on different climatic variables. Relationships were often subject to rigorous local calibrations, but proved to have limited global validity. Testing the accuracy of the methods under a new set of conditions is laborious, time-consuming and costly, and yet ET data are frequently needed at short notice for project planning or irrigation scheduling design.

The FAO Penman-Monteith method is recommended as the sole ETo method for determining reference evapotranspiration. The method, its derivation, the required meteorological data and the corresponding definition of the reference surface are described in FAO paper 56 (Allen et al. 1998).

While the Blaney-Criddle is not recommended for irrigation scheduling it has sufficient accuracy for initial planning and has the benefit of only requiring temperature and published climate factors (SCS, 1970). The Arizona Department of Environmental Quality uses a water reuse model based on Blaney-Criddle.

Unless the site is remote, seasonal ETo data is normally available from the California Irrigation Management Information System (CIMIS), which operates over 100 weather stations. CIMIS uses the Modified Penman to define normal monthly ETo and daily ETo. Daily ETo is available for download from their FTP site the following morning. CIMIS has also developed a map of California with 18 different zones of monthly ETo, shown in Figure 6-2.

Additional ET data is contained in Bulletin 113-3, Vegetative Water Use in California published by the California Department of Water Resources (DWR, 1974).

6.2.5 Crop Coefficients

Kc values are determined by the ratio of the measured ETc and ETo. The derived Kc is a dimensionless number (usually between 0.1 and 1.2) that is multiplied by the ETo value to arrive at a ETc estimate. Because of the method of calculation, Kc is dependent on the reference ETo used in the calculation. Kc values vary by crop, stage of growth, and by climate. Care should be used to match the Kc to the proper ETo. The University of California Cooperative Extension has prepared two leaflets on Kc:

Leaflet #21427 - "Using Reference Evapotranspiration (ETo) and Crop Coefficients to Estimate Crop Evapotranspiration (ETc) for Agronomic Crops, Grasses, and Vegetable Crops"

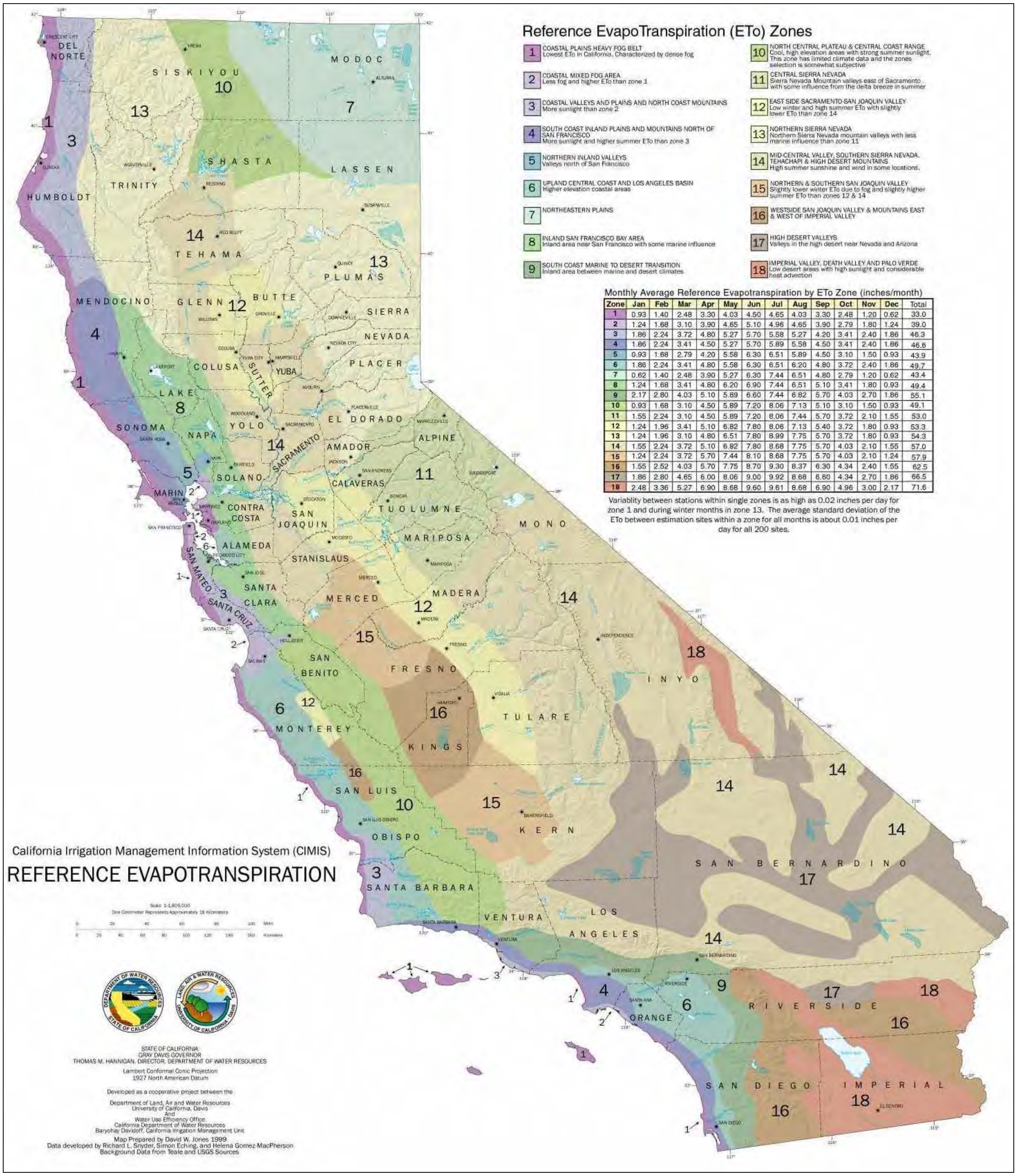
Leaflet #21428 - "Using Reference Evapotranspiration (ETo) and Crop Coefficients to Estimate Crop Evapotranspiration (ETc) for Trees and Vines".

These Kc values are designed for use with CIMIS ETo information. These leaflets are available by contacting:

CIMIS Help Line – 1 (800) 922-4647
Department of Water Resources-Water Efficiency Office
P.O. Box 942836
Sacramento, CA 94236-0001
http://www.cimis.water.ca.gov

Kc values change based on the growth stage of the plant and are commonly divided into four growth stages. The estimated length of growth stages for various crops is shown in Table 6-4.

1. Initial growth stage (10 percent ground cover)
2. Crop-development (up to 80 percent groundcover)
3. Midseason stage (effective full groundcover)
4. Late-season stage (full maturity until harvest)



Zone	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	0.93	1.40	2.48	3.30	4.03	4.50	4.65	4.03	3.30	2.48	1.20	0.62	33.0
2	1.24	1.68	3.10	3.90	4.65	5.10	4.96	4.65	3.90	2.79	1.80	1.24	39.0
3	1.86	2.24	3.72	4.80	5.27	5.70	5.58	5.27	4.20	3.41	2.40	1.86	46.3
4	1.86	2.24	3.41	4.50	5.27	5.70	5.89	5.58	4.50	3.41	2.40	1.86	46.6
5	0.93	1.68	2.79	4.20	5.58	6.30	6.51	5.89	4.50	3.10	1.50	0.93	43.9
6	1.86	2.24	3.41	4.80	5.58	6.30	6.51	6.20	4.80	3.72	2.40	1.86	49.7
7	0.62	1.40	2.48	3.90	5.27	6.30	7.44	6.51	4.80	2.79	1.20	0.62	43.4
8	1.24	1.68	3.41	4.80	6.20	6.90	7.44	6.51	5.10	3.41	1.80	0.93	49.4
9	2.17	2.80	4.03	5.10	5.89	6.60	7.44	6.82	5.70	4.03	2.70	1.86	55.1
10	0.93	1.68	3.10	4.50	5.89	7.20	8.06	7.13	5.10	3.10	1.50	0.93	49.1
11	1.55	2.24	3.10	4.50	5.89	7.20	8.06	7.44	5.70	3.72	2.10	1.55	53.0
12	1.24	1.96	3.41	5.10	6.82	7.80	8.06	7.13	5.40	3.72	1.80	0.93	53.3
13	1.24	1.96	3.10	4.80	6.51	7.80	8.99	7.75	5.70	3.72	1.80	0.93	54.3
14	1.55	2.24	3.72	5.10	6.82	7.80	8.68	7.75	5.70	4.03	2.10	1.55	57.0
15	1.24	2.24	3.72	5.70	7.44	8.10	8.68	7.75	5.70	4.03	2.10	1.24	57.9
16	1.55	2.52	4.03	5.70	7.75	8.70	9.30	8.37	6.30	4.34	2.40	1.55	62.5
17	1.86	2.80	4.65	6.00	8.06	9.00	9.92	8.68	6.60	4.34	2.70	1.86	66.5
18	2.48	3.36	5.27	6.90	8.68	9.60	9.61	8.68	6.90	4.96	3.00	2.17	71.6

Figure 6-2. CIMIS ETo Zones

If local Kc values are not available, estimates from Table 6-5 and Table 6-6 can be used. Coefficients for annual crops (row crops) will vary widely through the season, with a small coefficient in the early stages of the crop (when the crop is just a seedling) to a large coefficient when the crop is at full cover (the soil completely shaded). Orchards with cover crops between tree rows will have larger coefficients than orchards without cover crops.

Table 6-4. Length of Four Crop Growth Stages for Typical Annual Crops (Doorenbos and Pruitt, 1977)

Crop	Growth Stage (Days)			
	1	2	3	4
Barley	15	20-30	50-65	30-40
Corn	20-30	35-50	40-60	30-40
Cotton	30	50	55-60	45-55
Grain, small	20-25	30-35	60-65	40
Sorghum	20	30-35	40-45	30
Soybeans	20	30-35	60	25
Sugar beets	25-45	35-60	50-80	30-50

Table 6-5. Crop Coefficient, Kc, for Midseason and late Season Conditions (Doorenbos and Pruitt, 1977)

Crop	Crop Stages	Humid	Dry[b]
Alfalfa[c]	1-4	0.85	0.95
Barley	3	1.05	1.15
	4	0.25	0.20
Clover	1-4	1.00	1.05
Corn	3	1.05	1.15
	4	0.55	0.60
Cotton	3	1.05	1.20
	4	0.65	0.65
Grain	3	1.05	1.15
	4	0.30	0.25
Grapes	3	0.80	0.90
	4	0.65	0.70
Oats	3	1.05	1.15
	4	0.25	0.20
Pasture grass	1-4	0.95	1.00
Rice	3	1.1	1.25
Sorghum	3	1.00	1.10
	4	0.50	0.55
Soybeans	3	1.00	1.10
	4	0.45	0.45
Sugar beets	3	1.05	1.15
	4	0.90	1.00
Wheat	3	1.05	1.15
	4	0.25	0.20

[a]Humidity 70 percent, light wind 0-16 mi/h

[b]Humidity 20 percent, light wind 0-16 mi/h

[c]Peak factors are 1.05 for humid conditions and 1.15 for dry conditions

Table 6-6. Crop Coefficients for Perennial Forage Crops (Doorenbos and Pruitt, 1977)

Crop	Condition	
	Humid (light to moderate wind)	Dry (light to moderate wind)
Alfalfa		
Minimum	0.50	0.40
Mean	0.85	0.95
Peak	1.05	1.15
Grass for hay		
Minimum	0.60	0.55
Mean	0.80	0.90
Peak	1.05	1.10
Clover, grass legumes		
Minimum	0.55	0.55
Mean	1.00	1.05
Peak	1.05	1.15
Pasture		
Minimum	0.55	0.50
Mean	0.95	1.00
Peak	1.05	1.10

Kc (minimum) represents conditions just after cutting.

Kc (mean) represents value between cuttings

Kc (peak) represents conditions before harvesting under dry soil conditions. Under wet conditions increase values by 30 percent.

6.3 Nutrient Uptake

Nitrogen is often the limiting design factor, and several crops are heavy users of N. Nutrient uptake is related to dry matter yield, and crop stress will reduce yield. Nutrient loading should be balanced to avoid yield reductions from nutrient stress and environmental degradation from excess loading. The relationship of nutrient availability and yield is non-linear. If the N loading is reduced to half of the expected uptake, it cannot be assumed that half the uptake will result. The actual yield and nutrient uptake will be a function of the initial soil reserve and resulting nutrient stress. Crop residue, straw, and other matter that is left in the field after harvest will eventually contribute a portion of the nutrients back into the soil reserve. Soil and tissue analysis can help determine nutrient deficiency and proper nutrient loading.

The highest uptake of N, phosphorus, and potassium can generally be achieved by perennial grasses and legumes. It should be recognized that whereas legumes normally fix N from the air, they will preferentially take up N from the soil-water solution, if it is present. The potential for harvesting nutrients with annual crops is generally less than with perennials because annuals use only part of the available growing season for growth and active uptake. Typical annual uptake rates of the major plant nutrients: N, phosphorus, and potassium, are listed in Table 6-7 for several commonly selected crops.

The nutrient removal capacity of a crop is not a fixed characteristic but depends on the crop yield and the nutrient content of the plant at the time of harvest. Design estimates of harvest removals should be based on yield goals and nutrient compositions that local experience indicates can be achieved with good management on similar soils.

Table 6-7. Nutrient Uptake Rates for Selected Crops (USEPA, 1981)

Crop	Lb/acre·year		
	Nitrogen, N	Phosphorus, P	Potassium, K
Forge crops			
Alfalfa	200-600	20-30	155-200
Bromegrass	115-200	35-50	220
Coastal bermudagrass	350-600	30-40	200
Kentucky bluegrass	175-240	40	175
Quackgrass	210-250	25-40	245
Reed canarygrass	300-400	35-40	280
Ryegrass	160-250	50-75	240-290
Sorghum-Sudan	180-260	18-26	90-140
Sweet clover	155	18	90
Tall fescue	130-290	27	270
Orchardgrass	220-310	18-45	200-280
Field crops			
Barley	110	13	18
Corn	155-220	18-27	100
Cotton	65-100	13	36
Grain Sorghum	120	13	60
Potatoes	200	18	220-290
Soybeans	220	10-18	27-50
Wheat	140	12	18-50

Lb/acre year x 1.1208 = kg/ha year.

Alfalfa removes N and potassium in larger quantities and at a deeper rooting depth than most agricultural crops as shown in Table 6-8. Corn is an attractive crop because of its potentially high rate of economic return as grain or silage. The limited root biomass early in the season and the limited period of rapid nutrient uptake, however, can present problems for N removal. Prior to the fourth week, roots are too small for rapid uptake of N, and after the ninth week, plant uptake slows. During the rapid uptake period, however, corn removes N efficiently from applied wastewater (D'Itri, 1982).

Table 6-8. Typical Effective Rooting Depth of Plants (Burt, 1995)

Plant	Effective rooting depth (ft)
Alfalfa	4-6
Avocado	2-3
Banana	2-3
Barley	3-5
Beans	1-3
Citrus	2-5
Corn	3-5
Cotton	4-6
Deciduous Orchard	4-6
Grains, small	3-4
Grapes	3-6
Grass	3-4
Lettuce	1-2
Melons	2-3
Potatoes	2-3
Safflower	5-6
Sorghum	3-5
Strawberries	1-2
Sugarbeet	3-5
Sugarcane	4-6
Tomatoes	3-5
Turf grass	0.5-1.5

The rate of N uptake by crops changes during the growing season and is a function of the rate of dry matter accumulation and the N content of the plant. For planning and nutrient balances, the rate of N uptake can be approximately correlated to the rate of plant transpiration. Consequently, the pattern of N uptake is subject to many environmental and management variables and is crop specific. Examples of measured N uptake rates versus time are shown in Figure 6-3 for annual crops and perennial forage grasses.

The most common agricultural crops grown for revenue using wastewater are corn (silage), alfalfa (silage, hay, or pasture), forage grass (silage, hay or pasture), grain sorghum, cotton, and grains. However, any crop, including food crops, may be grown with food process/rinse water because there is little concern with microbial or viral contamination. In areas with a long growing season, such as California, selection of a double crop is an excellent means of increasing the revenue potential as well as the annual consumptive water use and nitrogen uptake of the crop system. Double crop combinations that are commonly used include summer crops of short season varieties of soybeans, silage corn, sorghum, or sudan grass and winter crops of barley, oats, wheat, vetch, or annual forage grass as a winter crop.

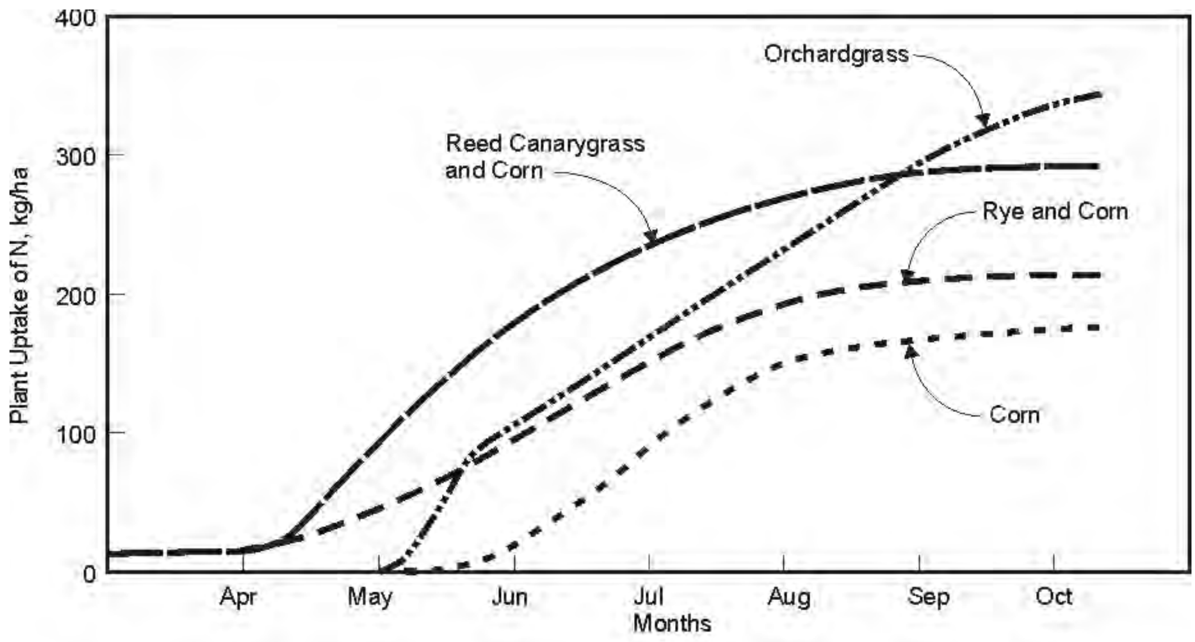


Figure 6-3. Nitrogen Uptake for Annual and Perennial Crops

Some forage crops can have even higher N uptakes than those in Table 6-7. The nitrogen crop uptake measured for turfgrasses in Tucson (common bermudagrass overseeded with winter ryegrass) is 525 lb/acre-yr (Pepper, 1981). "Luxury consumption" may occur in the presence of surplus soil N, and result in higher than normal crop uptake rates.

Essentially all N absorbed from the soil by plant roots is in the inorganic form of either nitrate (NO_3) or ammonium (NH_4). Generally young plants absorb ammonium more readily than nitrate; however as the plant ages the reverse is true. Soil conditions that promote plant growth (warm and well aerated) also promote the microbial conversion of ammonium to nitrate. As a result, nitrate is generally more abundant when growing conditions are most favorable. Once inside the plant, the majority of the N is incorporated into amino acids, the building blocks of protein. Protein is approximately 16 percent N by weight. N makes up from one to four percent of the plants harvested dry weight.

6.4 Salt Uptake

Along with N, crops also take-up other dissolved minerals including phosphorus, potassium, calcium, magnesium, and sulfur. These dissolved minerals can be measured as the portion (typically 50 – 70 percent) of the ash content of the plant. The ash content is approximately 10 percent of the dry mass of the plant, so increased yield directly correlates to salt uptake.

Table 6-9 shows actual field results of salt removal from various crops that were grown with process/rinse water. Additional crop uptake values are presented in Appendix H for other crops and other locations, all with process/rinse water irrigation. The procedure for determining the ash content of plant tissue is also provided in Appendix H.

Table 6-9. Yield and Salt Removal of Various Crops

	Average Yield dry tons/acre	Salts Removed lb/acre	Ash %
Alfalfa[a]	6.6	2093	16%
Barley[a]	3.9	759	10%
Corn[b]	11.7	1750	7.5%
Winter wheat[b]	5.2	1321	13%
Tall Fescue[a]	8.4	2083	12%

Source: Tim Ruby, Del Monte Foods Company

[a] Process water spray irrigation site located outside Boise, ID, three year average

[b] Process water surface irrigation site. Kingsburg, CA, one year

The uptake of the constituents that make up TDS is dependent on the crop and the crop yield. To determine the salts removed by the harvested crop, test the tissue samples for ash (mineral) content and multiply the results times the yield. Data in Table 6-10 can be used to conservatively estimate the uptake of selected constituents that are applied in process/rinse water. The total uptake of listed constituents in Table 6-10 understates total mineral removal because some ions (sodium and chloride) are not included or are only shown as elements, and the data are from a high rainfall/low salinity area. The actual or expected yield can be used to adjust from the yield values in Table 6-10. Use Table 6-10 for individual constituents only.

Table 6-10. Constituent Uptake Estimates for Crops

Crop	Yield Per Acre	N	P2O5	K2O	Ca	Mg	S	B	Cu	Fe	Mn	Zn	Totals
		lb/acre											
Alfalfa Hay	8 tons	415	94	401	151	36	26	0.43	0.11	1.67	0.45	0.3	1126
Bermudagrass Hay	8 tons	400	92	345	48	32	32	0.13	0.02	1.2	0.64	0.48	951
Corn, Grain	5.04 tons	170	70	48	15	16	14	0.12	0.06	0.15	0.09	0.15	334
Corn Stover	4 tons	70	30	192	27	34	16	0.05	0.05	0.9	1.5	0.3	372
Corn Silage	16 wet tons	160	67	160	28	33	20	0.11	0.07	0.7	1.06	0.3	470
Oats, Grain	16 tons	80	25	20	3	5	8	....	0.04	0.8	0.15	0.06	142
Oats, Straw	2.5 tons	35	15	125	10	15	11	0.05	0.04	0.15	0.15	0.36	212
Sorghum-Sudan Hay	4 tons	160	61	233	30	24	23	....	....	....	....	....	531
Tomatoes, Fruit	15 tons	50	12	108	3	14	20	....	0.07	1.3	0.13	0.16	209
Tomatoes, Vines	....	40	13	60	....	....	....	....	....	....	....	....	113
Wheat, Grain	2.4 tons	92	44	27	2	12	5	0.06	0.05	0.45	0.14	0.21	183
Wheat, Straw	3 tons	42	10	135	9	12	15	0.02	0.02	1.95	0.24	0.08	225

Notes:

1. *Data obtained from Auburn University, Alabama Cooperative Extension System and combines data from The Fertilizer Institute, Phosphate and Potash Institute, and independent research resources. (http://www.aces.edu/pubs/docs/A/ANR-0449/*
2. *Yields are for high-yielding Alabama crops. Values reported in this table may differ from values from other sources. Healthy, high-yielding crops can vary considerably in the nutrient concentration in the grain, fruit, leaves, stems, and pods. Plant "uptake" is also higher than crop "removal." Nutrients not actually removed from the land are returned to the soil in organic residues. Crop removal should be adjusted in proportion to the actual yield.*

6.4 References

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7. LOADING RATES AND SYSTEM DESIGN APPROACH

Land application systems may be controlled by one of a number of different loading rates: N, organic, hydraulic, or salt. The focus in this chapter is on determining appropriate loading rates for slow rate land application systems where the hydraulic application rates are similar to typical crop irrigation rates. Proper loading of a slow rate system 1) allows for sufficient retention time of the applied water in the aerobic zone of the soil to achieve oxidation of organics, 2) manages salts to prevent build-up in the root zone and unreasonable degradation of underlying groundwater, and 3) utilizes the nutrients and process water while balancing optimum treatment capacity and reuse. Properly designed and operated high rate or soil aquifer treatment (rapid infiltration) land application systems can also provide treatment of process/rinse water to prevent unreasonable degradation of groundwater. However, they provide d not provide irrigation reuse benefits to balance against potential degradation, and their design and regulatory considerations are significantly different (Crites, et al., 2006). Soil aquifer treatment land application systems are not directly covered in this manual, although some of the treatment processes described in this chapter also apply to soil aquifer treatment.

Hydraulic application rates rarely are what limit the capacity of a properly designed slow rate or irrigation reuse system. N and/or BOD are the common rate-limiting constituents for application of food process/rinse water. The seasonal N loading must balance with crop uptake and other N losses from the system. Total organic (i.e. BOD or a suitable surrogate) loading rate limits should be determined on a site-specific basis after considering soil infiltration rates, resting time between applications, and the applied BOD. The goals of a proper design for organics are effective stabilization of the organics, minimization of reducing conditions that could mobilize trace metals and minimization of the potential for nuisance odor and vector conditions.

Salts need to be managed to prevent accumulation in the root zone that will affect crop production and to ensure that leaching to prevent such accumulation occurs at a controlled rate that will prevent unreasonable groundwater degradation. Salinity in applied process/rinse water can be reduced by securing a better water supply, source control, alternative chemical usage, and/or treatment. Where supplemental water is necessary to meet the irrigation demand of a crop, its effect will typically reduce seasonal loadings and seasonal average concentrations.

Acceptable suspended solids loading varies with the method of application. Excess suspended solids loading can cause soil plugging and anaerobic mats on the soil surface with surface irrigation.

This chapter introduces the overall design approach and the concept of water quality risk categories. It then reviews loading rates for water, nitrogen, organics, salts, total acidity, and suspended and settleable solids, some of which can be linked to water quality risk categories, as applicable. The final section discusses incorporation of loading rates into the design.

7.1 Design Approach Overview

The overall design approach for a land treatment/reuse system for food process/rinse water is to determine the limiting constituents or factors and design a system that will adequately treat or reuse those limiting constituents and/or will meet the standards of a desired risk category. The approach typically includes selecting a site and crops, and designing pretreatment facilities and an irrigation system. These are the major controllable elements of a land treatment/reuse system. Each of these elements may have an effect on the limiting factors or constituents.

7.2 Water Quality Risk Categories

In designing a land treatment/reuse system, the potential risk of impacts to groundwater quality is a function of many factors, but loading rates of major constituents of concern are perhaps the easiest risk factors to quantify and measure. Risk categories can in turn be used to establish the necessary intensity of planning, operational management, and monitoring for process/rinse water reuse systems. Descriptions of the basic risk categories used in this and subsequent chapters are given in Table 7-1. In this chapter, "agronomic" loading rates mean constituents beneficial to crops applied in net amounts equal to what is utilized by the crops and that constituents not beneficial to crops are applied at rates comparable to local farming practices utilizing fresh water. Systems that have loading rates in excess of capacities calculated using the formulas and guidelines in this chapter may still function properly, but would be considered higher risk and thus the project proponent would encounter a greater level of regulatory scrutiny in seeking approval for the discharge.

Table 7-1. Water Quality Risk Categories

Risk Category	Description
1 (lowest)	Loading rates substantially below agronomic rates*. Risk indistinguishable from good farming operations. Waiver typically appropriate for small systems, depending upon current waiver eligibility criteria.
2	Loading rates or conditions up to agronomic criteria, providing minimal risk of unreasonable degradation of groundwater. Some risk for systems with water distribution, crop and/or operational problems; causing treatment and reuse effects to be inadequate or spotty.
3	Total loading rates above agronomic rates, but still within calculated capacities using formulas in this chapter, and with some safety factors. Requires detailed planning, good operation, and monitoring. May require specific design to enhance treatment and losses of some constituents.
4 (highest)	Loading rates above calculated capacities. Pilot testing and/or intensive monitoring likely to be required to prove efficacy.

** An agronomic rate is that amount of constituent which meets a crop requirement.*

Although a category 4 (highest risk) is defined in Table 7-1, it is beyond the scope of this manual to address all the site specific issues that would need to be considered and addressed for the sound design of a category 4 system. Systems designed in accordance with this manual should qualify to fall into categories 1 – 3.

Based on loading rates alone, category 1 systems should typically be eligible for a waiver or simplified waste discharge requirements. Waiver eligibility will be based on the terms of waivers currently in effect.

7.3 Nitrogen Loading

Nitrogen (N) loading should always be evaluated as a potential limiting loading rate because of the relatively high total N content of food process/rinse water. However, because of the high carbon to nitrogen (C:N) ratio of process/rinse water, significant denitrification and immobilization of N occurs in the soil. The main concern associated with the land application of food process/rinse water with high N concentrations is the potential for nitrate to be transported into the groundwater. The federal and state drinking water standard for nitrate-nitrogen is 10 mg/L. Greater nitrate levels in drinking water can lead to methemoglobinemia or "blue baby syndrome".

N in wastewater goes through transformations when applied to the soil matrix. The transformations are both chemical and biological and are a function of temperature, moisture, loading, pH, C:N ratio, plant interactions, and equilibrium with other forms of N. The fate of N compounds applied to the soil follows several paths that are illustrated in Figure 7-1 and summarized below:

- Organic nitrogen will mineralize to ammonia over time. The mineralization rate is similar to crop residues, with the organic nitrogen becoming plant available over a period beginning about a month after application and lasting up to a few years. Temperature, soil moisture, and C:N ratio of the process/rinse water all affect nitrogen mineralization rates. Nitrogen from food process/rinse water becomes available much more slowly than nitrogen from fertilizer or dairy wastes. For this reason, it is difficult to use the crop N uptake curves in Chapter 6 for the timing of nitrogen applications from process/rinse water. Therefore, nitrogen balances with process/rinse water are generally performed on an annual basis. Soil nitrate monitoring (Chapter 10) is recommended to provide site-specific data on how quickly applied organic nitrogen is being converted to nitrate.
- Ammonia will be lost partially to volatilization, especially if the ammonia is on the soil surface. The remaining ammonia can be oxidized to nitrate in the soil, adsorbed to soil, immobilized by bacteria, or taken up by plants. Under excessive loading conditions, some ammonia can be leached to shallow groundwater.
- In low oxygen (anoxic) conditions, some bacteria will effectively take oxygen from available nitrate and release the N as nitrogen gas. Nitrate will also be used by microorganisms for cell growth and taken up by plants. Excess nitrate may be leached from the soil profile into the underlying groundwater.

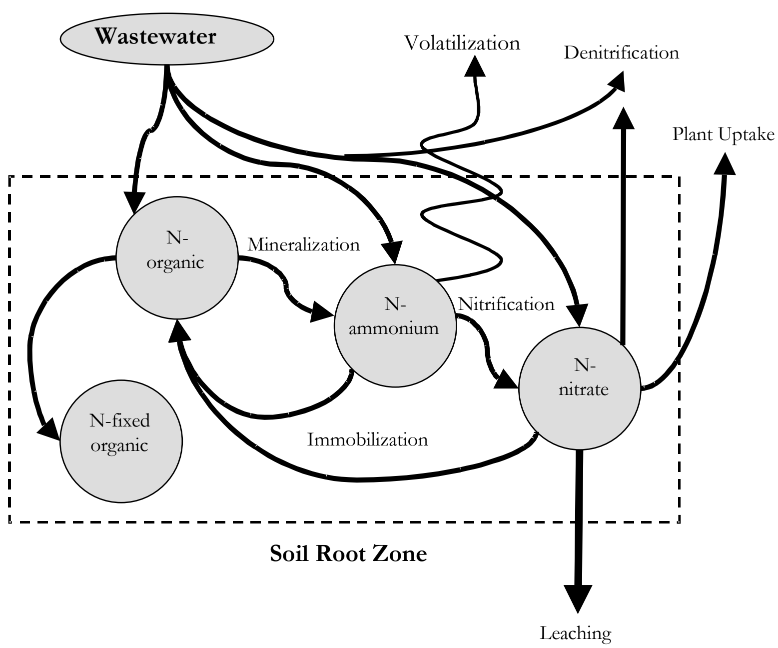

Figure 7-1. Soil Nitrogen Fluxes

During and immediately after land application by flooding, soils become temporarily deficient in oxygen causing a large percentage of the nitrate to be lost to the atmosphere through bacterial denitrification. Sprinkler irrigation tends to keep soil more aerobic than flood irrigation, resulting in somewhat less denitrification than with flood irrigation. Leach and Enfield (1983) found an average of 15 percent N removal by denitrification with rapid infiltration of municipal effluent using sprinklers on short cycles versus 30 percent to 80 percent N removal by denitrification with surface flooding on two to seven day cycles. Some denitrification continues to occur in well-drained soils in water filled pores creating anoxic microsites in the immediate vicinity of the decomposing organics
(Parkin, 1987).

Denitrification proceeds at a progressively slower rate at temperatures below 20°C (68°F) and practically ceases at 2°C (36°F). Denitrifying bacteria are sensitive to low pH conditions and their activity in acidic soils (<pH 5) is greatly restricted (Stevenson, 1982). The denitrification process is dependent on carbon availability and has been correlated to the amount of mineralizable carbon during seven days of incubation (Paul and Clark, 1996).

Soil microbes metabolize the organics in the wastewater. Microbes are about eight parts carbon to one part N. Because of the metabolic inefficiencies, about 1 part N is required to metabolize every 24 parts of carbon. When the C:N ratio exceeds 24:1, microbes will leave little inorganic N available in the soil profile. While the limited available N will reduce the threat of nitrate leaching, it can also stunt plant growth if the period of nitrate depression is lengthy. As the N is cycled, more carbon dioxide is released, reducing the C:N ratio of the soil (Brady and Weil, 2002).

Microbial growth on readily available carbon in wastewater normally leads to an increase in active soil organic matter. The active soil organic matter supplies readily mineralizable nutrients. Continued cycling of the carbon generates more complex enzymes and other polysaccharides that are precursors to stable humic material (Paul and Clark, 1996).

Soil humus is relatively resistant to decay and contains a significant portion of immobilized organic nitrogen. The soil humus has a half-life of hundreds of years and is 60 to 90 percent of the soil organic matter (Brady and Weil, 2002). Soil humus also adds structure, enhancing percolation in clay soils and moisture retention in sandy soils, and increases the cation exchange capacity and metal retention capacity in all soils. A soil with 1.5- percent organic matter, consisting of 80 percent humus with a C:N ratio of 10:1, will have nearly 1,200 mg/kg of immobilized N. In the top one foot of soil a concentration of 1200 mg/kg is equivalent to 4,500 lb/acre based on a soil weight of 2 x 10^6 lb/acre-furrow slice. An increase of organic matter by one tenth of a percent in the top 30 cm is equivalent to 300 lb-N/acre. As more research becomes available on practices that optimize the conversion of organic matter into soil humus, these practices should be incorporated into process/rinse water application site management.

Because of large influence of organic carbon on available N, a factor has been developed to account for N lost to denitrification, volatilization, and storage in soil humus. Table 7-2 contains the N loss factor as a function of the C:N ratio and irrigation method. Actual losses are dependent on other factors including climate, forms of the N applied, and application cycles. The USEPA recommends a denitrification range of 15 to 25 percent for design of municipal wastewater sprinkler irrigation systems, where low carbon to N ratios are the norm (USEPA, 2006). While the loss factors shown in Table 7-2 are useful for planning purposes, actual losses are documented through long term soil and crop monitoring. Initial design calculations should use loss factors at the low end of the ranges shown in Table 7-2 unless field data are available for a specific type of process/rinse water.

Table 7-2. Nitrogen Loss Factor for Varying C:N Ratios			
C:N ratio	Example	Nitrogen Loss Factor, f	
		Flood[a]	Sprinkler[b]
>8	Food processing wastewater	0.5 - 0.8	0.2 – 0.4
1.2-8	Primary municipal effluent	0.25 - 0.5	0.15 – 0.3
0.9-1.2	Secondary municipal effluent	0.15 - 0.25	0.1 – 0.25

[a] *Adapted from Reed et al., 1995*

[b] *Adapted from Leach and Enfield, 1983 and Reed et al, 1995.*

While existing inorganic and organic nitrogen in the soil may supply short-term crop needs, N deficiencies and resulting reduced yield will result if the net applied N does not exceed crop demand. Also, depletion of the soil organic nitrogen reserves will reduce soil health. The following equation combines the crop uptake and the N loss factors to provide an estimate of the desired N loading.

$$L_n = U/(1-f) \qquad (7\text{-}1)$$

L_n = Nitrogen loading, lb/acre
f = Nitrogen loss factor (see Table 7-2)
U = Crop uptake (Chapter 6), lb/acre

Experience in the Northwest has shown that an N loading rate of 150 percent of the expected crop uptake can overcome the N deficiency of most food processing/rinse water while protecting groundwater quality (Idaho DEQ, 2005).

While the ultimate objective is to minimize the impact on groundwater from nitrate and preclude concentrations from exceeding regulatory water quality limitations, some nitrate in the percolate is actually protective in preventing the leaching of metal ions (such as iron and arsenic) from the soil profile as is discussed later in this chapter.

7.3.1 Nitrogen Risk Categories

The recommended site management and monitoring intensity is a function of the relative risk of groundwater impacts. Three general risk categories for N loading are shown in Table 7-3.

Table 7-3. Process/Rinse Water Nitrogen Loading Rate Risk Categories		
Risk Category	Criteria (% of Crop N Requirements)	Notes
1	<= 50%	Supplemental fertilizer required for optimal crop yield and in keeping with recommended agronomic rates for the crop grown.
2	50% to 150%	Similar to typical irrigated agriculture. Greater risk for upper-end rates on sandy soil.
3	> 150%	Requires designing to maximize nitrogen losses and monitoring to ensure the losses and uptake balance the applications.

7.4 Organic Loading

The soil profile removes biodegradable organics through filtration, adsorption, and biological reduction and oxidation. Most of the biological activity occurs near the surface where organics are filtered and adsorbed by the soil, and where oxygen is present to support biological oxidation. However, biological activity will continue with depth even under anoxic or anaerobic conditions if a food source and nutrients are present, though at slower rates. Figure 7-2 shows some of the removal mechanisms for BOD in land treatment systems. The acclimation of soil microbial populations for assimilation and treatment of BOD is essentially not a limiting factor in well aerated conditions.

The BOD loading rate is defined as the amount of BOD applied to a site in one loading cycle divided by the area and the cycle period. For example, if a hypothetical 7-acre site has a cycle period of seven days, (one day of application plus six days of drying), then one acre receives water every day. If 1,400 lb of BOD is applied in each daily application, the day-of-application loading is 1,400 lb/acre and the BOD loading rate (i.e. the cycle average) is 200 lb/acre•day.

Excess organic loading can result in (1) odorous anaerobic conditions, (2) incomplete removal of organics in the soil profile, (3) mobilization of iron, manganese, and other compounds, or (4) increases in bicarbonate in the soil solution via carbon dioxide dissolution. Maintaining an aerobic upper soil profile between irrigations is managed by organic loading, hydraulic loading, drying time, and cycle time; not organic loading alone. It should also be noted that if nitrate reduction is a treatment objective, some duration of anoxic conditions during each irrigation cycle is actually desirable. The mechanisms of increased minerals in percolate water from organic loading are discussed below.

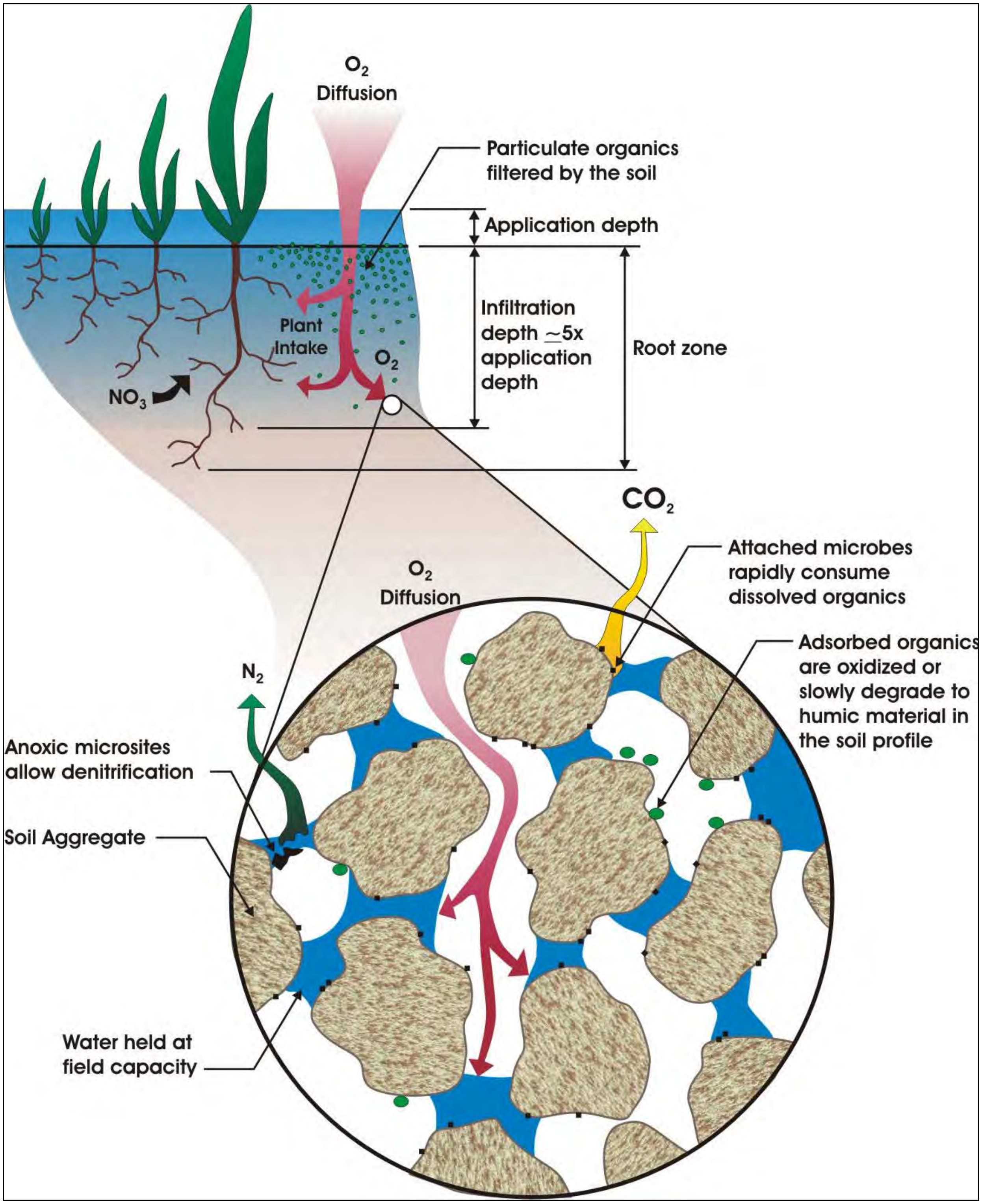

Figure 7-2. Removal Mechanisms in Land Treatment Systems

7.4.1 Reduction-Mobilization

Prolonged periods of oxygen deficiency lead to the bacterial reduction of oxidized compounds to their reduced state. In moderately reduced soils, nitrate nitrogen is denitrified (NO_3 to N_2 gas) and manganese forms such as MnO_2, can be reduced to soluble Mn^{2+}. Once the nitrate and manganese are reduced, ferric iron can be reduced to the ferrous (Fe^{2+}) form. Where arsenic is found in soils, it is often adsorbed to iron oxide coatings on soil particles. Reduction and dissolution of iron can concurrently mobilize the previously adsorbed arsenic. In highly reduced conditions, sulfate will reduce to sulfide. Eventually, under prolonged anaerobic conditions, even carbon dioxide and degradable organic carbon will be reduced to methane. Figure 7-3 shows the active electron acceptors and the corresponding redox sequence.

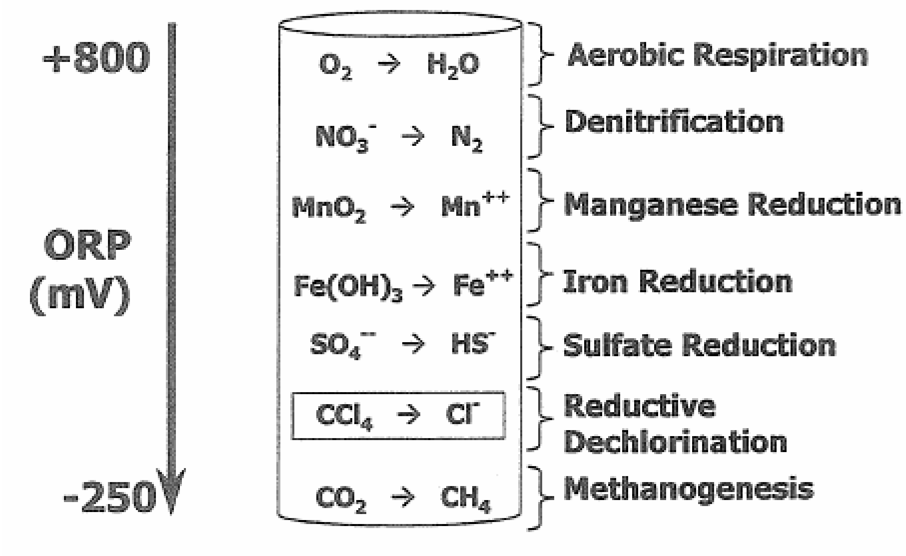

Figure 7-3. Idealized Sequence of Electron Accepting Processes (Spalding, 2002)

When the soil remains at the low redox potential for extended times, solubilized metal ions will be subject to leaching. When the soil or groundwater oxidative state increases due to the renewed presence of oxygen or nitrate, most of the reduced compounds re-adsorb on the soil, precipitate, or are chemically oxidized into acids. Most of the acids generated through chemical oxidation are weak or dilute and do not impact soil pH. Organic acids are oxidized biologically and do not affect soil pH beyond the top few feet of soil. The primary threat of groundwater degradation from increased leaching of mobilized compounds is from the manganese, iron oxides, and sometimes arsenic in the soil and the wastewater. In a recent study of land application of food process/rinse water, it was found that iron and manganese concentrations in the percolate increased with BOD loading rate; however, TDS and EC did not (Sharmasarkar, et al., 2002).

7.4.2 Carbon Dioxide Dissolution

In addition to reduction-mobilization reactions, an increase in dissolved solids can occur from increases in bicarbonate caused by carbon dioxide generated from the breakdown of organics. This effect in excess of 500 mg/L has been seen under landfills (SWPC, 1961).

Carbon dioxide is a byproduct of aerobic and anaerobic breakdown of organics. Its solubility increases with increasing concentration in soil gas. It can react with solid calcium carbonate to form disassociated calcium and bicarbonate. One mole of carbon dioxide generates two moles of bicarbonate.

$$\underset{}{CO_2} + H_2O \leftrightarrow \underset{\text{carbonic acid}}{H_2CO_3}$$

$$H_2CO_3 + \underset{\text{calcium carbonate}}{CaCO_3} \leftrightarrow Ca^{++} + \underset{\text{bicarbonate}}{2HCO_3^-}$$

Carbon dioxide will continue to form carbonic acid and dissolve calcium carbonate or other salts (e.g., magnesium silicates and dolomite) until the bicarbonate reaches equilibrium with the aqueous carbon dioxide. The entire process will reverse itself when the concentration of carbon dioxide in the soil gas decreases due to diffusion to the atmosphere. The process will also reverse when concentrations of calcium, bicarbonate, and other ions in soil pore water increase during extended soil drying periods. The key to preventing an increase in bicarbonate and associated cations is to avoid long term soil saturation conditions that prevent the venting of carbon dioxide. This generally should not be a problem in well operated and designed slow rate style land application/reuse systems.

7.4.3 Oxygen Transport into Soil

Aerobic conditions and carbon dioxide venting can be maintained by balancing the total oxygen demand with oxygen transport into the soil. Management practices that allow an adequate supply of oxygen to the root zone are important for the vigor of many crops.

An American Society of Agronomy (1967) publication stated that the oxygen uptake for fallow soil typically ranged from 24 to 48 lb/ac•d. This is equivalent to a BOD loading of 24 to 48 lb/ac•d. Oxygen uptake by plant roots was estimated to range from 48 to 96 lb/ac•d. Based on several studies, the addition of stable or green manures increases soil oxygen uptake by 24 to 48 lb/ac•d. Therefore the total oxygen uptake can range from a minimum of approximately 24 lb/ac•d for fallow soil to a maximum of approximately 192 lb/ac•d for soil amended with manures and having a growing crop.

McMichael and McKee (1966) reviewed methods for determining oxygen transport in the soil after an application of wastewater. They discussed three principal mechanisms for reaeration: (1) dissolved air carried in the soil by percolating water, (2) the hydrodynamic flow of air resulting from a "piston-like" movement of a slug of water, and (3) diffusion of air through the soil pores. Dissolved Oxygen (DO) is not significant in high BOD process/rinse water streams. The "piston-like" effect may have a substantial impact on the oxygen available immediately after drainage, but quantifying the exact amount is dependent on the dynamics of draining soils. McMichael and McKee (1966) solved the non-steady state equation of oxygen diffusion based on Fick's law and conservatively ignored hydrodynamic air flow effects. They used the equation as a tool for determining the flux of oxygen (mass of O_2 per area) that diffuses into the soil matrix over a given time, and it is possible to use this as a basis of design.

The flux of oxygen across the soil surface does not address the destination of the oxygen, but as long as a gradient exists the oxygen will continue to diffuse into the soil pores. The gradient is based on the oxygen concentration at the soil surface and the initial concentration in the soil. McMichael and McKee (1966) assumed total depletion of oxygen in the soil matrix. Overcash and Pal (1979) assumed a more conservative 140 g/m^3 based on a plant growth limiting concentration (Hagen et al. eds., 1967). Carlile and Phillips (1976) used essentially the same methodology as Overcash and Pal to estimate oxygen transfer rates of 571 to 857 lb/ac•d for several different soil types.

BOD_u is defined as the ultimate BOD, and can be roughly approximated as 1.4 x BOD_5 for process/rinse waters. BOD_u includes nitrogenous oxygen demand. The maximum possible value for BOD_u is the COD of the process/rinse water, although BOD_u is usually slightly less than COD.

From the BOD_u, the time required to diffuse an equivalent amount of oxygen can be determined. The diffusion equation follows:

$$N_{O2} = 2(C_{O2}-Cp) \cdot [Dp\ t/\pi]^{1/2} \tag{7-2}$$

Where:

N_{O2} = flux of oxygen crossing the soil surface ($g/m^2/d$)
C_{O2} = vapor phase O_2 concentration above the soil surface (ppm)
Cp = vapor phase O_2 concentration required in soil to prevent adverse yields or root growth (140 ppm)
t = aeration time; t = Cycle time – infiltration time (t_i in EQ 7-4)
Dp = effective diffusion coefficient
Dp = 0.6 (s)(D_{O2})
Where
s = fraction of air filled soil pore volume at field capacity
D_{O2} = oxygen diffusivity in air (1.62 m^2/d)

Equation 7-2 is conservative in that it:

- Underestimates oxygen transfer immediately after irrigation.
- Ignores the fact that the degradable organics from the process/rinse water are typically deposited most heavily at or near the soil surface rather than uniformly throughout the soil.
- Ignores other oxygen transfer mechanisms, such as barometric pumping.

Soil column tests with synthetic wastewater (Coody et al, 1986) demonstrated the maintenance of good continuous soil oxygen levels at loading rates up to approximately 500 lb BOD_u /ac•d (see Table 7-4). This supports the statement above that Equation 7-2 is conservative, as it would predict a capacity of approximately 300 lb BOD_u /ac•d for a seven day cycle and similar sandy soil conditions. The columns in the experiments were dosed daily so the data in Table 7-4 for day one and day five show the oxygen levels in the soil at the beginning of the weekly cycle and at the end. Reaeration occurred over the two days of non-application each weekend. Week 12 was selected to illustrate an acclimated period during the testing.

Table 7-4. Oxygen Levels Versus Organic Loading Rate in Soil Column Tests

Loading Rates		O_2 at 25 cm depth, week 12 (mol/m^3)		CO_2 (mol/m^3)	
BOD_u (lb/ac•d)	TOD (lb/ac•d)	day 1 (~max)	day 5 (~min)	day 1	day 5
0	61	6.46	3.97	0.38	0.93
237	298	6.35	4.75	0.45	1.92
473	534	6.26	4.03	0.82	4
947	1008	5.28	0.56	2.3	6.6

From Coody et al, 1986

Atmospheric O_2 and CO_2 concentrations are 8.56 and 0.014 mol/m3, respectively.

The data shown at 12 weeks is representative of results in well established conditions. Day 1 is the first day of application and day 5 is the fifth day of application prior to 2 days resting in a 7 day cycle.

Equation 7-2 can be solved with respect to time:

$$t = \pi / Dp \cdot [N_{O2}/2(C_{O2}\text{-}Cp)]^2 \quad (7\text{-}3)$$

Cycle time is a function of required aeration plus the time for the soil to drain down to field capacity. For surface irrigation, the time to reach field capacity can be estimated with the infiltration time calculated by dividing the depth of process/rinse water applied by the steady state infiltration rate.

$$t_i = 3600 \cdot d/I \quad (7\text{-}4)$$

t_i = Time to infiltrate and drain to field capacity, hr
d = depth, cm
I = steady state infiltration rate, cm/s

Sprinkler irrigation that minimizes ponding typically keeps the soil surface aerated and the soil moisture content somewhere between field capacity and saturation. Therefore, it is reasonable to ignore the infiltration/drainage time for sprinkler irrigation.

Cycle average oxygen transfer capacity predicted using Equations 7-2 and 7-4 is highest for well drained soils and short cycles. The infiltration/drainage time and fraction of air-filled pore volume are soil-dependent variables that need to be developed on a site-specific basis. An important point to note is that even additional clean irrigation water can increase the required cycle time due to increasing infiltration/drainage time. The time required for the upper zone of the soil to drain is also partly a function of climatic conditions.

7.4.4 Organic Loading Rate Risk Categories

Recommendations for design, management, and monitoring intensity versus organic loading risk category are shown in Table 7-5.

Table 7-5. Organic Loading Rate Risk Categories

Risk Category[a]	Average[b] BOD_5 Loading Rate, lb/acre•d	Depth to Groundwater[c], ft	Notes
1	<= 50[d]	> 5 ft	De-minimus loading rate is indistinguishable from common agronomic conditions. Good distribution is important.
2	<= 100[d]	> 5 ft	Good distribution more important.
3	> 100[d]	>2 ft	Use Eqs. 7-2 and 7-4 in design. Good distribution very important. See Chapter 10 for monitoring recommendations.

[a] Both loading rate and depth-to-groundwater conditions should be met to qualify for a particular category.
[b] Cycle average.
[c] Depth to groundwater is measured from the soil surface and should be calculated as the average during the application season.
[d] Increase by 50% for sprinkler application on well-drained soil.

Factors that affect the acceptable BOD loading rate for a site include soil type and permeability, soil drainage, method of application, depth to groundwater from the soil surface, temperature, and presence or absence of a cover crop. Soil type and permeability are important, as noted above, because the faster the drainage of the soil pores after an application, the sooner the oxygen can re-enter the soil and re-establish aerobic conditions. Soil drainage to avoid water-logging conditions will also enhance the re-oxygenation. Tile drain systems serviced by drainage districts or under permit from the Regional Water Board have benefited agricultural production on marginal soils. Tile drains improve soil characteristics and inhibit the water table from rising too high (less than two feet) into the root zone and area of active biological oxidation of organics. Tile drain discharge water quality must be indistinguishable from normal agricultural drainage water or a discharge permit for the tile drain water could be required. Overall, the topsoil must drain fairly rapidly to establish aerated conditions, which is why a well-drained soil with good texture and structure is important for higher loading rates of BOD.

Soil temperature affects the activity of soil microbes (Crites, et al., 2000). Vela found that although soil microbe activity drops in colder weather, the number of soil microbes can increase so that overall organics removal is still effective (Vela, 1974). In the Central Valley of California, most land application operations are not impacted by cold weather.

As pointed out in the re-oxygenation discussion, sprinkler application is more conducive to re-oxygenation of the soil than flood irrigation because the dosing is more uniform, can be much shorter in duration and does not necessarily result in saturated soil conditions. Finally, fallow land will generate less oxygen demand than cropped land, so the absence of a crop, if nutrient removal is not critical, can add to the organic removal capacity of a site as long as oxygen diffusion is not restricted by crusting.

7.4.5 Safety Factors

Use of the oxygen diffusion equation (Eq. 7-2) will provide a conservative approach to establishing BOD loading rates in areas with good soils. Generally the agronomic loading of water and N will yield an application area such that the BOD loading rate is substantially less than the calculated limiting value.

Some situations, such as heavy and/or compacted soils, may reduce oxygen transfer substantially. These cases may warrant particularly conservative assumptions for variables such as fraction of air filled soil pore volume and steady-state infiltration rate used in the oxygen diffusion calculations. To apply these safety factors, adjust the assumptions in Equation 7-2 as needed.

Example calculations for oxygen transfer are shown in Chapter 12.

7.5 Hydraulic Loading

The hydraulic loading rates for slow rate land application systems are generally similar to loading rates for clean irrigation water. Slow rate land application systems may have periods during the year when hydraulic loading rates exceed crop needs (USEPA Type 1 slow rate; USEPA, 2006), but during most of the year the goal is to satisfy crop needs (USEPA Type 2 slow rate). Systems with sustained hydraulic loading rates over 10 cm/wk are considered soil aquifer treatment systems and should be designed in accordance with appropriate reference manuals (USEPA, 2006).

Providing adequate water for plant needs is accomplished by maintaining soil moisture content between 50% and 100% of field capacity between irrigations. The design hydraulic loading rate is a function of crop ET, irrigation efficiency, and desired leaching rates.

$$I = (ET - Re - Ws) \bullet (1+LR) / eff \tag{7-5}$$

Where:

I = Irrigation Water Requirements
ET = Crop Evapotranspiration
LR = Leaching Requirement (from Section 7.5)
Re = Effective Rainfall (rainfall that remains in the plant root zone)
Ws = Change in Soil Water
eff = Irrigation Application Efficiency

There are some factors that can limit process/rinse water hydraulic loading to below normal irrigation rates. First, the depth of process/rinse water applied in a single irrigation must not be allowed to cause an extended period of ponding. Second, for process/rinse water with a very high BOD concentration, soil reoxygenation between irrigations may be a limiting factor. Other agronomic considerations affecting hydraulic loading include the need to dry for harvesting or to create plant stress to force bloom.

Standing process/rinse water for extended periods of time creates an oxygen deficit in the root zone, potentially odorous conditions, and environments for mosquito breeding. The infiltration rate can be compared to the application depth to ensure that standing water will not occur for an extended duration. Some crops are more sensitive than others to oxygen deficits, and standing water should be limited accordingly. The infiltration time, defined in equation 7-4, should generally not exceed 24 hours, and this is typically imposed on operations as a regulatory requirement. The application rates for sprinklers should not significantly exceed the infiltration rate either, to avoid excessive ponding and runoff.

For high BOD process/rinse waters applied using surface irrigation, the maximum hydraulic capacity based on oxygen diffusion limitations is determined from the maximum application depth and minimum reaeration time using the equations shown and explained in Section 7.3. The maximum hydraulic loading based on oxygen diffusion limitations can then be determined by dividing the maximum application depth by the irrigation cycle time (time between the beginnings of sequential irrigations).

$$L_h = d_m/T_c \tag{7-6}$$

L_h = hydraulic loading, cm/d
d_m = maximum application depth, cm
T_c = irrigation cycle time, d

If there is an existing site and the hydraulic capacity must be determined, multiply the hydraulic loading by the area. If there is a known flow and the required land area must be determined, divide the flow by the hydraulic loading rate.

7.6 Salt Loading

Food process/rinse water usually contains elevated concentrations of TDS as dissolved solids are typically a result of the products themselves and are utilized in the production of foodstuffs. A significant percentage (typically 40 to 70 percent) of the dissolved solids is organic. These organic dissolved solids in food process/rinse water include proteins, carbohydrates and organic acids from the raw products. Organic dissolved solids are broken down in the soil profile, as contrasted with inorganic dissolved solids, or FDS, which are conservative in nature. Conversely, some of the carbon dioxide from the breakdown of organics can increase concentrations of bicarbonate and other ions in soil water as discussed above in Section 7.4.2. Ionized organic acids aid in maintaining soil buffer capacity. Plant macronutrients, such as ammonium and nitrate-N, phosphorus and potassium; and minerals, such as calcium and magnesium, are part of the inorganic dissolved solids and to a significant degree are removed in land application systems that incorporate growing and harvesting of crops. Sodium, chloride, sulfate, and other ions are also taken up by crops in varying amounts as discussed in Chapter 6. The remaining inorganic dissolved solids are either leached from the soil profile or precipitate out into non-soluble forms. When inorganic dissolved solids accumulate in the soil, they increase the osmotic stress in plants, reduce yields and prevent germination.

Irrigated agriculture adds salts from the source irrigation water, applied fertilizer, and amendments applied to the soil profile, and these can leach to groundwater. Salt from the source water is equal to the concentration in the irrigation water times the amount of irrigation water applied. Salt from fertilizer applications is often more than the net amount of nutrients added to the soil because of non-nutrient ions and impurities in the fertilizer. Fertilizer salt index values have been developed as a measure of the salt concentration that fertilizer induces in the soil solution. Typical amounts of salts added from fertilizers for a corn crop are listed in Table 7-6.

Table 7-6. Typical Amounts of Salts Added Annually with Fertilizers for Corn Crop

Nutrient	Net Nutrient Utilization (lb/ac)	Commercial Fertilizer	Nutrient Concentration	Salt Index[a]	Equivalent NaCl[b] (lb/ac)
N	240	Ammonium Nitrate	34%	104.7	481
P_2O_5	100	Superphosphate	45%	10.1	15
K_2O	240	Potassium Chloride	50%	109	340
Total					835

[a] *Relative to $NaNO_3$ at 100*
[b] *Using salt index of NaCl at 154*
Source: Western Fertilizer Handbook

Many farmers in the Central Valley of California routinely add gypsum to their fields to improve the calcium: sodium balance in the soil profile. The typical amount of gypsum added annually in the southern San Joaquin Valley is one to two tons per acre, although some farms will amend with up to four tons/ac (Sanden; 2004, 2005). Gypsum and other soil amendments add to the salt loading from common irrigated agriculture.

The California Legislature and Regional Water Boards strongly encourage the reuse of wastewaters to replace or substitute for the use of potable water and extend the State's and Region's finite potable water supplies. Both have established that wastewater is of sufficient public interest to compromise in other areas. For example, the California Water Code (Section 13523.5), which states that, "A regional board may not deny issuance of water reclamation requirements to a project which violates only a salinity standard in the basin plan". The section does not mean that water quality objectives set by the Basin Plan for groundwater can be violated, but that violation of effluent standards short of that are of little importance compared to promoting the use of reclaimed water. Although water reclamation standards were not written to apply directly to process/rinse water, the point is that this section clearly indicates a legislative intent that the benefits of substituting reclaimed water for potable water offsets some of the associated impacts from salts in the reclaimed water. Though it does not allow dilution of wastewater with potable water to avoid reasonable and best effort treatment and controls, the Central Valley Regional Water Board does allow blending with potable water to supplement the water supplies of water short areas of the Central Valley, which are many. Further, past decisions establish it unreasonable to require that wastewater salt content be less than that of the potable water supply that would otherwise be used.

As to what reflects reasonable and best efforts to control salt, the typical increase in mineral dissolved solids for municipal wastewater compared to municipal source water is approximately 150 to 380 mg/L (Tchobanoglous and Burton, 1991). In the Tulare Lake Basin Plan, the Central Valley Regional Water Board determined that the maximum reasonable incremental increase in EC through water use for all type discharges is 500 μmhos/cm (nominally equivalent to 320 mg/L mineral salinity), and that the maximum effluent limitation for all discharges is 1000 μmhos/cm (nominally equivalent to 640 mg/L mineral salinity). For perspective, the Santa Ana Regional Water Board allows an incremental addition in mineral salinity of 250 mg/L.

Salt removal by plants is estimated using the ash content of the harvested crop as discussed in Chapter 6. Salts in excess of crop uptake are applied even in good irrigation practices because there is no reasonable way to control the salt sources, and leaching of these excess salts is required to limit salt build-up in the root zone.

The leaching requirement is the ratio of deep percolation to the applied water. The same ratio exists between the concentration of the conservative mineral salts applied and the concentration of conservative mineral salts in the percolate. A simple form of this relationship is presented in Equation 7-9. The equation is only valid when weathering and precipitation of salts are insignificant.

$$LR = \frac{D_d}{D_a} = \frac{C_a}{C_d} \tag{7-7}$$

LR = leaching requirement, unitless
D_d = drainage depth, m
D_a = depth applied, m
C_a = salinity of applied water, dS/m
C_d = salinity in drainage water, dS/m

Equation 7-7 and other equations used to analyze irrigation related salinity issues typically express salinity in terms of EC. EC can overstate the potential for impact on groundwater salinity in food process/rinse water because of degradable conductive organic acids present in the rinse water that will be transformed into carbon dioxide in the soil, which in turn can vent to the atmosphere. The EC due to mineral salts can be estimated by dividing the mineral salinity (in mg/L) of process/rinse water by 0.64 (Luthin, 1978).

If equation 7-7 is solved for C_d, the salinity of the drainage is equal to the salinity of applied water divided by the leaching fraction as presented in Equation 7-10. For minimizing salinity effects on crops during the irrigation season, only water applied during the irrigation season should be considered in equation 7-8.

$$C_d = \frac{C_a}{LR} \tag{7-8}$$

All terms are described above.

The leaching requirement is determined based on the crop sensitivity presented in Figure 7-4. The average root zone salinity can be calculated based on solving the continuity equation for salt throughout the root zone (Hoffman and van Genuchten, 1983). Alternatively, the method of Isidoro-Ramirez et al (2004) can be used to determine the site-specific soil-water salinity (2004).

The salinity thresholds shown in Figure 7-4 are based on EC extracts of the soil (ECe) normally measured under trial conditions of 50 percent leaching. The average root zone salinity is adjusted to the ECe by dividing by a factor of two. The osmotic stress of 50 percent leaching fraction is accounted by subtracting the mean root zone salinity at a given leaching fraction by the mean root zone salinity at 50 percent leaching. Hoffman (1985) found the best agreement when comparing this model to published ECe threshold values. The results of this model are presented in Figure 7-5. The graph in Figure 7-5 can be used in place of Equation 7-7 to determine leaching fraction from crop salt tolerance and the salinity of applied water. When EC_d (same as C_d in Eq. 7-7 and 7-8) is equal to EC_e of the soil extract that results in a 50 percent reduction in yield from Figure 7-4, the average root zone EC is at the 5 to 10 percent yield reduction (Hagan, et al, 1967).

In addition to crop sensitivity considerations, groundwater quality impacts from the salinity of drainage water may need to be reviewed, especially for process/rinse water with significantly elevated salinity. For calculating average annual C_d of deep percolate when evaluating potential effects on groundwater salinity, effective rainfall should be included in the applied water and crop uptake of salt (from chapter 6) should be subtracted from the salt applied. It is generally more convenient to calculate annual C_d on a concentration (mg/L, ppm) basis than on an EC basis for compatibility with the units of mass uptake of salt by the crop.

The groundwater uses quality and flux beneath the site should be reviewed to assess the potential impact of the leachate on groundwater. Some precipitation of particular minerals will continue to occur below the root zone; reducing, at least for a time, the salinity loading that reaches groundwater.

7.6.1 Salinity Measurement for Monitoring

As was discussed previously, salinity of process/rinse water is best measured using FDS. The laboratory procedure for measuring FDS involves heating solids filtered from the water to 550 degrees C to burn off the volatile fraction of the solids prior to weighing the remaining solids. The volatile fraction includes organic compounds, waters of hydration for certain minerals, and a portion of the mass of bicarbonate and carbonate. Therefore, the standard laboratory procedure typically slightly underestimates mineral dissolved solids because of the loss of some of the mass of the bicarbonate in the test. The most accurate method for calculating mineral dissolved solids is to add up the concentrations of all major ions. Because of cost considerations, the laboratory FDS test is still the most valuable test to use on a routine basis, while periodically checking and correlating it to the sum of major ions. The relationships among various salinity and organic measurements are discussed in greater detail in Appendix G.

7.6.2 Effects of Individual Ions in Applied Process/Rinse Water

Some mineral ions have greater impacts on groundwater quality and beneficial uses than other ions. For example, sodium in water used for irrigation can be particularly damaging to soil structure while calcium and magnesium can actually be beneficial (see Chapter 4 for additional discussion). Process/rinse water that is relatively high in calcium, bicarbonate, and sulfate will also tend to encourage the precipitation of those minerals in the soil, reducing the total salinity of percolate by 30 percent or more for up to several decades (Jury and Pratt, 1980). Potassium can be beneficial for irrigation and other uses, being a vital nutrient for both plant and animal health. Potassium can also be beneficial to soil structure. Where minerals are added to process/rinse water for specific purposes (such as in cleaning compounds), substituting minerals with beneficial characteristics (such as potassium, calcium, and magnesium) for minerals with adverse characteristics (such as sodium) can help in making the project environmentally acceptable by reducing the concentrations of the least desirable ions that actually reach groundwater.

7.6.3 Salinity Risk Categories

Recommendations for design, management, and monitoring intensity versus minerals salinity concentrations risk category are shown in Table 7-7.

Table 7-7. Mineral Salinity Concentration Risk Categories		
Risk Category	Process/Rinse Water FDS[a] (mg/L)	Notes
1	< local irr.[b]	Low-level risk.
2	< local irr.+ 320 AND < 640 mg/L	Similar to local agriculture. Implement BPTC measures.
3	>local irr.+320 OR >640 mg/L, but not excessive for crops grown	Greater than local agriculture. Evaluate fate of salts, effects on crops and groundwater quality. Implement BPTC measures.

[a] *FDS values for applied water for all categories are guidelines. Actual discharge requirements are determined by the Regional Water Board on a site-specific basis. Although FDS is slightly less than the total mineral salinity of process/rinse water, it is a reasonable basis for comparison with irrigation water TDS, which represents slightly less than the total salinity from irrigated agriculture including fertilizers and soil amendments.*

[b] *"Local irr." refers to the upper end of the range of TDS concentrations of local irrigation wells near the process/rinse water reuse area.*

The risk categories in Table 7-7 are based on a comparison to agronomic practices and to objectives from the Tulare Lake Basin Plan. The Central Valley Regional Water Board is in its infant stages in developing a region-wide salt management policy. Until this new policy is adopted, emphasis will be on source control and site-specific protection of groundwater resources. In the Central Coast Region, potential groundwater impacts can be compared with the salinity objectives adopted in the 1994 Basin Plan. Other specific salinity policies and objectives may be applicable in other regions.

One approach that can be used to prevent unreasonable salinity impacts to groundwater quality is to plan the process/rinse water facilities such that the calculated average annual C_d as discussed above, including effects from rainfall and crop salt uptake, is not greater than background groundwater concentration on a statistically significant basis. Background groundwater as used in this context means the greater of either: 1) natural background groundwater TDS or 2) non-natural background groundwater TDS if less than 500 mg/L. Natural background groundwater is defined as TDS conditions in groundwater prior to 1968. Non-natural background groundwater is groundwater unaffected by process/rinse water irrigation on the site, but affected by constituents from other human activities.

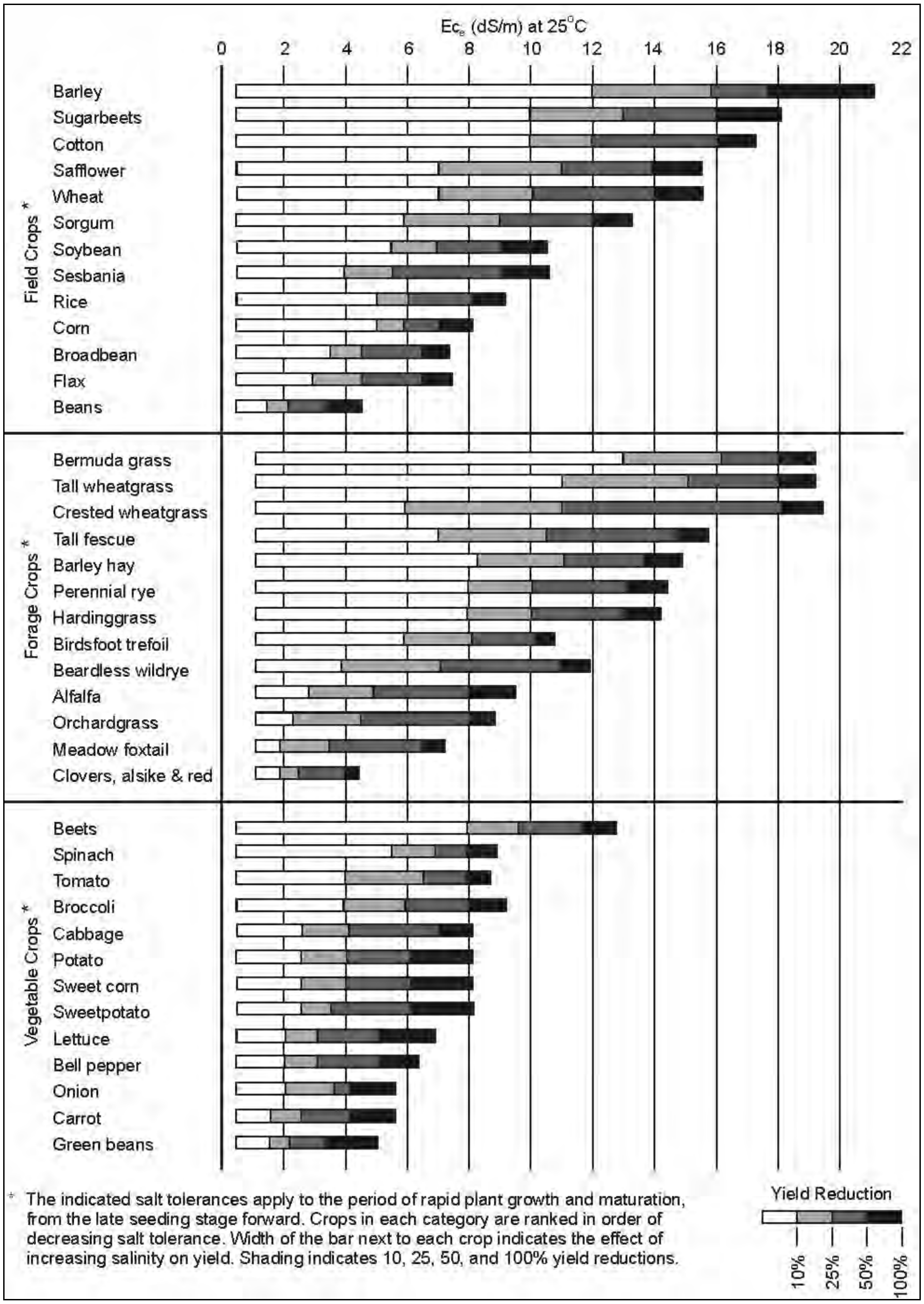

Figure 7-4. Effect of Salinity on Growth of Field Crops (USDA, 1992)

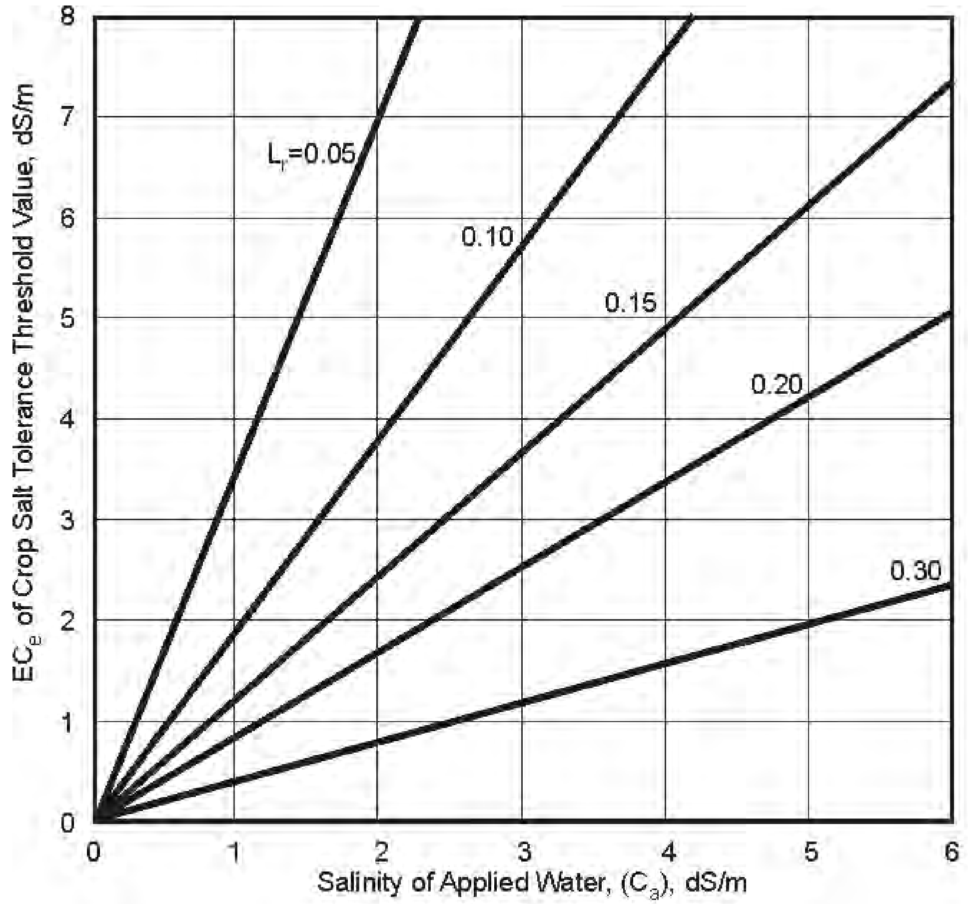

Figure 7-5. Requirement as a Function of Applied Salinity and ECe of Crop Salinity Threshold (based on Hoffman, 1985)

7.7 Settleable and Suspended Solids

In general, it is most advantageous to remove solids with any economic value from the process/rinse water stream prior to land application. Land application systems are very effective for the removal of remaining settleable and suspended solids. Filtration in the soil profile is the principal removal mechanism.

TSS are generally readily degradable organics from the food product or clays brought in from fields. Successful sprinkler application loading rates of 500 lb/ac•d of TSS have been performed year round on grass-covered sites (Crites et al., 2000). The grass will capture some of the suspended solids and reduce potential soil clogging.

Settleable solids may include coarse solids, such as peelings and chips, or fine solids such as silt. Settleable solids only limit sprinkler or drip irrigation to point that they may clog nozzles and emitters. A general rule of filtration recommendations is presented in Table 7-8. For example, a 3/16-inch sprinkler nozzle can be adequately filtered with 0.030-inch screen. When border strip irrigation is used, suspended solids often deposit heavily within the first 10 to 15 feet down the strip. The high deposition of solids forms a mat that prevents oxygen diffusion and results in odor-causing anaerobic conditions. Because of the potential for solids matting, border strip irrigation should not be employed when total settleable solids exceed 10 mL/L.

Because of the higher velocities in furrow irrigation, settleable solids can be applied at up to 15 mL/L. Sprinkler irrigation is best for high concentrations of settleable solids.

Table 7-8. Filtration Recommendations by Application Method (Burt and Styles, 1994)

Irrigation Type	Required Filtration
Drip	1/10 emitter size
Microspray and Sprinkler	1/7 nozzle size

7.8 Total Acidity Loading

Natural biochemical reactions drive the soil pH to a neutral condition. A range of pH between 3 and 11 has been applied successfully to land treatment systems. Extended duration of low pH (<5.5) can change the soil fertility, restrict denitrification, and lead to leaching of metals. When the acidity is comprised of mostly organic acids the water will be neutralized as the organics are oxidized.

The acidity of wastewater can be characterized with the total acidity with units of mg $CaCO_3$/L. The total acidity represents the equivalent mass $CaCO_3$ required to adjust the pH to a specific pH, commonly defined as 7.0. The soil buffer capacity is reported as mg $CaCO_3$/kg or tons $CaCO_3$/acre. The buffer capacity represents the soils ability to neutralize an equivalent amount of acidity. A balance between the total acidity applied in the wastewater and the buffer capacity of the soil can indicate the capacity of the soil to effectively neutralize the acid in the wastewater. The buffer capacity of the soil is restored after organic acids are broken down.

Most field crops grow well in soils with a pH range of 5.5 to 7.0. Some crops like asparagus or cantaloupes with a high calcium requirement prefer a soil pH greater than 7.0. If the pH of the soil begins to drop, liming is recommended to return the pH to the desirable range for crop production. A range of optimum pH values for various crops is presented in Table 7-9.

Because of the soil's ability to treat large amounts of organic acids, it is recommended that pH adjustment of process/rinse water only be considered for extreme pH conditions (pH < 4.5 or > 8.5). The impacts of additional salt loading should be evaluated if chemicals are used for pH adjustment.

Table 7-9. Suitable pH of Mineral Soils for Various Crops

		Soil pH: 4–5	5–6	6–7+
Herbaceous plants	Trees & shrubs	Strongly acid and very strongly acid soils	Range of moderately acid soils	Slightly acid and slightly alkaline soils
Alfalfa Sweet clover Asparagus Buffalo grass Wheatgrass (tall)	Walnut Alder Eucalyptus Arborvitae			
Garder beets Sugar beets Cauliflower Letuce Cantaloupe	Currant Ash Beech Sugar maple Poplar Tulip tree Lilac Yew Lucaena Ponderosa pine			
Spinach Red clovers Peas Cabbage Kentucky blue grass White clovers Carrots	Juniper Myrtle elm Apricot Red oak			
Cotton Timothy Barley Wheat Fescue (tall & meadow) Corn Soybeans Oats Alsike clover Crimson clover Rice Bermuda grass Tomatoes Vetches Millet Cowpeas Lespedeza Rye Buckwheat	Birch Dogwood Douglas fir Magnolia Oaks Red cedar Hemlock (Canadian) Cypress Flowering cheery Laurel Andromeda Willow oak Pine oak Red spruce Honey Locust Bitter hickery			
Red top Potatoes Bent grass (except creeping) Fescue (red & sheep's) Western wheatgrass Tobacco	American holy Aspen White spruce White Scotch pine Loblolly pine Black locust			
Poverty grass eastern gamagrass Love grass, weeping Redtop grass Cassava Napier grass	Autumn olive Blueberries Cranberries Azalea Rhododendron white pine Red pine Teaberry Tea Blackjack oak Sumac Birch Coffee			

Ranges of pH in mineral soils that present appropiate conditions for optimal growth of various plants. Note that the pH ranges are quite broad, but that plant requirement for calcium and sensitivity to aluminum toxicity generally decreases from the top group to the bottom group.

Adapted from Brady and Weil, 2002.

7.9 Incorporating Loading Rates into Design

Because of the interrelated elements and site specific conditions, the planning and design of land treatment/reuse systems is not a linear process. The design process is more like a convergent trial-and-error process where the designer performs estimates based on initial assumptions and then refines each element of the land treatment/reuse system until the total system design is optimized. The desired water quality risk category should be taken into account during all phases of system planning and design. The design steps are further described below. Design examples are given in Chapter 12.

The major elements of a land treatment/reuse system include:

- Site
- Crops
- Pretreatment
- Irrigation System and Operation
- Monitoring

7.9.1 Initial Hydraulic Loading Rate Evaluation

The initial step in a planning or design process should be a preliminary hydraulic loading rate evaluation. This should be performed using typical grass, hay or feed crops grown in the region and the methodology from Chapter 6. Initial estimates of irrigation efficiency and leaching requirements should be taken from typical regional values obtained from the USDA Resource Conservation Service, local Agricultural Extension office or other local sources. The hydraulic evaluation (also sometimes referred to as a "water balance") should be performed on an average month-by-month basis. The result of this initial evaluation is an estimate of the land area required for process/rinse water flows.

7.9.2 Initial Pretreatment Selection

Pretreatment is discussed later in Chapter 8. For most process/rinse waters, a minimum level of pretreatment with parabolic static screen or rotary drum screens is almost always economically justified. Therefore, screening of process/rinse effluent should be a component of the system design for initial solids removal. The organic reductions from this level of pretreatment should be considered in the estimate of organics in the land applied process/rinse water.

7.9.3 Initial BOD Loading Rate Evaluation

If regulatory permits have been issued for similar facilities in the region and those permits contain limits on BOD, an initial land area calculation should be performed for BOD as shown in Equation 7-9.

$$A = TL / LL \tag{7-9}$$

TL = total anticipated mass loading, lb/d
LL = loading limit, lb/ac•d
A = required area, acres

If regulatory permits for similar facilities are not available, a loading limit of 150 lb/ac•d can be assumed for initial calculation purposes. Lower target loading rates may be desired so as to fall into a lower risk category (Table 7-5) with potential for less intensive management and monitoring.

7.9.4 Site Selection

The irrigation site for process/rinse water reuse is typically selected based on size, proximity to the factory, soil, depth to groundwater, proximity to residences, and institutional/ownership considerations. The required size of the site can be initially estimated from the greater of the areas in the initial hydraulic and BOD loading rate calculations given above. One or more potential sites with sufficient size should be identified for further evaluation.

Any site suitable for irrigated agriculture is feasible for land treatment/reuse of food process/rinse water. Preferred characteristics of land treatment/reuse sites include relatively level topography, deep sandy soil, and sufficient separation and downwind direction from residential developments. The availability of supplemental irrigation water can also be an important consideration in site selection.

7.9.5 Initial Crop Selection

Crop selection was discussed in Chapter 6. Crops are typically selected to maximize water usage, maximize N uptake and have good regional marketability. Crop cultural practices should also not conflict with the seasonality of flows from the factory. Several crops with promising characteristics should be selected within the evaluation.

7.9.6 Initial Irrigation Plans

One or more potential initial irrigation methods should be selected based on the initial crop selection and irrigation practices in the area. The selection of an initial irrigation method may also be dictated by the irrigation facilities preexisting on the site. Suspended solids concentration and pretreatment will also influence the choice of irrigation system. Irrigation system planning and design is presented in detail later in Chapter 9.

7.9.7 Refinement of Loading Rate Calculations and Design

Once initial alternatives for the site, crops and irrigation systems have been identified, detailed calculations of limiting loading rates should be performed using the factors appropriate for the site (e.g. infiltration rate, field capacity, etc.) and the equations and tables presented earlier in this chapter. These calculations should be performed for each reasonable combination of alternatives. The costs of each reasonable combination of alternatives should also be estimated. Once a limiting constituent is identified for each combination of alternatives, the designer can look into additional ways to reduce the limiting constituent and the associated costs of reduction. Risk categories for major constituents should be considered because lower loading rates may reduce ongoing regulatory compliance related costs while providing better utilization of water and nutrients. A preferred combination of pretreatment-site-crop-irrigation alternatives should become apparent. This convergent trial-and-error process should result in an appropriately designed and sized land treatment/reuse system.

7.10 References

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8. PRETREATMENT AND SOURCE CONTROL

This chapter introduces an approach to identifying opportunities and methods for reducing process/rinse water generation and/or strength; thereby minimizing the potential impact of land application on groundwater. This approach can be used to help meet requirements for best management practices and best practicable treatment and control (BPTC) of process/rinse water, as specified in the state's Antidegradation Policy (refer to Chapter 3). Consistent with the policy, the Regional Water Board typically requires completion of a source reduction evaluation as a condition of WDRs. Overall, source reduction and recycling efforts are consistent with the industry's vision for operating in an environmentally, socially, and economically sustainable manner.

Sources and characteristics of process/rinse water will vary by facility depending on the type of product, nature of processing activities, size of the plant and other factors. Volume and chemical composition of effluent may vary hourly, diurnally and seasonally. At most facilities, concentrations of organics (BOD), salts and N are the primary concerns. Typical process/rinse water sources include:

- Filtration backwash from influent water treatment
- Water softener regenerate
- Reverse osmosis treatment brine
- Boiler blowdown
- Cooling water
- Flume or other transport water
- Storage and processing solutions
- Cleanup and sanitation water
- Storm water runoff from external processing areas

Techniques for waste minimization and BPTC to reduce the concentration and/or volume of these streams can be classified as follows, in order of most to least favorable for mitigating the environmental impacts of operations (EPA, 1988):

1. Eliminate process water generation by process modifications, changing processes and operational changes.
2. Reduce the amount of process water produced by process modifications, changing processes and operational changes.
3. Recycle process water to other processes, or to offsite facilities.
4. Treat process water at the source, where constituents are more concentrated and easier to treat. This may facilitate further reuse of the effluent, and also reduces conveyance requirements.
5. Treat process water at the end-of-pipe (or route to a publicly-owned treatment works [POTW]).

A systematic approach for identifying, evaluating and implementing waste minimization measures within a food processing facility is presented below, followed by descriptions of a number of specific waste minimization options that can be implemented. Additional options that are not classified as waste minimization strategies by EPA, including water conservation and pretreatment, are also discussed in detail below.

8.1 Waste Minimization Approach

The general approach for evaluation and implementation of appropriate BPTC measures at food processing facilities is adapted from the USEPA Waste Opportunity Assessment Manual (EPA 1988). It consists of the following steps:

- **Planning and organization.** At the outset of the planning process, senior management and/or the owners of the company should agree to support this effort; the long-term success of the program will hinge on their commitment. The planning process includes defining the objectives for assessment of the facility and designating staff to be responsible for the program. Ideally, facility managers who are very familiar with these operations will be involved. The assessment objectives will be contingent on how much is already known about the facility and operations.
- **Assessment.** The assessment step includes compiling and evaluating existing facility data, such as facility design details, workflow, source water volume and chemistry, volume of processed materials, chemical usage information, individual waste stream characteristics, total process water effluent characteristics, energy use, operating and maintenance activities and permit requirements. After evaluating existing information, it may be necessary to collect additional data to fully characterize the discrete process/rinse water streams and sources of constituent loading to each stream.

  Based on the assessment findings, the project team can generate a set of options for waste minimization or treatment of the various streams and total effluent. In accordance with USEPA's hierarchy for most to least environmentally favorable, these options should (1) seek to reduce the amount of source material added to the process/rinse water in the course of operations, (2) reduce or reuse the water within the facility for other processes, or (3) reduce loading by means of a treatment system. Most likely, BPTC will consist of a combination of these approaches, such as reuse within the facility facilitated by interim treatment.

  The operational modifications and/or technologies initially identified by the team as possible options are likely to have varying degrees of economic and technical feasibility. Therefore, the list should be broadly screened against cost and benefit criteria to define a smaller set of the most promising options for detailed feasibility analysis.
- **Feasibility Analysis.** This step involves thorough technical and economic evaluation of each potential option to identify the preferred option(s). The level of effort necessary to complete this evaluation will be a function of cost, ease of implementation and degree of risk for the option. For example, a housekeeping change with low cost, low effort to institute and low risk of failure requires very little consideration, while a costly, innovative treatment plant may require research and very careful analysis before selection. Many companies have specific financial evaluation procedures or worksheets that they use to make decisions on capital investments; these should be used in the economic evaluation of options. In other words, waste minimization projects can be evaluated against the same financial criteria that are used for other facility improvements, as long as the potential environmental benefits of each project are also factored into the evaluation.

  After evaluating the options, a waste minimization action plan should be developed for future reference. The plan should contain a description of existing production activities and process/rinse water collection and treatment systems, options that were considered, results of the feasibility analysis, rationale for the selected option(s), and a schedule for implementation. The schedule should focus on minimizing the impact of installation on the facility's ongoing operations. It should also reflect any management decisions to stagger the implementation to better allocate capital investments over time.

- **Implementation.** Implementation may include equipment installation and/or material or procedural changes. Details of implementation will vary widely depending on the complexity of the selected approach and other site-specific logistical considerations. All work should be managed for quality control in accordance with company procedures. A monitoring program should be launched to ascertain whether the improvements are effective and the goals for the facility are being achieved on an immediate and long-term basis.

8.2 Options for Waste Minimization

A number of options for waste minimization in food processing facilities should be considered, including source reduction and recycling techniques, as outlined below.

8.2.1 Product Substitution

Products used in food processing operations or cleaning are often made from materials that constitute sources of waste (e.g., an alkaline product cleaner) in process/rinse water. By changing materials, significant reductions in specific constituents can sometimes be achieved. For example, replacing a salt-containing cleaner or oxidizer with one containing less salt can reduce the salt content in the process/rinse water. The kind of salt is also an important consideration. A number of processors have switched from sodium-based cleaners to potassium-based cleaners because potassium is a nutrient that can be taken up by bacteria and plants.

For processes that rely on chlorinated cleaning solutions, it may be possible to substitute peracetic acid or similar non-ionic, non-sodium, non-chloride cleaners. This substitution is beneficial not only to reduce effluent salinity, but also to preclude formation of trihalomethanes (THMs), a potentially carcinogenic by-product of chlorination in the presence of organic substances. When reviewing effluent monitoring data to assess the potential feasibility of product substitutions, it is important to account for products that may have been used when the effluent was sampled.

For peeling operations, substitution of potassium hydroxide for sodium hydroxide should be encouraged. While potassium hydroxide is more expensive and yields similar FDS concentrations in process/rinse water, unlike sodium it is beneficial to crop production. The substitution also reduces the amount of sodium and total salt that can potentially reach groundwater. Steam peeling for tomatoes rather than caustic peeling is another preferred approach to reduce sodium concentrations, depending upon end product quality requirements.

8.2.2 Good Housekeeping

Changes to housekeeping practices, such as storage and clean-up methods (for example, dry sweeping rather than wet rinses) and modifications to materials handling can be inexpensive but effective ways to reduce waste production. By enlisting facility personnel who are responsible for housekeeping activities in identification and implementation of improvements, additional reductions may be found. Employee education is a critical component of the waste minimization process.

8.2.3 Process Modification

Process modifications for waste minimization are best determined by persons who are the most knowledgeable on the subject process. For example, a product substitution to use alkaline cleaners may be reduced with the development of Standard Operating Procedures (SOPs) that involve process modifications. Often piping, pumping or layout changes can be implemented to improve processes and minimize wastes. This can include changes such as replacing water softeners used for boiler feedwater, cooling tower water or ingredient water conditioning with small reverse osmosis systems.

8.2.4 Operating Procedure Changes

Incorporating waste minimization measures into the formal written processes and SOPs for the facility, such as testing, maintenance and treatment system operation, can help integrate these measures into the culture and make the waste minimization program more effective and consistent. For instance, procedures for operating processing equipment may require that the condition of the equipment be checked or monitored weekly and repaired or replaced if necessary.

8.2.5 Recycling/Reuse

Recycling/reuse (R/R) techniques can reduce waste and save energy. These techniques can consist of direct reuse, such as using cleaning chemicals more than once prior to discharge or offsite disposal, to highly technical methods involving reverse osmosis, ion exchange, and distillation to repurify materials. Some facilities use clean-in-place (CIP) systems to recover spent cleaning solutions for reuse.

8.3 Water Conservation

Although water conservation methods are beneficial in conserving water supplies, they do not necessarily reduce the amount of constituents generated because the lower volume of water may carry a correspondingly higher concentration of constituents. However, with more concentrated effluent, recovery or treatment processes may be more efficient, reducing costs. Water conservation can also improve the feasibility or economics of other options such as recycling or disposal.

Water conservation can take many forms. During cleaning operations employees can help by using less water (e.g., dry sweeping and cleanup) or by installing flow-reducing devices, timers, and automatic shutoff valves to limit water use. With further evaluation, it may be possible to modify cleaning and rinsing processes to use less water while still maintaining acceptable results. The more highly concentrated rinse waters can sometimes be treated and recovered in a more cost effective manner, and/or can be combined with other similar streams and recovered.

8.4 Pretreatment Systems

If waste minimization techniques are not sufficient to achieve desired quality for subsequent land application, pretreatment may be necessary. Plans for pretreatment should themselves be subject to evaluation for waste minimization because chemicals used in some treatment processes can inadvertently add constituents to the discharged waste stream. For example, ammonium hydroxide is sometimes added to pond systems to neutralize pH. This can results in conversion of the added N to nitrate, which can pose a problem when the effluent is subsequently applied to land. Switching to more natural pH neutralization techniques, such as recirculation of alkalinity generated from biodegradation of process water in the pond should be considered.

If a treatment system is not designed or operated properly, discharges of incompletely treated process/rinse water or system overflows can potentially occur. To avert this, an evaluation of the pretreatment system should consider:

- Emergency storage capacity
- Back-up treatment units

- Multiple stage processes
- Monitoring and control features
- Formal operating and maintenance procedures

Also, the system should be evaluated to determine whether segregation of certain process/rinse water streams would enhance treatment or facilitate recycling. Pretreatment options to address solids, salts, organics (BOD) and nitrogen are summarized below.

8.4.1 Solids Removal

By reducing solids in the process/rinse water stream there may be a substantial reduction in the BOD load in the wastewater. Other benefits are to reduce plugging of distribution system nozzles and valves, and to eliminate or reduce solids build-up on the irrigated land, which can be a significant source of odors.

Screening

The most widely used method of solids removal in the food industry is screening, but solids removal can also be done by centrifuging, gravity settling, flotation, and micro filtration, nanofiltration or ultra-filtration. Mechanical separation of solids from process/rinse water by screening is by far the least expensive form of treatment and should be utilized to the maximum extent that is practical prior to using other more costly methods. A brief description of each removal method is provided below.

Many types of screens are available. The two basic categories are static screens and dynamic screens. These are further defined by the type of screening material, such as mesh screen, perforated plate or wedgewire. Each material is available for both static and dynamic screens. Mesh screen is basically the same material one would find used as window screen, and is available in a wide variety of wire size and mesh openings. Usually screens are made from various grades of stainless steel. Wire size will determine the durability of the screen, and mesh opening will determine the extent of solids removal. Perforated plate also can be used for screening and is available in various gauges of plate and many different hole sizes and patterns. Wedgewire is a triangular shaped wire which is welded to cross bars to hold the wires parallel to one another to make a screen surface with one flat edge of the wires facing toward the incoming waste stream. The cross bars are welded to the points of the triangular wires on the back side, away from the incoming flow. Wedgewire screen is slightly less effective than mesh or round hole screen because there is more opportunity for oblong material to pass. Any screen, regardless of type or surface material, will need to be kept clean either by manually washing the surface or by using spray bars with water under fairly good pressure, sprayed intermittently or continuously across the entire screen surface. Each screen type has its particular advantages and should be carefully chosen for the intended application. In general, the smallest mesh screen that will work with the product should be selected to maximize removal.

Static Screens. These screens are usually parabolic screens or sometimes called side hill screens. The water is pumped or flumed by gravity, if elevation permits, to the top of the screen, where the flow cascades down the surface of the screen. Water falls through the screen surface, and the solids roll or slide down the top of the screen surface to a collection bin or auger at the bottom. These screens are effective in separating larger solids and are very inexpensive to use. They are usually very sturdy. The screen surface will typically be wedgewire, although mesh screen can be used successfully. Screening can also be done within enclosed housings that usually use a stationary mesh or wedgewire screen cylinder and a rotary cleaning mechanism with backwash capability. This type of screening is usually best suited to flows that have minimal solids loadings, therefore they are usually not used in the food industry, where higher concentrations of solids are typical.

Dynamic Screens. Dynamic screens are usually either vibratory (shaker) screens or rotary drum screens. Vibratory screens typically use a mesh screen surface. Solids may sit on the screen for a period of time, which allows more de-watering to take place but can also result in the solids breaking up causing more fines to enter the process/rinse water stream. Drum screens are fed either from the outside, and use a doctor blade to scrape the drum surface clean, or are internally fed by a flume or a pipe. Rotary drum screens are usually made with wedgewire drums, although perforated drums are still available. Internally fed screens tend to produce dryer solids than externally fed drums, require little maintenance and have essentially no path for short circuiting. These can break solids into smaller particle sizes through their tumbling action, which allows more total solids to pass through the drum and enter the discharge stream. Externally fed drums have a shorter solids residence time on the drum that may not leave the solids as dry as the internally fed drum. Externally fed drums also have end seals that require maintenance attention. The primary advantage of the externally fed drum is the doctor blade that scrapes the drum surface and reduces blinding of the drum; however, the doctor blade may become “stapled” by solids that can lift the blade and allow solids to pass underneath.

Wedgewire drums, either internally fed or externally fed, are available in many different sizes. The diameter, length and wedgewire spacing will determine the capacity of the screen, but the wire spacing alone will determine the removal efficiency. Most manufacturers are reluctant to sell screens with anything less than 0.01-inch spacing, but screens with openings as small as 0.005-inch are available. The most effective screening will be product-dependent, and trial screens are often available for in-plant testing.

Centrifuging

Centrifuges are available in vertical and horizontal styles and two-phase or three-phase configuration. Most food processing applications call for two-phase machines that separate solids from liquid. Three-phase machines are used primarily where fats or oils are also present and a separate wastestream is desired. Centrifugation tends to be more energy intensive and more costly in both initial investment and operating expenses than screening. Characteristics of the process/rinse water to be separated will determine whether heating or chemical addition is required. Heating or chemical use can add significantly to the operating costs of using a centrifuge. Centrifuges tend to produce very dry solids but can have high maintenance expenses.

Gravity Settling

Settling, or sedimentation, allows particles that are more dense than water to accumulate at the bottom of a tank or basin and be removed with the use of a collection mechanism or seasonally removed with mobile equipment. Settling can be very economical, provided enough space is available to allow the flow to be calm for a long enough period of time for solids to settle out.

Settling basins should be sized to provide adequate storage for settled solids, but not so long as to be a source of anaerobic odors. Ideally, hydraulic retention time should only be a few hours. A variable elevation outlet structure should be provided so that the water surface level can be increased as solids accumulate in a basin. A two foot cap of aerobic water above the accumulated solids helps prevent odors. Two or more basins are recommended to minimize the size of individual basins and so that one basin can be taken out of service for solids removal.

The bottoms of settling basins usually seal well with the accumulation of solids. However, the potential effects of percolation from the settling basins on groundwater quality will likely need to be evaluated. This could include performing permeability tests in existing basins. The results of a groundwater impact evaluation could indicate the need for lining.

For space-constrained facilities, lamella plate packs can reduce the space required or detention time by providing parallel channels between plates that reduce the settling distance that the solids travel. Plate packs are usually inclined so that the solids slide down the plate face and ultimately accumulate at the bottom of the tank or basin. Plate packs require regular cleaning to reduce slime buildup. Screening is usually used ahead of any settling basin to remove larger solids for more rapid disposal and to prevent additional solids in the tank or basin from breaking down and contributing further to the loading.

Dissolved Air Flotation

This method uses fine air bubbles (dissolved air) attached to the waste particles to float the contaminants to the surface of the separation vessel, where they are scraped off by a mechanical scraper mechanism. The dissolved air system is often called a "white water" system since the bubble size is so small that clear water will usually turn a milky white color.

Dissolved air flotation (DAF) systems utilize one of three different strategies for introducing air to the treatment chamber. The first is full flow pressurization, where the entire process/rinse water flow is pressurized in a vessel and compressed air is added which entrains air into the process stream. The water is then released into the treatment tank through a back-pressure valve and the air, when no longer pressurized, is released from the water but remains attached to suspended particles which then float to the surface for removal. Chemicals are often combined with this process to coagulate smaller particles into larger conglomerates. Coagulant chemicals and dosages should be selected carefully to avoid increasing the salinity of the process/rinse water and particulate residue. The other methods of introducing air are partial flow pressurization, where just a portion of the flow is pressurized in the air chamber, and recycle pressurization where a portion of the cleaner water leaving the treatment unit is run back through the air chamber and reintroduced to the waste stream entering the treatment tank. Recycle pressurization takes away some potential capacity of the DAF unit by adding flow to the incoming process water stream (usually about 25 percent) but tends to perform better since the water used in the air pressurization system is cleaner.

Screening is usually the first step in process/rinse water treatment even ahead of DAF units. Many DAF manufacturers require screening ahead of their units to prevent plugging of the air control valves. DAF units retain some ability to remove the solids that will still settle out. It is typical to have at least a daily blowdown of the accumulated solids on the bottom of the unit.

Filtration

Filtration is in essence a much finer form of screening and is usually not applicable to entire food processing plant process water streams. Filtration comes in many forms from cartridge filters to sand filters to diatomaceous earth filters and micro- (or ultra-) filtration. RO is another type of filtration, but it is generally not used alone; a pre-filtration step is required. Pumps are usually required to force the water through the filter media for periodic cleaning or backwashing of the filter material, which may also require acids or other cleaning agents. When filtration is utilized, the filtered water stream is often clean enough to consider reuse within the plant.

8.4.2 Salt Reduction

Salt concentrations in food process/rinse water to be applied to land can be a significant concern. Exacerbating the problem, the salt content of incoming fresh water used by a processing plant may have salt concentrations that are intrinsically higher than the desired levels in the effluent process/rinse water stream. Accordingly, it is critical to keep salts out of the plant water as much as possible using the process and operational techniques highlighted above.

A few treatment strategies exist for salt reduction that are applicable to processing operations. However, they are all costly and result in a difficult brine disposal problem, so careful evaluation of the economic feasibility of these approaches is paramount. Technologies to address salt loading are primarily membrane treatment, either through the use of RO or nanofiltration (NF). These technologies require pretreatment steps to avoid fouling and frequent, expensive cleaning and operating measures. Membrane systems essentially separate the water from its dissolved components by pushing the water through a semi-permeable membrane. The dissolved components are left to concentrate on the feed side of the membrane. The result of this process is a clean water stream, generally suitable for discharge or reuse applications, and a concentrated brine stream, which must be disposed of (Tchobanoglous, et al, 2003).

Electrodialysis reversal (EDR) is a process by which a stream can be demineralized through the use of semi-permeable ion-selective membranes. The City of San Diego, at its North City plant, has an EDR system operating on tertiary effluent for salinity reduction.

Another option is evaporation via shallow ponds, if sufficient land is available. Mechanical evaporators can also be used for desalting process/rinse effluent or concentrating membrane reject streams. The salt brine or cake will then need to be disposed of properly, which is again difficult and expensive to accomplish.

8.4.3 Biochemical Oxygen Demand Reduction

The need for pretreatment steps to reduce BOD loading will be contingent both on the effluent concentration of BOD and the sustainable agronomic capacity of land application site, as detailed in Chapter 7. BOD can be either soluble (dissolved) or non-soluble. Non-soluble BOD is largely particulate matter that can be almost entirely removed through a combination of screening, DAF, or the other solids removal methods listed above. Soluble BOD is material that is dissolved in the process/rinse water and will pass through all of the mechanical separation technologies other than reverse osmosis. Thus, biological treatment methods are generally the most effective approach for soluble BOD. In essence, a biological treatment system provides an environment that encourages naturally occurring biological populations to consume the dissolved nutrients, leaving behind nutrient-free water. The treatment operator's responsibility is to create the optimum environment for the microorganisms or "bugs" to thrive.

Prior to biological treatment, as much of the suspended material (non-soluble BOD) should be removed as is economically feasible. Biological treatment generally falls into two broad categories: aerobic and anaerobic treatment. Aerobic processes involve the use of bacteria that require oxygen and metabolize the dissolved organics into carbon dioxide and water. These types of systems can be expensive and complex, and require significant amounts of energy to supply the required oxygen for the bacteria due to the high BOD concentrations in process/rinse water. They are generally effective in reducing BOD to levels below 100 mg/L. However, treatment levels that can be achieved are highly dependent on the influent process water characteristics. These systems are likely to be most economical for treatment of lower strength process/rinse waters, but at lower concentrations BOD may not warrant treatment prior to land application.

Anaerobic systems utilize bacteria that metabolize dissolved and suspended organics in the absence of oxygen. The resulting end products of the metabolic process are methane and carbon dioxide. These types of systems can be more robust than their aerobic counterparts, but often have higher capital costs. They may be cost-effective in cases of high-strength food process/rinse waters due to energy efficiency. While generally useful to treat more highly concentrated process/rinse waters (3,000 mg/L or higher of influent BOD), the systems cannot achieve treatment levels as low as aerobic systems. Anaerobic treatment can often reduce high BOD concentrations to levels more easily managed by land application.

Aerobic biological treatment is typically accomplished in lagoons or in concrete or steel tanks. Regulatory requirements usually specify that treatment must be done in containment to prevent percolation to groundwater. Systems include aerated lagoons, trickling filters, oxidation ditches, sequencing batch reactors and bioreactors or combinations of these. Because the biological population takes time to establish for a given set of conditions, these systems may not be well suited to treat process/rinse water flows that are highly variable in strength or volume over time.

8.4.4 Nitrogen Reduction

The reduction of nitrogen compounds in process water is commonly addressed through biological treatment. Although other treatment technologies exist to reduce or remove nitrogen compounds, including ion exchange, chemical oxidation, and air stripping, these types of technologies are less appropriate for process/rinse water applications. Specifically, ion exchange and chemical oxidation generally increase salt loading in the effluent, and air stripping requires operation at pH levels of 11 or higher and also results in increased salt loading.

Biological treatment for N removal is fairly complex and expensive. It is generally achieved through the use of nitrifying bacteria that metabolize ammonia into nitrite and nitrate. Further operation of the biological system under anoxic conditions converts the nitrate into nitrogen gas. These types of processes are commonly used in the municipal wastewater treatment industry, and could be similarly applied to process/rinse water treatment applications, if warranted.

8.4.5 pH Control

The acceptable pH range for food process/rinse water depends on the soil buffering capacity, soil pH, and selected crop (see Chapters 6 and 7). As noted above, many food plants use cleaning chemicals that can result in a pH of up to 12 during the sanitation shift, and the total effluent pH can vary depending on the product, volume of flow and other factors. If waste minimization techniques and/or flow equalization are not sufficient to control the pH of the final effluent, additional steps may be necessary prior to land application. Automatic controls are often used to inject a lime slurry, CO_2 or other buffering agents into the waste stream as a final step after pretreatment, prior to leaving the plant site. However, the use of chemicals will add to the fixed dissolved salts of the wastewater.

8.4.6 Offsite Disposal or Recovery

It may be advantageous to manage certain small quantity, highly concentrated process water streams, such as salts, by trucking them offsite for disposal or treatment, rather than developing costly systems for recycling or pretreatment at the facility.

Some process streams with high dissolved solids have been utilized as animal feed supplements because calcium, iron, manganese, chloride, and zinc may benefit animal nutrition and, in general, can be used as a medium for augmenting feed mixtures to improve palatability. Sources of calcium, chloride and magnesium can also be used to control fugitive roadway dust by increasing the density of roadway materials, reducing evaporation, and attracting moisture.

8.5 References

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9. PROCESS/RINSE WATER DISTRIBUTION SYSTEM

The important features of process/rinse water delivery and distribution systems for land application systems are reviewed in this chapter. Required system components, options, and considerations in selecting or designing a system are discussed. Once a land application system has been designed conceptually, the detailed engineering aspects of system layout, configuration, and construction follow standard engineering practices. Technical details of system design are not addressed here; readers are referred to technical engineering texts for this detail (Burt, 1995; Pair, 1983; EPA, 1981; WPCF, 1981, Roy F. Weston, Inc., 1982). Crites et al. (2000) have provided a guidance document for municipal and industrial land application systems that may also be consulted. The Natural Resources Conservation Service (NRCS) provides a comprehensive guide to determine irrigation requirements and irrigation scheduling (SCS, 1993). This chapter describes commonly used equipment for process/rinse water land application and management needs for successful operation of these systems.

9.1 Initial Irrigation System Planning

Many facets of irrigation system selection and operation are treated in the same way for conventional irrigated agriculture and process/rinse water land application. Most successful land application programs are operated using conventional irrigated agriculture methods, as much as possible. Specific differences that must be addressed are highlighted in the following sections. Factors that distinguish process/rinse water land application from conventional irrigation include:

- Process/rinse water irrigation amounts are generally limited by loading restrictions based on process/rinse water quality (see Chapter 7.7). As a result, supplemental irrigation water supply may be required to meet crop water use requirements.
- Process/rinse water discharge often occurs over a longer season than conventional irrigation, resulting in process/rinse water application in the late summer and fall (or year-round) when irrigation requirements are decreasing.
- Maximizing irrigation efficiency is not always the optimum approach for managing process/rinse water.
- Environmental monitoring, in addition to agronomic monitoring, is generally required for land application systems (see Chapter 10).
- A critical factor for existing processing facilities considering land application or system expansion is identifying available acreage with suitable soils near the facility.
- Irrigation rates and the recommended frequency of application differ between process/rinse water land application and conventional irrigated agriculture.
- Crop selection is often determined by operational needs of the land application system. For example, forage grass for silage or hay may be chosen over crops with a higher rate of financial return because crop management is more flexible and will not interfere with irrigation schedules.

In the following sections, the major components of a land application distribution system, basic design considerations, and implementation factors are discussed.

9.1.1 Overall Land Application Area Size

Land application system planning (or updating of an existing system) should begin with an initial estimate of irrigated acreage required. A design level calculation is more complex because it is based on a number of system factors. At the initial planning stage, a preliminary evaluation of process/rinse water quantity and quality is used to assess land area requirements.

The general method used to determine acreage required involves determining the limiting factor for land application (Crites et al., 2000). For food process/rinse water, the limiting factor is generally hydraulic loading, nitrogen application, or BOD loading. An initial estimate of acreage requirements based on irrigation water needs can be made using total facility water flow and local area irrigation requirements. Facility flow can vary throughout the year and the designer must determine the season in which the most restrictive flow conditions exist (storage facilities affect this calculation as well). Acreage planning should take into account additional capacity requirements for future facility expansion. Crop water use and irrigation water requirements depend on the projected cropping and irrigation method. For purposes of preliminary acreage calculations, a conservative water application rate per acre should be assumed. These rates can generally be found in local area weather stations or irrigation scheduling service records such as the California Irrigation Management Information System (www.CIMIS.water.ca.gov) or Western Regional Climate Center websites (www.WRCC.DRI.edu). The detailed approach and formulas for calculating area requirements were presented in Chapter 7. Example calculations are presented in Chapter 12.

As shown in Chapter 7, other process/rinse water constituents may limit loading and require a higher minimum acreage. If another constituent is limiting, then the acreage calculation for that constituent should be used for preliminary estimation of acreage requirements.

It is not good practice to use the minimum acreage without additional acreage to accommodate other needs. It is typical to increase the minimum estimated required acreage by up to 25 percent to account for roadside buffers, unsuitable ground, and other factors. It is prudent to have an additional 25 percent of the minimum acreage available so that crop rotation, use of fallow seasons, resting periods between irrigation cycles, accommodating long return period wet year runoff, and use of crops that will not accept process water can be part of the cropping strategy for the facility. Finally, irrigation acreage could be sized to accommodate future projected flows. This is particularly important in situations where available agricultural acreage may be scarce in the future.

9.2 Basic System Components

A land application system consists of components starting at the facility's process/rinse water discharge point to an irrigation area typically located at some distance from the facility. The basic features of these components, as well as key management considerations, are summarized in Table 9-1.

Table 9-1. Basic Process/Rinse Water Distribution System Components	
Component	Function
In-plant collection system	Collect process/rinse water in a central location for discharge from the facility.
Pre-treatment	Initial treatment of process water: settling, screening, pH control, aeration are common processes.
Storage lagoon, pond, or tanks	Provide temporary surge control for varying flows, allows mixing. Often incorporates some aspects of pre-treatment and pumping.
Main pump station/ Booster station	Pumping is required to distribute process/rinse water and supplemental irrigation water. Sprinkler irrigation systems may require higher pressures to be developed at booster stations.
Transmission and distribution pipelines	Moves flows from the facility to irrigation areas. For large-acreage systems, additional distribution pipelines including dual pipes for process/rinse water and supplemental supplies may be required.
In-field distribution/irrigation system	A variety of standard agricultural irrigation systems are used for land application systems. These are described in Table 9.2.
Irrigation return flow/ tailwater pumping	For surface irrigation methods, irrigation return flow is required to recycle runoff water (called tailwater).

In practice, the components of the water distribution system include:

- An in-plant collection system that routes water to a common collection point
- Pretreatment and storage devices
- A pumping station to move water from the facility to the irrigation system
- Primary transmission lines to carry water from the facility to the land application fields
- Agricultural fields or areas, used for land application
- A distribution system (pipelines, ditches, or both) including a booster pump station, if required.
- In-field irrigation systems including a method of application and, if necessary, a tailwater collection system.

Each of these components should be designed using standard engineering practices and should also address regulatory and safety requirements.

9.2.1 Process/Rinse Water Collection

Process/rinse water collection systems within a facility are generally established during facility construction. Design of these systems is generally based on processing needs rather than process/rinse water discharge. Key considerations for the in-plant collection system include simple operation; access for cleaning, maintenance, and inspection; separation of domestic wastewater and process/rinse water flows; and routing of flow to a central location for removal from the facility. Part of this in-plant design should address the need, if any, for process/rinse water pre-treatment prior to discharge. Depending on other facility design features, pre-treatment may include (Chapter 8 provides a more complete discussion):

- Settling, screening, or other solids removal
- Aeration
- pH control

Often, space or water volume requirements for these are combined with the need for temporary process/rinse water storage.

9.2.2 Incorporation of Storage into a Land Application Program

Incorporating storage lagoons, ponds, or tanks in a process/rinse water distribution system provides flexibility to streamline land application operations. The basic factors to consider in assessing whether to incorporate storage within a distribution system are:

Pretreatment. Pretreatment of process/rinse water storage may be required as part of the treatment. Solids settling, aeration, and pH control can be accomplished in a lagoon or storage vessel (see Chapter 8). Odor control is a key objective of pre-treatment systems, particularly for storage impoundments.

Flow Control. A storage facility can act as a surge basin to dampen changing volumes of process/rinse water outflow upstream of the distribution system. Storage is useful to decrease peak flows and can be used to blend flows of different water quality during the course of a day (for instance, normal processing water and clean-up flows). Six to twenty four hours of storage is typically adequate to address the peak flow leveling and water quality blending needs. Storage volumes should be evaluated on a facility by facility basis.

Storage during adverse weather conditions. Storage within a distribution system may be needed to allow temporary cessation of irrigation when conditions are not appropriate or allowed under permit conditions. Cold weather or excessively wet soil conditions are common reasons to temporarily cease irrigation. Typically, storage of one to five days of process water is adequate.

In some cases, winter storage of process/rinse water has been suggested or is a regulatory requirement. In this case, storage might be sized to hold facility flow for as long as November through March, including an allowance for precipitation and subtracting evaporation losses. Typical design requirements include maintaining two feet of freeboard and sizing to handle precipitation and storm flow from the 100-year maximum precipitation conditions. Monthly design precipitation values should be taken from the 100 year annual rainfall distributed monthly according to average monthly precipitation patterns. For process/rinse water systems, an evaluation of potential groundwater quality impacts will likely be required. If there is a substantial risk of impacts to beneficial uses of groundwater, some form of lining and leak detection may also be required.

Odor Control. Storage ponds can develop odor if process water is held for periods long enough to develop anaerobic conditions. Odor generation is minimized by pre-treatment practices, maintaining aerobic conditions, addition of chemicals for pH adjustment and odor suppression. Odor generation must be considered when incorporating storage into a system.

Pump Station. A storage facility is often a logical or necessary location to place a pump station to supply water to the land application system.

Flow Mixing. In situations where process/rinse water is to be mixed with supplemental irrigation water supplies, a lagoon or pond may facilitate this function. If this use would increase the size of the lagoon beyond the capacity needed for other purposes, other methods of mixing should be evaluated.

Lagoon and pond design must be done according to standard engineering principles and procedures. Plans and specifications should be prepared and certified by a professional engineer. It should be noted that the size of a storage facility should anticipate future facility expansion needs. Additional storage volume costs less to incorporate during initial construction than when added later.

9.2.3 Pump Stations

Pumping stations and transmission systems vary depending upon application system used and distance to the land treatment site. These are required for most land application systems and should be designed using standard engineering practices and certified by a professional engineer.

There may be several pump stations within a land application system: a main facility pump station to deliver water to the distribution system, booster pumps at irrigation fields to supply sufficient pressure for distribution, and a tailwater pump station for surface irrigated fields. Considerations for pump station design include:

- Pumping systems should be designed with redundant capacity, particularly if no surge pond volume is available for temporary water storage.
- For a main pump station serving a facility, it is common for each of two pumps to be sized for the maximum facility flow. This provides a back-up pump for use during routine operations and maintenance procedures.
- The calculation of flow should also incorporate the decrease in pumping efficiency for raw wastewater (as low as 40 to 50 percent of that of clean water; Crites et al., 2000).
- The main pump station must also be designed to accommodate total head requirements, head loss, and elevation change of the transmission pipeline between the facility and the land application fields.
- Booster pumps are often used with sprinkler irrigation systems that may require higher pressure for application than is necessary for transmission. These can be sized based on the acreage they will serve. A common design method is to size the pumps (and pipeline and irrigation system) to supply sufficient water to meet a maximum evapotranspiration week. For a maximum of 3 inches of ET per week (0.43 inches per day), design flow would be 8 gpm per acre served. Maximum ET should be evaluated based on local area weather conditions as mentioned in Section 9.1.1. If the maximum evapotranspiration period is long, consideration must also be given to increasing design flow to compensate for harvest delays, maintenance activities, and irrigation efficiency.
- Tailwater pumps are often sized at 25 percent of the irrigation water supply flow for the area they serve.

9.2.4 Transmission Pipelines and Ditches

Sizing of transmission systems can be accomplished using a method similar to that used for determining acreage requirements (Section 9.1.1) and main pump station sizing (Section 9.3.2). The most conservative size criterion is to supply irrigation water to an entire land application area. This would, in theory, allow complete flexibility in a transmission system. This maximum size method can be reduced substantially by incorporating more system-specific details such as elevation change within the system, crop water needs by month, use of booster pump stations, and other soil and physical environmental factors.

Ditches are a common transmission method for surface irrigation fields. They supply water economically because pumping costs are minimized. Water is primarily moved by gravity and can be controlled by weirs and gates. Ditches are also effective for mixing process/rinse water and supplemental irrigation water flows. Care should be taken to prevent erosion and excess seepage from unlined ditches. Pipelines are also used for transmission, especially when distances are long and terrain is not sufficiently level for ditch systems. Several additional factors deserve special consideration when designing transmission systems or pumping stations for process/rinse water distribution systems.

Pipeline and Ditch Cleaning. Process/rinse water transmission lines and other pipelines generally require more flushing and cleaning than pipelines using cleaner water supplies. During pipeline and pump station sizing, it is common to design for relatively high velocities (3 to 5 feet per second) to minimize settling. While this method minimizes the settling problem, there are still occasions when pipelines should be cleaned, either to remove sediment or to remove bacterial and other growths that promote anaerobic conditions and create odor. It is common for land application system pipelines to have access ports at intervals along the transmission line so that in-line brushes (called pigs) can be inserted and used to clean sediment, bacteria, and slimes from the lines. In similar fashion, process/rinse water pipelines can be designed so they can be drained or flushed with clean water between uses. Draining pipelines or flushing them with clean water removes BOD and other process/rinse water constituents that may result in chemical reactions, biological activity, and odor.

Dual Water Sources. If process/rinse water and supplemental irrigation water are not mixed prior to transmission, the transmission conveyance may need to be designed to accommodate pumping of different water supplies from different sources within the transmission and distribution network. These designs are necessarily site-specific. If more than one water supply is used, backflow prevention devices are required to protect clean water supplies. If blending is planned to reduce the concentration of a process/rinse water constituent, thorough mixing should be assured using a blending chamber or in-line mixer.

Dual Pipelines. In large process/rinse water distribution systems, it is common that certain pipeline sections may need to move both process/rinse water and supplemental irrigation water, perhaps in different directions and at different times. If field irrigation scheduling will allow it, a single pipeline can be used for these functions. It is often the case, however, that dual pipelines must be installed at certain locations within a transmission and distribution system in order to accommodate dual flows.

Leak Detection. Process/rinse water transmission pipelines may be equipped with leak detection features because: a) process/rinse water quality makes leakage more of a threat to local groundwater; and b) the facility may depend on the pipeline to remove process/rinse water and keep the facility operating. Timely discovery of pipeline failures can minimize facility work stoppage to correct problems. Leak detection for ditches is typically done by periodic observations of wet spots, anomalous vegetation growth, or unexplained decrease in ditch flow. Leak detection in pipelines can be accomplished by flow meters, and/or regular inspection of the pipeline route for wet spots or anomalous vegetative growth.

9.3 In-Field Distribution Systems

A variety of irrigation systems are used to distribute water in irrigated fields, including land application sites. Systems fall generally into three broad categories:

- Surface application
- Sprinkler irrigation
- Drip irrigation

Each of these system types has a place in land application programs, although drip irrigation is limited in applicability. In the following paragraphs, a number of distribution systems, including specific applications, are briefly described. Table 9-2 summarizes in-field distribution systems commonly used for land application programs. These systems have different features and varying costs. As a result, each has different applications for which they are appropriate. In the following sections, features, advantages, and disadvantages of various irrigation systems are reviewed. In Section 9.4, some aspects of design for irrigation systems are addressed. For all irrigation systems, water application rates must be matched to site soil infiltration capacity, as well as crop needs (based on ET).

9.3.1 Surface Irrigation Systems

Surface irrigation systems are commonly used when initial capital expense must be minimized. These systems are also appropriate when energy consumption must be minimized. A basic requirement for the surface irrigation method is a land area that must be quite regular in slope and generally quite flat. Most systems operate best at slopes of less than 2 percent, although slopes up to 8 percent can be accommodated with appropriate design.

The focus of this chapter is on “slow rate land application systems.” These systems apply process/rinse water for agricultural purposes at low irrigation rates that are commonly used for crop growth

(Crites et al., 2000). Slow rate infiltration systems are managed to control leaching and runoff so that most water is stored in the root zone for beneficial use by crops. Overland flow is an alternate land treatment technology which utilizes surface runoff flow through a vegetated soil system to accomplish treatment. Rapid infiltration is another alternate treatment technology which utilizes coarser soils as an in-situ biological filter to treat wastewater applied at high rates. These alternate land treatment technologies are not the focus of this manual, but are mentioned herein because of their potential applicability in some situations and because surface irrigation is often utilized with them. Common surface irrigation methods include:

Flood irrigation. This is the most basic method. Irrigation water is turned out into a field with minimal distribution or control of the flows. Water is allowed to move downward through the soil and across the field, until irrigation is completed. The lack of control with flood irrigation systems makes their use inappropriate for process/rinse water management.

Table 9-2. In-Field Irrigation Methods

Type	Description	Advantages/Disadvantages
Surface Irrigation		Inexpensive technique Requires tailwater recovery
Flood	Uncontrolled application to a vegetated surface via gravity or low head pumping.	Poor uniformity of application Not generally suitable for process/rinse water application
Furrow	Application to a leveled field via small ditches between crop rows.	Primarily for row crops Careful leveling is required. Requires labor to move sets. Uniform application especially difficult on coarse textured soils.
Border	Application to a leveled field in 20 – 100 foot wide strips.	Primarily for grass or perennial crops. Requires labor to move sets. Careful leveling is required. Uniform application especially difficult on coarse textured soils.
Sprinkler Irrigation		Components can be sensitive to process water chemistry. Almost eliminates runoff. Susceptible to wind drift. Good method for coarse and medium textured soils.
Solid set	Permanently or semi-permanently installed sprinklers are used in blocks.	High initial capital expense but less labor. Good for winter irrigation if subsurface piping is used. Harvest and tillage are difficult around the sprinkler risers. Rapid rotation among blocks is feasible to promote evaporation in winter.
Wheel line	Moveable sprinklers cover field in sets.	Labor requirement to move sprinklers makes long sets common (this increases the potential for runoff). Inexpensive equipment.
Big gun	Large diameter orifices operating at high pressure spread water. Traveling hose reels allow big guns to irrigate strips over uneven ground.	Requires high pressure for maximum area coverage. Water impact can damage crops and soil. Relatively high irrigation rate.
Center pivot	Sprinkler system with central water supply moves in a circle to irrigate 20 to 160 or more acres.	High instantaneous application rate. Flexible, efficient irrigation with proper design. Frequent light irrigation of fields is used in winter to minimize soil storage. Most systems do not irrigate the corners of fields.
Linear move	Similar to center pivot, but moves in straight line to cover rectangular area.	More capital and labor cost than center pivots, but provide full field coverage.
Drip Irrigation		Emitter clogging limits utility of drip irrigation with wastewater and may require filtration. Precise control of irrigation water. Expensive technique
Surface drip	Low flow emitters placed on the ground surface apply water to crops roots but not between rows	Newer wastewater applications use “micro-sprinklers” to minimize clogging problem.
Subsurface drip	Emitters are buried 6 – 12 inches deep as a semi-permanent installation.	Some difficulties with rodent damage and microbial growth in emitters.

Border irrigation. These systems take the basic concept of flood irrigation and refine it to add an element of control to the application amount and locations within the field. Irrigation water is applied to the field at one end and it flows by gravity through the field to the far end. Some systems are managed without tailwater while others incorporate tail water return systems. Uncontrolled tailwater is unacceptable. Tailwater can not leave a land application site without regulatory authorization and specific monitoring. Border strips range from 20 to 100 feet in width and can be 200 to 1000 feet in length. Common design flows are between 5 and 70 gpm per foot of width (Crites et al., 2000).

Border irrigation fields are smooth and often have been leveled to create a favorable environment for surface water flow. Common border irrigation fields are at slopes of 2 percent or less. Careful management and supervision of the application operation are required to provide adequate results, including uniform applications over the irrigated area and determination of actual amount applied. Border irrigation is best suited for continuous canopy crops (not row crops), such as pasture, grasses, and trees.

Rill or furrow irrigation. This irrigation method is the most common surface irrigation method used for row crops in California. Furrow irrigation fields are smooth and uniformly leveled. Instead of releasing water to the field across one entire side of the field, water is instead released in small ditches called 'rills' or 'furrows'. These ditches flow between rows of crops and provide a water supply to crop roots by lateral flow from the ditches to the crop rows. Because this system relies on lateral flow to reach the crops, it is more practical for sites with finer textured soils. For these conditions, furrows can be spaced 3 to 4 feet apart and lengths can range from 400 to 1,300 feet for applications of 2 to 3 inches per irrigation cycle. In sandy soils, irrigation rills can be as close as 12 inches apart to ensure that water will reach plant roots. Irrigation uniformity decreases as furrow lengths increase. Furrow lengths should be 600 feet or less. Furrow irrigation generally requires tailwater collection so the water that flows through the field, without being absorbed in the soil, can be recycled and reused.

9.3.2 Sprinkler Irrigation Systems

Sprinkler irrigation systems are a flexible alternative to surface irrigation systems. These systems deliver water under pressure to the land surface via nozzles that provide a relatively uniform distribution of water. Sprinklers are often regarded as an improved irrigation system with respect to surface irrigation methods because they cover the entire field surface, do not require land leveling, have higher irrigation uniformity and efficiency, and do not have a tailwater collection requirement,. Sprinkler systems require pressure to operate, are affected by wind, may require buffers in populated areas, and have higher capital and energy costs than surface irrigation systems. Although initial capital cost is lower for surface irrigation, labor costs can be greater.

The common types of sprinkler irrigation systems used in land application are solid set sprinklers, movable systems, "Big gun" systems, and mechanical move irrigation systems.

Solid set sprinklers. These sprinklers and associated piping are placed permanently in fields to provide the necessary water supply for crop production. Irrigation application rate for these systems is controlled by selection of appropriate nozzles to deliver the required irrigation amount. Based on the system pressure (in the range of 35 – 85 psi) and sprinkler characteristics, the spacing of nozzles with respect to each other can be calculated. In general, common spacing for sprinkler heads ranges from 30 feet on center to 80 feet on center. Depending on design details, these systems can deliver up to 1 inch per hour over a field. Designs should be performed by professionals following conventional methods (Pair et al., 1983). Because solid set systems are always in place in the field, the labor required to implement irrigation is quite low. The presence of permanently installed sprinklers creates challenges for crop management and harvest.

Hand-movable systems. There are a wide variety of hand-movable sprinkler systems that operate in a manner quite similar to that of solid set sprinklers. These sprinklers can be moved from location to location in the field, and, while the sprinkler is in a single position, irrigation of that area can be accomplished. Nozzles are spaced 25 to 50 feet apart (depending on operating pressure, commonly 35 – 75 psi, and the sprinkler is moved approximately the same distance between irrigation sets. This allows for some overlap of irrigation among nozzles to provide a uniform application and account for potential wind drift of water. It is of note that, given proper design, hand-move irrigation can be applied to a much larger area than with solid set sprinklers but many more sprinkler heads are required. These irrigation systems have the advantages of less capital expense for irrigation equipment and they provide unimpeded access for cropping. At the same time, the disadvantage is that the system requires labor for movement in order to irrigate an entire field.

"Big gun" systems. These systems rely on a very large sprinkler nozzle operating at a high pressure to apply irrigation water to a relatively large area. The technique is sound, because for low capital expense, a relatively large area can be irrigated. In addition, big guns have the capacity to irrigate non-level ground. Big gun irrigation systems can be constructed with fixed gun locations in an irrigated field or can be movable. Movable systems include those where the big gun is moved manually to different irrigation risers. Another popular movable irrigation system is the 'traveling big gun.' A hose reel attached to the big gun is laid out and the sprinkler, when activated, returns along the hose line path by means of either hydraulic pressure or an auxiliary motor supplying power to roll up the irrigation hose and move the sprinkler. A common traveling big gun system in use in both agriculture and land application may operate between 80 and 150 psi, cover a swath 300 feet in width, and apply between 0.5 and 3 inches of water per acre when moving.

Center pivot and linear move irrigation systems. Center pivot irrigation systems operate from a central water supply with a movable irrigation lateral that travels in a circle around the pivot point. Such irrigation systems are moderately expensive for initial capital cost, but have very low maintenance and manpower requirements and can be simply operated from a central location. Center pivot systems require tailored sprinkler engineering because sprinklers closest to the pivot must have much lower flow than those at the far end of the pivot where more acreage must be covered during the course of a single pass.

A common design flow for a center pivot is between 7 and 9 gpm per acre. This results in application rates of 0.35 to 0.45 inches per day under normal operating conditions. Smaller applications can be applied by increasing the movement rate of the device. Because of the potential for high frequency applications, center pivots often provide the most aerobic soil conditions of all process/rinse water application techniques. Center pivots also have relatively high instantaneous application rates, making them unsuitable for use on some low permeability soils.

Operating pressures are between 20 psi for low pressure sprays to 75 psi for impact sprinkler heads. Because of the circular water distribution pattern, quarter-mile long center pivots typically cover approximately 130 acres, leaving corners of rectangular fields without irrigation. End guns and corner swing arms can be added to cover corner areas.

Linear move irrigation systems can be thought of as center pivots that move in a straight line, taking the water feed from a ditch or series of riser valves along the edge or center of the field. Linear move systems are more expensive and require more labor than center pivots, but are better suited for large rectangular-shaped fields.

Sprinkler irrigation technology is quite popular in the agricultural sector, and operating guidelines and practices are well developed. Sprinkler systems provide both good irrigation efficiency and irrigation uniformity when compared with surface irrigation methods. Sprinkler systems require pressure for efficient operation; although, increasingly, low pressure systems are being developed to increase energy efficiency and decrease water losses.

9.3.3 Drip Irrigation Systems

In areas where water supply is scarce, drip irrigation systems are frequently used. This irrigation method makes use of small irrigation nozzles operating at low pressure and placed adjacent to crops. They are especially appropriate for row crops and tree crops where locations for irrigation do not cover the entire land area. Drip irrigation systems commonly operate at low pressures and relatively low flow rates, relying on longer sets to supply needed irrigation amounts.

The most common drip irrigation technology relies on inexpensive plastic irrigation pipe laid on the ground surface along crop rows. Because the systems are on the ground surface, they must either be removed or destroyed during crop harvest. Surface drip irrigation systems have the disadvantage of small orifices that can plug when water supplies are not of high quality. Even highly treated process/rinse water may have sufficient solids to cause line or nozzle plugging. In addition, any supply of nutrients may create a favorable environment for microbial growth that can also plug systems.

Subsurface irrigation methods are an alternative to surface drip systems, but have the advantage that the ground surface remains clear. Subsurface systems have the same low pressure operation and exact placement of water supplies where they are needed. In addition, problems associated with line and nozzle plugging also occur with these systems. Subsurface systems are more expensive than surface systems, because of the cost of placement, but this can be offset because more than one season of use is gained from the installation. Permanent crops or precision cultivation of row crops are required to successfully use subsurface drip irrigation for more than one season.

9.4 Site Characteristics that affect Irrigation System Selection

There are a number of site- and facility-specific features that affect selection of irrigation distribution systems. A number of these factors are directly related to system design as well. Because system design should be done using conventional engineering design principles, engineering calculations based on site features are not discussed here. These matters are treated in detail in irrigation and land application system design manuals (Crites, et al., 2000; Burt, 1995; Pair, et al., 1983).

Table 9-3 provides a summary of site features and how they impact irrigation distribution selection. The table does not address the process/rinse water flow and quality factors that affect irrigation practices but treats the land application site factors of site layout, soil properties, climate, and crops. Comparisons in Table 9-3 do not include drip irrigation systems.

Primary site layout factors are field size, field shape, and slope. Surface irrigation methods are only suited to nearly level sites because they rely primarily on gravity flow. Sprinkler and drip systems do not have particular limitations related to slope. Field size is limited for these systems because, if fields become too large, supply pipelines and pumping capacity also become large and expensive.

The key soil properties that affect system selection are infiltration rate, soil texture, and soil water storage capacity. Application rates should be matched to the soil infiltration rates for both sprinkler and surface systems. The relationship is more complex for surface systems because these methods require both water infiltration and some surface lateral flow to move water down the field. Often, a surface system starts irrigation with a flow rate higher than the infiltration capacity and slows flow once water has advanced a suitable distance down the field.

Table 9-3. Site Features that affect Distribution System Design		
Feature	**Surface Irrigation**	**Sprinkler Irrigation**
	Site Layout	
Field size	Length of downslope run affects flow rate and number of irrigation blocks	Either system pumping capacity or irrigation frequency (set by soil water storage and ET rate) can limit size of single irrigation blocks
Slope	Slopes > 4% are not ideal; >8% may require sprinkler or drip system	Systems can tolerate moderate slopes and uneven terrain
	Soil Properties	
Number of soil types	More than 1 soil type causes design difficulties, may require separate irrigation blocks	More than 1 soil type causes design difficulties, may require separate irrigation blocks to manage irrigation frequency and duration
Infiltration rate	Sets maximum application rate due to both infiltration and furrow advance rate	Sets maximum application rate due to infiltration; sets travel rate and/or nozzle sizing for moveable systems
Soil water storage capacity	Establishes duration of irrigation set and maximum time between irrigations	Establishes duration of irrigation set and maximum time between irrigations
Erodibility	Affects design of tailwater collection system	Can limit application rate
	Climate	
Precipitation pattern	Affects season of irrigation	Affects season of irrigation
Evapotranspiration	Determines design irrigation requirement Major factor in irrigation scheduling	Determines design irrigation requirement Major factor in irrigation scheduling
Need for cooling or frost control		Affects irrigation scheduling but is likely addressed with supplemental water supply
	Crops	
Peak water requirement	Affects irrigation system design and irrigation schedule	
Irrigation season	Crops are selected to match water supply and irrigation requirement	
Rotation needs	Rotation is selected to match water supply and irrigation requirement	
Harvest scheduling	Harvests are staggered between fields when possible	

Soil water storage capacity is required to hold irrigation water in the crop root zone until it is needed for crop transpiration. Fine textured soils with a large storage capacity can be irrigated less frequently than coarse textured soils that store little water and must be irrigated every few days, depending on climate conditions. The duration of irrigation is affected by the infiltration rate and water storage capacity of the soil. The infiltration rate establishes how much irrigation can be applied per hour. The capacity sets the cumulative amount that can be applied.

Soil texture doesn't directly affect irrigation system design or suitability but it is commonly used in design manuals (Crites et al., 2000; Burt, 1995; Pair et al., 1983). This is appropriate because the specific soil physical factors that affect erodibility, length of surface irrigation fields, spacing of furrows, frequency of irrigation, and other design factors are difficult to measure. These are related to soil texture, a much easier soil property to evaluate in the field.

Climate is one of the most important factors in determining irrigation strategy. Any irrigation method must account for precipitation as well as evapotranspiration. Climate affects overall irrigation requirement and also affects timing and duration of irrigation, as discussed above. Climate may also influence the decision to incorporate storage into a land application program.

9.5 Management of Irrigation Systems

Management of an irrigated farm is a complex task under normal agricultural circumstances. Use of process/rinse water adds additional complexity for the reasons mentioned in Section 9.1. The primary challenge for irrigation scheduling is to manage both process water and supplemental irrigation water to meet but not exceed both hydraulic and constituent loading rates. The primary challenge for crop management is to produce marketable crops while meeting the requirements of environmental protection.

9.5.1 Irrigation Scheduling

In practice, irrigation scheduling is managed by establishing hydraulic requirements for each field-crop-process water quality combination. The Natural Resources Conservation Service (SCS, 1993) has extensive, practical and technical guidance that can be used to develop irrigation scheduling programs based on water requirements. Once hydraulic needs are known, the decision whether to use process water or supplemental irrigation water can be based on the supply of process water to the farm, crop growth stage, pipeline capacity, and other factors. The times when irrigation scheduling is most difficult are: a) during the peak evapotranspiration season when pipeline capacity is almost entirely used, and b) during planting and germination when process/rinse water irrigation may harm small plants and supplemental water supplies must be used.

9.5.2 Whole-Farm Cropping System Integration

The land application program crop selection procedure incorporates a number of variables to be optimized. While conventional agriculture generally sets a crop plan based on projected sale price and potential to make a profit, land application programs have this goal as a secondary priority. The first priority is to have a crop mix that allows the farm manager to irrigate all the process water without damaging crops or overloading any fields in the process. In general, large land application farms make use of double cropping including a good winter cover crop, staggered planting for fields with the same crop, and a mixture of crops to provide additional flexibility. Smaller land application programs often cannot use this approach because acreage is limited. As a result, there may be times when irrigation occurs under less than ideal conditions. An example of this is excess pre-irrigation of bare ground when an entire crop has been harvested at once to optimize harvest efficiency. This does not optimize process water use efficiency. A solution to this example is to maintain a small field with a cover crop to be used when most of the acreage is harvested as a unit.

9.6 Irrigation System Comparisons

Each of the irrigation methods described in Table 9-3 can be used in land application systems. Surface irrigation methods are low capital cost alternatives but have the disadvantage of providing imprecise control of water delivery to fields and crops. In addition, need for land leveling and treatment of irrigation return flow are added factors and costs that other methods do not have.

Sprinkler irrigation methods have widespread application in California agriculture. They afford good control of water application and can be operated on non-level sites. They are moderately expensive and have ongoing energy costs due to their reliance on pressurized delivery. Solid set and center pivot sprinklers can be used to apply water efficiently when water supply is scarce but can be operated at lower efficiency during non-growing season months when water supply is plentiful. The selection of a specific sprinkler system is generally based on site conditions (slope and soil type), and the availability of labor to operate the systems. For minimum labor, solid sets and center pivots are selected. For winter application (involving frequent, light applications and ability to withstand freezing conditions), solid sets are best but center pivots can be used with design adaptation. Solid set sprinklers make crop harvest awkward and are therefore generally used at dedicated land application sites or where grazing is part of the crop removal strategy. Traveling big gun systems are used on sites with uneven topography and hand move systems are used when an inexpensive system is required and labor is available.

Drip irrigation is most common on high value crops where high precision water delivery is important. These systems have high water use efficiency. Because the drip emitters can clog when used with process/rinse water, they have had limited use in land application systems.

9.7 References

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10. SITE MONITORING

Site monitoring is a critical part of operating and managing a process/rinse water land application system to ensure that effective land treatment and reuse are occurring, and that groundwater is protected. This chapter addresses routine land application site monitoring and documentation for key system components, including:

- Process/rinse water flow and water quality;
- Supplemental irrigation water quality;
- Process water residuals generation and recycling;
- Soil and vadose zone conditions;
- Groundwater quality;
- Crop yield and biomass; and
- Routine maintenance, inspection, and record-keeping.

For best results from a monitoring program, data collected in each of these areas, including short-term and long-term observations, should be integrated and evaluated over time. Ongoing data management, evaluation, and record keeping are critical to the success of a monitoring program. Data evaluation and operational adjustments and modifications are discussed in the final sections of the chapter.

10.1 Basic Structure of a Monitoring Program

Monitoring efforts can be divided into two categories with different objectives: (1) operational or process control monitoring and (2) compliance monitoring. Operational monitoring is typically conducted by the personnel responsible for operating the land application system, and includes both quantitative and qualitative observations and other data required to document process control. These observations may include details regarding functioning of the physical infrastructure, as well as crop management issues, including both field management and irrigation. During the course of monitoring, the observer will learn more about the behavior of the land application system, and this often leads to developing improved operating procedures or adjusting equipment to improve system performance. Common modifications based on operational monitoring can include changing irrigation practices; scheduling harvest, replanting, and other crop management activities; scheduling preventative maintenance and repair; and expanding or improving the system. By providing system feedback on a regular basis, operational monitoring serves an important "early warning" function. Minor problems that are identified quickly can be corrected before groundwater or cropping impacts are incurred.

The second, equally important category of monitoring, compliance monitoring, is intended to provide system operations documentation for regulatory oversight and compliance with the Monitoring and Reporting Program (MRP) associated with the facility's Waste Discharge Requirements (WDRs). The MRP typically identifies points of compliance for monitoring both the process/rinse water and groundwater. Process/rinse water is monitored to allow determination of loading rates. Groundwater monitoring is conducted to assess whether water quality impacts have occurred that could be attributable to the applied water. Factors to be considered in establishing compliance monitoring points are discussed in subsequent sections of this chapter.

Often, the scopes of monitoring activities for operational control and compliance overlap or are complementary. Examples of monitoring requirements for the two types of monitoring objectives are compared in Table 10-1. MRPs generally require documenting system performance on a monthly or annual basis, while operational management observations are often gathered more frequently for short-term evaluation and decision-making.

The requirements for process/rinse water flow monitoring are a good example of the differences between compliance and operational monitoring. Daily or weekly or monthly measurements of total flow from a facility may be required in the MRP. In addition, for a land application site with more than one field, field-by-field flows and timing are recorded to determine loading rates. For operational monitoring, irrigation amounts (including both process/rinse water and supplemental irrigation water) are instead measured on a daily basis so that a decision about where to apply facility flows for the following day can be made. This decision relies on the additional monitoring information for a more in-depth analysis that takes into account time of last irrigation, soil moisture status, current and projected weather conditions, cropping patterns, and scheduling needs for other fields within the land application program.

Table 10-1. Typical* Compliance and Operational Monitoring Activities

Sampling Category	Compliance Monitoring	Operational Monitoring
Process/Rinse water	• Total monthly flow (gallons), annual sum • Average monthly concentrations of organics, salts, nutrients	• Total daily flow (gallons) • Daily or continuous pH and EC
Residuals (Solids)	• Weekly mass applied; annual total • Average quarterly nutrients, salinity	• Weekly solids water content
Field-by-Field Loadings	• Daily to monthly process/rinse water application, inches • Annual solids loading, pounds • Calculation of organic, nitrogen, and salt loadings	• Daily to monthly supplemental irrigation water application, inches • Daily to monthly climate data (precipitation, evapotranspiration)
Soil Testing	• Annual or semi-annual chemistry, nutrients, salinity	• Annual available P, available K for crop nutrient supply analysis • Periodic soil moisture readings
Crops	• Harvest dates, biomass yield, and nutrients removed by field	• Annual tissue ash weight, total N
Groundwater	• Quarterly water level and constituents of concern for each well • Annual general minerals, BOD or TOC for each well	• BOD or elevated TOC in groundwater indicating broken seal or short-circuiting • Long term trends in compliance monitoring results may be used in determining operational changes.
Routine Inspection Needs	• Odors or spills	• Pumping system operating pressures, field operating pressures, proper operation of irrigation system, leaks along pipeline, ponding, crop health, runoff, etc.

**For risk category 2 or 3 process/rinse sites. Monitoring at risk category 1 sites will normally be less intensive and less frequent than the values shown in the table.*

In developing detailed monitoring programs, the discharger may wish to consult several land treatment system design texts and manuals (Asano and Pettygrove, 1984; Crites et al., 2000; EPA, 1995; EPA, 1981; EPA, 2006; Idaho Department of Environmental Quality, 2005). Each of these addresses monitoring in a general way. The discussion of site characterization and design principles provides valuable background for how a land treatment system should function and what data collection would assist the operator in managing a system.

10.1.1 Facility Sampling Plan

Successful land application sites are almost always monitored in accordance with a site-specific sampling and analysis plan. A sampling plan may be required by a facility's WDRs and MRP. The sampling and analysis plan is developed to document and provide detailed guidance regarding monitoring requirements, analytical/measurement methods, sampling frequency, analysis, and reporting. The plan should contain a description of both measurement protocols for regulatory compliance and those used for operations monitoring. Table 10-2 summarizes the suggested contents of the sampling plan. The plan should provide necessary information only; too much detail may make the document unwieldy and limit its usefulness as a reference.

The sampling plan should address the key media to be monitored. For a land application system, this usually includes soil, water, groundwater, and crops. For each of these, the plan should specify required measurements, frequency of measurements, location of sampling, and other special instructions. The sampling plan should also include procedures, instrument calibration, sample shipping and chain-of-custody procedures, review of data upon receipt, etc. Detailed supporting material, such as standard procedures for sampling and sample handling or equipment calibration instructions can be included as appendices. Sampling plan appendices often include the site health and safety plan, a reference list of analytical methods, example data forms, and a copy of the WDRs and MRP.

Table 10-2. Sampling and Analysis Plan Outline

Section	Contents
Introduction	• Purpose and scope of the sampling plan • Site location maps and access instructions • List of facility and emergency contact names
Basic techniques and information	• Sample shipping protocol, chain of custody, sample holding times (usually obtained from lab) • Schedule of sampling dates and reporting obligations • Data analysis procedures • Quality control/quality assurance program
Requirements by sample medium	• Sections for each: process/rinse water, soil, crop, and groundwater • Each section should address: equipment and supplies, sampling technique, in-field monitoring measurements, sampling location(s), frequency of sampling, sample preservation, required laboratory tests, QA/QC needs, additional observations
Possible Appendices	• Health and Safety Plan • Example data collection forms, chain-of-custody form • Detailed description of groundwater sampling methods (eg. EPA 1995) • Copy of the facility's Waste Discharge Requirements and Monitoring and Reporting Program

10.2 Water Monitoring

WDR permits issued to a facility for land application routinely require measurement of flow and water quality parameters. In addition, more detailed observations are needed to document timing and distribution of flows. This section addresses monitoring for flow and water quality that may be required under the WDR permit and/or recommended for evaluation of the land application system operations and water distribution management.

10.2.1 Flow and Volume Measurements

Detailed measurements of process/rinse water flow are required to determine irrigation volumes and field constituent loading rates. Monitoring of any supplemental water flow, if used when the process/rinse water effluent is not sufficient to meet all irrigation water requirements, is also important. Along with flow measurements, monitoring water in storage and tracking climatic factors will enable a site water balance to be calculated. Flow and volume monitoring is summarized in Table 10-3.

Table 10-3. Water Flow and Volume Monitoring

Parameter	Measurement
Process/rinse water	Process/rinse water flow*
Supplemental irrigation water	Applied volume
Lagoon or storage pond	Water level in relation to maximum and minimum operating levels
Field by field application amounts	Process/rinse water application Supplemental irrigation water application Visual inspection for runoff, equipment malfunctioning, standing water, erosion
Pumps and pipelines	Routine visual inspection for leaks Routine pressure checks to identify leaks, other equipment failures, need for maintenance
Climate	Precipitation* Evapotranspiration*

** Recommended frequencies are monthly for risk category 1, weekly for risk category 2, and daily for risk category 3. Climate data is typically available through CIMIS (http://wwwcimis.water.ca.gov).*

Flow monitoring for a process/rinse water application site is typically conducted at a central, accessible location where process/rinse water exits the facility. Ideally, there should be one discharge location identified for sampling. Table 10-4 outlines methods used to measure process/rinse water flows and summarizes the advantages and disadvantages of these methods.

Table 10-4. Flow Measurement Methods

Method	Alternatives	Advantages/Disadvantages
Intrusive flow meters	• Impeller, paddle wheel • Hot wire anemometer	• Intrusive devices can clog with solids or from biological growth; higher friction loss/pressure drop • Low pH or high Electrical Conductivity can cause failure of sensing components resulting in higher maintenance
Non-intrusive flow meters	• Magnetic • Ultrasonic/Doppler	• These sensors have no parts in the flow • Higher capital cost: often, these are used at main pump station and alternate methods are used for individual fields
Open channel flow measurements	• Weir-type • Parshall flume	• Requires controlled channel to establish proper conditions for measurement • Simple, reliable operation; measurements can be recorded continuously
Incoming water supply correlation	• Discharge volume is estimated as a percentage of incoming water consumption	• Supply water is clean, relatively simple to measure using meters • A correlation between incoming flow, in-plant loss, and process/rinse water discharge is required
Pump run time and output calculation	• Flow for individual fields can be estimated proportionally from total flow	• Requires a master pump station flow meter or some calibration • Irrigation fields must be maintained so they operate according to specifications • Primarily applicable to sprinkler irrigation systems or surface irrigation using siphon tubes or gated pipe
In-field methods	• Rain gauge/catch cans in individual fields	• Approximates net irrigation (amounts actually received) rather than gross irrigation delivered • Rain gauges are applicable to sprinkler irrigation only

Direct flow measurement devices provide reliable data when properly installed and maintained (including periodic inspection, preventative maintenance, and calibration). The type of measurement device or flowmeter selected depends upon the flow conveyance used in the facility. Direct measurement of the process/rinse water flow is usually accomplished using either flow metering for process/rinse water conveyed in a pressurized pipe, or open channel flow measurements.

The type of meter installed should allow measurement of the instantaneous flow rate of process/rinse water and record the total volume. This type of meter is known as a totalizing flowmeter. Flow measurement requires sufficient straight length of pipe or channel to develop uninterrupted, smooth laminar flow to provide consistent and reliable data. Details of requirements for specific measuring devices can be obtained from manufacturers' specifications or, in the case of open channel flow, an engineering hydraulics text (e.g. Dingman, 1994). Typically, a straight length of approximately ten (10) diameters should be available upstream of the flowmeter and the piping should remain straight for approximately four (4) pipe diameters downstream.

Flow measurement in pipe applications is accomplished using sensing equipment of two general types: intrusive and non-intrusive. Intrusive sensors that make a direct measurement of the fluid within a pipe are based on a variety of sensing technologies, including flow measurement using an impeller/paddle wheel, pressure against a transducer, a venturi meter, or cooling of a hot wire with known current applied. For a detailed explanation of the technical principles underlying these instruments, the reader is referred to manufacturers' information (e.g., Omega Engineering, 1992).

A disadvantage of intrusive flow measurement devices is the effect of process/rinse water on the sensor itself. Since process/rinse water is often contains solids, sensors can accumulate material that can result in incorrect flow readings. If process/rinse water pH is low or electrical conductivity (EC) is high, the sensing element may deteriorate over time. Intrusive measurement devices require on-going data review and inspection to verify the proper functioning and more frequent calibration and preventative maintenance may be required. Intrusive flow measurement devices are often less expensive to install than other metering methods, however, operating and maintenance expenses may be higher and reliability lower.

Non-intrusive flow measurement devices are becoming more widely used. Although these devices, which use sensors that do not have direct contact with process/rinse water and are often more expensive to purchase and install, they have several advantages. Common non-intrusive sensing technologies include magnetic flowmeters (known as "mag meters") and ultrasonic/Doppler type sensors. For measurement of process/rinse water with high solids content, the ultrasonic transit type is recommended because solids can interfere with the signal transmission in the Doppler type. Manufacturers of "mag meters" and ultrasonic flowmeters include Rosemount and Peak, respectively.

Open channel flow measurements are used for both total flow measurements in some facilities and often to measure the flow distributed to individual fields under surface irrigation. Open channel flow measurement devices typically direct the flow through a well-defined channel shape and past a flow restriction to allow measurement of water elevation behind a weir or the velocity of flow through the restriction (Dingman, 1994).

In the absence of direct flow measurements, a number of other methods are used to estimate process/rinse water discharge flows:

- Discharge flow can be estimated as a percentage of the facility's incoming water supply. This method requires accurate measurement of incoming flow and calibration to establish losses of water, including use of water in the product, between the incoming water supply and outgoing process/rinse water.
- For applications where process/rinse water is pumped, flow estimates can be made based on pump specifications and using an hour-meter to measure duration of pump operations. Measurement of pump discharge pressure to verify the actual operating point (and flow) is recommended. This method also requires initial calibration and periodic calibration checks.
- For facilities with storage and intermittent flows, methods based on change in storage volumes can be used. The change in water level in the storage tank or pond is multiplied by the storage tank's or pond's surface area to estimate volume change. This method requires infrequent level changes and separate inflow and discharge cycles to allow accurate estimation of volume changes and flows. If incoming flow to storage tank or pond is often present, then this is not a good alternative.
- Flow can also be estimated using in-field measurements of the applied process/rinse water. This method is discussed in the following section.

10.2.2 In-Field Irrigation Water Measurement

For land application systems, total facility flow and the distribution of process/rinse water among irrigation fields (for facilities with multiple fields) should be measured. This is important for calculating hydraulic and other constituent loadings for the land application area and to avoid application rates that would result in leaching. The type of application method (pumped conveyance, surface irrigation, sprinklers, etc.) influences the choice of in-field distribution monitoring method. The most commonly used flow measurement methods were listed in Table 10-4, and are further described in this section. These typically involve either direct or indirect measurement, as detailed below.

Direct Measurement. For systems where process/rinse water is pumped to the field(s), the direct measurement flowmeters described in the previous section are appropriate for in-field flow measurement. Use of hour-meters and estimation of flow from pump discharge and system pressure data is also feasible for estimating in-field distribution of water. Use of on-going pressure measurements in conjunction with this method is recommended because process/rinse water suspended solids may affect system pressures and water delivery by restricting flow in the pipelines or plugging sprinkler nozzles or gated pipe openings. Monitoring pressures in the field can be combined with performing on-going, routine maintenance/inspection of the irrigation system.

For a facility using surface irrigation methods, flow measured in major distribution system pipes or ditches can be proportioned by area irrigated assuming that gated pipes or siphon tubes are set in a reasonably uniform manner. The estimates of field flows must take into account the loss and return or "tailwater" flow, if return of the tailwater from the end of the irrigated area is practiced.

Indirect Measurement. Indirect measurement methods measure or estimate "net irrigation" or the amount of water actually reaching the field. Net irrigation accounts for losses between the point of discharge to the irrigation system (called "gross irrigation") and actual application in the field. These methods provide data useful for agronomic and irrigation decision-making and can provide estimates of in-field variability.

In the most common method, the soil water balance method makes use of weekly (or more frequent) measurements of soil water supply. This dataset is used to calculate water additions or losses using the following equation, where a positive net irrigation value indicates the amount applied:

$$\text{Net Irrigation} = (\text{Stored soil water this date} - \text{Stored soil water last date}) - \text{Precipitation} + \text{Evapotranspiration} + \text{Percolate Loss}$$

All inputs are in inches of water. Stored soil water is calculated by adding the series of soil water measurements taken at different depths through the crop root zone. The net irrigation calculation provides information to assess both the irrigation amount and the soil water available to crops. This information is also used for irrigation scheduling. Soil water measurements from the bottom or below the root zone can be used to assess whether leaching has occurred.

10.2.3 Climate Monitoring

Climate data, specifically, precipitation and evapotranspiration data, are used to schedule irrigation and as input to some of the indirect methods of applied water monitoring discussed above. Local climate data are generally not collected by individual facilities, but instead are obtained from the following and other sources. The State of California has an excellent network of National Weather Service stations for this data (Western Region Climate Center). The University of California Cooperative Extension Service has an excellent agricultural weather network (California Irrigation Management Information System) that maintains weather data and irrigation scheduling tools for use by agriculturists and other irrigators.

10.2.4 Process/Rinse Water and Supplemental Irrigation Water Quality Monitoring

The requirements for process/rinse water quality data specified in the facility's WDRs generally focus on data needed to calculate field loadings and for evaluating potential impacts to groundwater quality. The MRP generally specifies analytical procedures and the required frequency of monitoring. If these are not specified, the facility operating personnel must specify them. Typical water quality monitoring parameters and frequencies for process/rinse water are given in Table 10-5. Typical water quality monitoring for supplemental irrigation water and process/rinse water related facilities are given in Table 10-6. The rationale for monitoring these constituents is addressed in Chapter 4, and load calculation procedures are explained in Chapter 7.

Table 10-5. Typical Process/Rinse Water Quality Monitoring Parameters and Frequency

Parameter	Objective: Compliance (C), Operational (O) or Both (B)	Risk Cat.	Typical Frequency	Comment
pH	B	1	Monthly	Low pH may be used as an indirect indicator of anaerobic conditions.
		2	Weekly	
		3	Daily or continuous	
EC	B	1	Monthly	The EC is primarily a result of the dissolved inorganic ions in the sample – measurement can be correlated with FDS and with TDS when BOD is negligible.
		2	Weekly	
		3	Daily/cont.	
Temperature	B	all	Process specific	Often not of critical importance
BOD/COD	C	1	2 / year	BOD loading rates assigned in WDRs should reflect site assimilation capacity and need to prevent nuisance odors. COD is a good proxy for BOD for high frequency characterization.
		2	2 / month	
		3	Weekly	
TSS	C	1	2 / year	Higher TSS levels can result in fouling of pipelines and nozzles. High TSS may not be distributed well with border strip irrigation.
		2	Monthly	
		3	2 / month	
FDS	C	1	2 / year	Measurement of the inorganic portion of TDS, without the organic fraction, is important; FDS, measured by heating a sample to eliminate the organic fraction, does this.
		2	Monthly	
		3	Weekly	
Salt ions	C	1	Initial	Sum of ions is a good way to directly measure the inorganic portion of TDS. Important ions include Ca, Mg, Na, K, Cl, SO_4, HCO_3
		2	Annual	
		3	2 / year	
Nitrogen	B	1	Annual	TKN, NO_3-N, NH_3-N should be measured
		2,3	Monthly	

Table 10-5. Typical Process/Rinse Water Quality Monitoring Parameters and Frequency

Parameter	Objective: Compliance (C), Operational (O) or Both (B)	Risk Cat.	Typical Frequency	Comment
Phosphorus	O	all	Annual	Phosphorus is measured for crop nutrition
Others	O	all	Annual or less frequently	Other parameters, such as boron or molybdenum, which affects plant health, can be important to monitor. Monitoring for trihalomethanes may be required if chlorine or bromine are used as principal disinfectants in the factory. If there is a risk of cross-connection with a sanitary sewer or other source of pathogens, initial coliform bacteria sampling may be required.

Definitions: Biochemical Oxygen Demand (BOD), Electrical Conductivity (EC), Total Kjeldahl Nitrogen (TKN), Nitrate-Nitrogen (NO_3-N), Ammonium-Nitrogen (NH_4-N), Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), Sulfate (SO_4), Chloride (Cl), Bicarbonate (HCO_3), Fixed Dissolved Solids (FDS), Total Dissolved Solids (TDS)

Table 10-6. Typical Supplemental Irrigation Water and Other Process/Rinse Water Quality Related Monitoring

Source or Facility	Parameters
Supplemental irrigation water	• Minimum testing is annual for nitrogen species, salt ions (Na, Ca, Mg, K, Cl, SO_4, HCO_3, CO_3), BOD, other parameters known to be of concern and present (e.g. Boron)
Lagoon or storage pond	• Nitrogen species, salt ions, BOD, other parameters known to be of concern and present, water level, freeboard
Field by field application amounts	• Constituent loading can be calculated from flows and constituent concentrations

Definitions: Biochemical Oxygen Demand (BOD), Electrical Conductivity (EC), Total Kjeldahl Nitrogen (TKN), Nitrate-Nitrogen (NO_3-N), Ammonium-Nitrogen (NH_4-N), Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), Sulfate (SO_4), Chloride (Cl), Bicarbonate (HCO_3), Carbonate (CO_3), Phosphate (PO_4), Fixed Dissolved Solids (FDS), Total Dissolved Solids (TDS)

The frequency of sampling should result in generation of a data set that provides a "reasonable" characterization of the applied water. Reasonableness can be assessed by comparing the value of additional data collection against the cost. If the additional data would provide incrementally minor improvements in the characterization at a significant cost, the existing characterization may be shown to be sufficient. However, before reaching this conclusion, the degree of variability in the data must be established. With low variability in a data set, less monitoring is needed to ensure the system is operating as designed. Table 10-5 reflects cases of moderate variability. Consequently, variability is an important factor in calculating permit limits, determining compliance and setting the monitoring frequency. Various statistical methods are available to evaluate variability. The state has not specified a preferred approach. The method chosen should provide a representative computation of loading rates.

At well managed facilities, routine compliance monitoring frequency can sometimes be adjusted to reflect variability in individual parameters and best meet the reasonableness objective. For example, relatively consistent parameters could be sampled at a reduced frequency, compared to more highly variable parameters. The intent of these adjustments would be to establish a monitoring program that facilitates detection of most events of noncompliance, without requiring needless or burdensome monitoring and associated costs. This approach is called "Tiered Monitoring." Requests for facility-specific monitoring frequency adjustments should be discussed with the Regional Water Board staff assigned to the facility.

Sampling locations must be selected to allow collection of samples that are representative of the flow to be monitored. Process/rinse water quality can change from point to point within the distribution system, particularly when storage is a component. Facility personnel should consider this variability when selecting sampling points for regulatory compliance or to calculate field loading rates. For operations monitoring, samples should sometimes be collected from multiple locations within a distribution system to evaluate changes or problems such as uneven distribution.

Samples can be collected as either grab or composite samples, depending on monitoring requirements and objectives. Samples meant to represent a single point in time and give a "snapshot" of conditions at that instant are usually collected via grab sampling. Grab sampling involves filling containers manually. When samples are intended to represent daily, weekly, or monthly conditions, 24-hour composite sampling is often used. In a composite sample, process/rinse water is collected at several times over the course of the sample collection period. These individual samples are combined into the composite sample, and an aliquot is submitted for analysis.

Automated composite sampling is used when the number of samples is large and/or the staff resources for sample collection are limited. Automated sampling equipment can be purchased or leased from manufacturers such as American Sigma and ISCO. These samplers can be programmed to collect samples at specified time intervals or on a "flow proportioned" basis. With flow proportioned sampling, a flowmeter is set up to send flow signals to the sampler, and the sampling is performed when preprogrammed flow criteria are met. Criteria can include achievement of flowrates over a certain threshold or recording a specified volume of flow. Flow proportioned sampling more accurately reflects the composition of the total discharge when the discharge composition (water quality and/or flow rate) varies significantly.

10.3 Residuals Monitoring

Food processing facilities often generate significant quantities of byproduct solids (called residuals) as part of their operations. Sources of residuals may include initial screening of process/rinse water, material removed from sedimentation basins, and solids that settle in lagoons or other water storage locations.

If the process/rinse water land application site is also used for solids land application, routine monitoring of residuals is necessary for operational management to determine loading rates. Standard monitoring parameters and needs include:

- **Amount of material**. Weight of material should be recorded, along with date of generation.
- **Material quality.** Prior to land application, residuals from stockpiles should be analyzed for potentially land-limiting constituents, which are likely to be nitrogen or phosphorus. A composite sample should be collected from the stockpile and submitted to a laboratory for analysis for total solids, nitrogen species (organic-N, Ammonia-N and Nitrate-N), and total phosphorus. Portions of the sample should be collected from different areas of the stockpile to yield a representative sample.
    - **Site evaluation.** Prior to land application of residuals, soil samples should be collected for nutrient analysis as discussed in Section 10.4, soil monitoring. This helps provide an estimate of soil capacity for additional loading.
    - **Application records.** When solids are land-applied, records need to be maintained that document date, amount applied, application method, incorporation methods (if materials are mixed with the soil), and other field observations. Residuals are often applied on a wet weight basis. If this is done,

analytical data must be converted using measured moisture content. A log of the sites used for solids land application should be maintained in facility records.

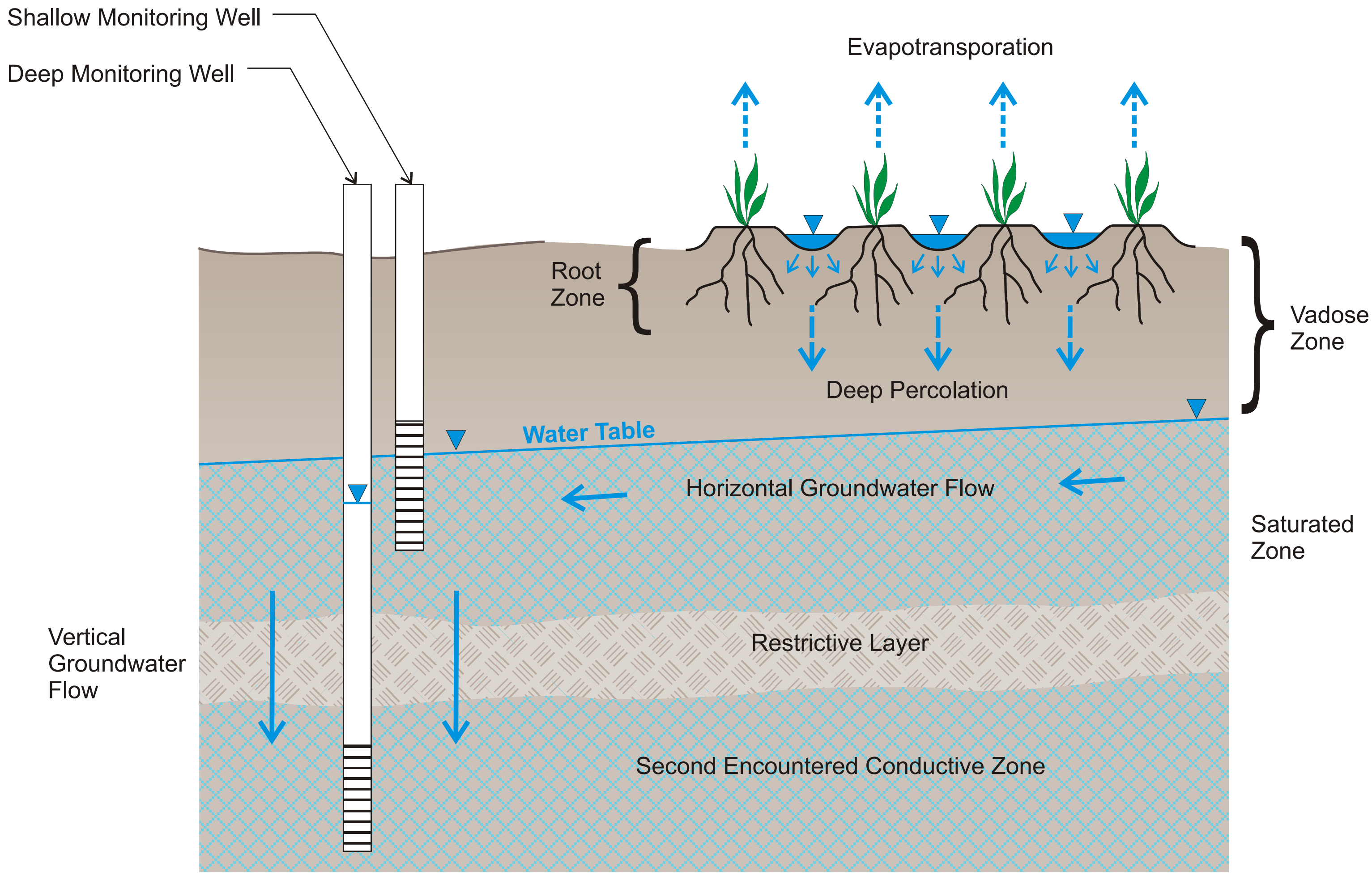
Under a Central Valley Regional Water Board Resolution regarding use of food byproducts, Stanislaus County began conducting a study in 2006 to determine the effect of the land application of food processing byproducts on water quality, and whether any changes to their program for food byproducts use are necessary to ensure protection of water quality and the environment. Results of the study, which are due to the Regional Water Board on July 1, 2007, may contribute to the understanding of best practices.

10.4 Vadose Zone Monitoring

The term 'vadose zone' is used to describe the unsaturated subsurface zone that lies above the groundwater table. The relationships between the vadose zone, saturated zone, and other defined subsurface features at a process/rinse water reuse site are illustrated in the schematic cross section in Figure 10-1.

Land application sites need to be designed and managed such that the most effective soil chemical and physical treatment processes occur within the root zone. Some water and constituents may move downward into the lower vadose zone where monitoring data may be desired; however, this monitoring is difficult to accomplish in a consistent, reliable manner due to the variability of subsurface conditions. Accordingly, monitoring wells are the primary means of assessing groundwater quality for land application system compliance purposes, except for situations where well installation would be impractical from a cost and data utility perspective. Specifically, this may occur when the land application site is underlain by "deep groundwater" (greater than 100 feet bgs, as a "rule of thumb") that would not likely be affected by surface activities for many years. In those cases it may be appropriate to use relatively more intensive soil monitoring in the vadose zone to provide an indication of ongoing effectiveness of land treatment to avoid unwanted water quality impacts. Soil monitoring should also be a part of all process/rinse water application operations to monitor system effectiveness.

Using vadose zone monitoring to estimate the actual rate of transport of constituents is considered to be primarily a research tool because considerable analysis is required to properly interpret results, and measurement methods are intricate and susceptible to error due to installation methods and operation. The best use of vadose zone monitoring data is for trend analysis of constituents of concern throughout and below the root zone. Interpretation of vadose zone monitoring data is discussed below for each monitoring technique.



BROWN AND CALDWELL	PROJECT 129633-900	SITE CLFP	Figure 10-1
	DATE 11-2-06	TITLE Schematic Cross Section of Defined Monitoring Features	

10.4.1 Soil Monitoring

Soil testing and analysis is an important part of land application site operational monitoring, especially for the vadose zone. Soils data are used for a number of purposes in land application systems:

- Assessment of nutrient supply for crops;
- Evaluation of treatment efficiency of the soil plant system;
- Evaluation of soil chemistry suitability for crop vigor and soil structure maintenance;
- Soil water monitoring to support irrigation scheduling and soil water balance calculations; and
- Assessment of the land application site condition over time.

While this information is useful for operational monitoring, as detailed further below, soil monitoring results can be highly variable on a spatial as well as a temporal scale. As a result, soil data are generally not utilized for compliance purposes when groundwater is accessible as an alternative. Groundwater monitoring provides a more reliable and accurate indication of conditions at the point of compliance. When first groundwater is deep and/or groundwater monitoring is difficult, soil sampling may be used as a surrogate for groundwater monitoring. For these cases, if soil sampling results show evidence of inadequate treatment effectiveness, groundwater monitoring may still ultimately be required.

A well-designed soil sampling program can address both environmental and agricultural production monitoring objectives. A flow chart for determining the appropriate scope of the monitoring program is provided in Appendix E. Basic monitoring parameters and the use of the measurements are summarized in Table 10-7. In-situ measurements of soil properties such as soil aeration are discussed later in the chapter.

Soil Chemical and Physical Analysis

The most common soil sampling methods for land application systems rely on removal of soil samples from within land application fields. Samples should be collected at several depths within the crop root zone. In addition, each sample should be a representative composite based on a minimum of 10 cores for surface samples and at least three cores for subsurface depths. Sampling locations should be recorded on a figure and/or using GPS coordinates for future sampling consistency.

The suggested intensity of soil sampling at an application site generally correlates with site variability and the water quality risk category for that site, as defined in Chapter 7. Suggested monitoring would include one composited soil sample taken for approximately every 50 acres for category 1 and 2 sites and one composited sample taken for approximately every 30 acres for category 3 sites. For risk category 3 sites, it is recommended that soil samples be collected in spring and fall, or following each crop harvested during the year if double-cropped. At a minimum, one set of samples per field, composited from the same subsample points each time, should be sampled. The set of samples should be from specific depth intervals representing the root zone. More samples may be needed for sites with numerous soils types. In addition, a greater number of samples should be taken at sites where soil samples are used for compliance in place of groundwater monitoring. Site conditions, variability, crop rooting depth, and management practices are also factors to consider when developing a soil monitoring program.

Table 10-7. Soil Chemical and Physical Monitoring Guidelines

Parameter	Risk Category	Frequency	Depths (feet)	Considerations
Organic matter, CEC, TKN	1	Initial	0-2	Slowly changing basic soil parameters.
	2,3	5 years	0-1, 2-3, 4-6	
pH, EC_e, NO_3-N, NH_4-N	1	Annual	0-2	Mobile constituents and good indicator parameters to assess soil fertility and process water loading capacity.
	2	Annual	0-1, 2-3, 4-6	
	3	2 / year	0-1, 2-3, 4-6	
Available K, Available P	1	5 years	0-2	Low mobility nutrients
	2,3	Annual	0-1, 2-3, 4-6	
Extractable Na, Ca, Mg, Cl, SO_4, SAR, ESP	1	5 years	0-2	Soil salinity and sodicity status parameters, some mobile
	2,3	Annual	0-1, 2-3, 4-6	

Definitions: Electrical conductivity of saturated paste extract (ECe),Total Kjeldahl Nitrogen (TKN), Nitrate-Nitrogen (NO_3-N), Ammonium-Nitrogen (NH_4-N), Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), Sulfate (SO_4), Chloride (Cl), Phosphorus (P), Sodium Absorption Ratio (SAR), ESP (Exchangeable Sodium Percentage)

The basic soil chemistry analyses are:

- **General soil chemistry.** pH and electrical conductivity are general measurements used to characterize the soil environment. These parameters are monitored to verify that they are within ranges acceptable ranges for crop growth (Chapter 5). Organic matter percentage is a slowly changing basic soil parameter.
- **Nutrients.** Nitrogen and phosphorus are commonly measured constituents. Table 10-6 provides a list of recommended monitoring parameters. Available potassium may also be tested to address potential fertilization needs. The need for fertilization and addition of soil amendments is determined using soil monitoring data (see Chapters 5 and 7 for a more complete discussion). In addition, nutrient accumulations in the soil can be an indication of potential overloading.
- **Soil Salinity.** In addition to electrical conductivity measured on a saturated paste extract, specific cations are often measured in the soil (sodium, calcium, magnesium, and sometimes potassium) to assess total salinity and the cation balance. This evaluation provides information to address possible impacts to crop tolerance and soil physical properties from process/rinse water applications (see Chapter 5 for a discussion of salinity, sodium adsorption ratio, and effects of salt on crop growth and soil properties).

Often soils laboratories will provide analytical panels of parameters that will include the parameters in Table 10-7 along with micronutrients and other parameters. Depending upon site specific soil conditions, the additional parameters may be useful in determining the suitability of certain crops and/or whether special soil amendments should be considered to enhance crop vigor.

Advanced Soil Analysis

In respect to soil properties, the ultimate goal of a land application system should be the conversion of readily available and degradable organic matter to stable organic matter. The end result should be to increase the humic portion of the organic matter in the soil. With additional research, there may be more accurate methods for assessing what is happening at a land application site by assessing specific microbial health indicators. Common research methods for measuring soil quality assess the activity of the living portion of the soil organic matter that is undergoing transformation and providing treatment. The most common soil quality research tests are:

- microbial biomass carbon composition
- microbial biomass nitrogen composition

These tests and others may become more common for land application sites as their value is proven through research.

Evaluation of Soil Sampling Data

Trend Analysis. Flow charts for soil monitoring interpretation and trend analysis are shown in Appendix E. Under good management, over time nitrate levels should be fairly stable, but there may be some variation between years. Site operators should focus on the long term trends in the soil profile. The 4 foot to 6 foot depth in the soil is the key factor to monitor for potential impacts to groundwater quality. Nitrate levels should be decreasing to depth, but fluctuations at a given depth can be acceptable when excess nitrate from one year can be recovered by crops in the next year.

Generally Acceptable Ranges. Although trend analysis is the primary tool for interpreting soil monitoring data, soil parameters can also be compared with generally acceptable ranges. When values for soil parameters are outside these generally accepted ranges throughout most of a field on a sustained basis, operational changes may need to be considered to assure ultimate protection of groundwater quality and/or crop productivity. Operational changes could have a substantial effect on soil nitrate values in less than a year, while changes to soil pH could take several years. Some suggested ranges for major parameters are given in Table 10-8. Generally accepted ranges for other constituents typically accompany soil analysis results.

Table 10-8. Generally Acceptable Ranges of Major Soil Parameters

Constituent	Generally Acceptable Range
NO_3-N (mg/Kg, post-harvest)	10 – 40
pH	5.5[b] – 8.5
EC (mmhos/cm, paste extract)	0 - 2

[a] *Acceptable soil pH can be lower for some crops, particularly in high rainfall areas with naturally low soil pH. See Table 7-9.*

Soil Moisture Monitoring

The purpose of soil moisture monitoring is to assist irrigation scheduling and to identify periods of leaching at land application sites. Soil moisture measurements are taken at more than one depth in the soil profile, because moisture content changes with depth. The overall depth and number of measurements should correspond to crop rooting depth. Measurements taken at three depths should be adequate for field crops, while additional measurements may be desirable for permanent crops. Moisture measurements should be made at a weekly to bi-weekly frequency depending on climate, irrigation system type, and monitoring technology to assess soil water status for crop growth. Because soil moisture monitoring is primarily performed for operational purposes rather than regulatory compliance, the frequency and depths of sampling can be selected based on site-specific needs. Soil moisture monitoring results are particularly useful for calibration of water balance calculations using published ET values (such as through CIMIS).

A variety of techniques exist for measuring soil moisture (American Society of Agronomy, 1986). There are a number of alternatives to consider in selecting routine soil moisture monitoring. Factors to consider in selecting a method are cost, ease of operation, and reliability. Commonly used methods for routine soil moisture monitoring include:

- **Gravimetric.** Gravimetric sampling, which consists of collecting samples from the soil using a soil auger or soil probe, then weighing and drying the samples to determine moisture content by difference between the wet and dry weights. This method can be used, but it is labor intensive, disturbs the soil profile for each measurement, and requires time to dry the samples. It is not widely used as a routine monitoring tool. It should be noted that the field investigation of the soil by sampling or just digging for inspection is a valuable exercise. Experienced irrigators often do this to observe the soil water status or estimate water supply (and need for irrigation) using the "feel" method.
- **Electrical Resistance Sensors.** These sensors have long been used to supply data for irrigation scheduling. They are inexpensive, can be recorded for automated operation, and are fairly reliable once calibrated.
- **Neutron Probe.** The neutron probe is a device that measures hydrogen in the soil which correlates with volumetric soil water content. This device is in common use in the agricultural industry. The neutron probe is easy to use and allows fairly rapid measurement of soil moisture conditions by depth in the field. As a result, this method is ideal for making rapid decisions regarding soil moisture status and need for additional irrigation.
- **Time Domain Reflectometry (TDR) and Frequency Domain Reflectometry (FDR).** These soil moisture measurement techniques are often selected for automated soil moisture monitoring installations. In a standard installation, an electronic device is installed in the field with sensors at several depths measuring electrical properties of the soil, which vary with soil water content. The sensor readings are recorded using a portable data logger that is left in the field with the equipment. Several equipment suppliers currently offer automated installations of this type and will record the data for a service fee.

In-situ measurements such as neutron probe, TDR, FDR, electrical resistance, capacitance, and heat dissipation methods (American Society of Agronomy, 1986) are generally preferred.

10.4.2 Soil Water Balance

The soil water balance calculation for estimating net irrigation is covered in Section 10.2. It is used to determine overall soil moisture status and the need for irrigation. This calculation is routinely used to assess when irrigation is required for a given field based on past conditions, current soil moisture status, and likely future weather conditions. Soil water balance calculations can also be used to estimate the amount of deep percolation.

10.4.3 Soil Water Sampling Using Lysimeters

A comparison of vadose zone sampling techniques is presented in Table 10-9. Additional technical information is available in ASTM standards (ASTM, 1992). The lysimeter methods in Table 10-9 are designed to measure concentrations of constituents in the water in the vadose zone soil pores. Because of the high costs and high spatial variability of results, lysimeter monitoring related to land application sites is best suited to use in areas with a high degree of control over water applications and cultural practices, such as research or test plots.

Suction lysimeters are relatively simple to operate. Samples are collected from the device by applying a vacuum (generally for 24 hours prior to sampling), which draws soil solution into the lysimeter and samples can then be collected. The sample is analyzed to determine concentrations but interpretation of this "simple" result is complex.

Concentrations of constituents in samples from suction lysimeters are substantially affected by the moisture content of the soil. Samples taken from soil at saturation are much more representative of mobile water in the soil profile, while samples taken from partially drained or dried soil are more representative of tightly bound, immobile pore water. Concentrations of constituents in this immobile water are affected by evapoconcentration and other factors, and are not representative of water percolating to groundwater.

Interpretation of suction lysimeter data should take these factors into account. Moisture content and spatial variability factors are reasons why suction lysimeters may be reasonable tools for detecting the presence of constituents of concern, but are marginal tools for quantifying the transport of constituents through the vadose zone.

Suction lysimeters often appear to be a low cost monitoring choice because the basic sampling equipment is relatively inexpensive. This is often not the case when replicate installations to provide representative results and the requirement to provide an accompanying soil moisture content measurement are included in the cost of monitoring.

The more capital intensive pan, basin, and wick lysimeters offer some improvements over the suction lysimeter method because they provide a solution sample that has been collected as a result of downward flow of water. They provide both a sample for chemical analysis (although sample holding time exceedance may weaken results) and an estimate of water flow based on the volume of water collected. Depending upon soil characteristics and installation, these types of lysimeters can also be adversely affected by soil-water flow bypass and/or preferential flow. Lysimeters are often considered to be a permanent installation because of the relatively complex installation procedure.

Table 10-9. Vadose Zone Sampling Techniques Comparison

Method	Description	Advantages/Disadvantages
Soil Sampling	Soil samples are collected and analyzed for general chemistry, salts, nutrients	+ Simple and reliable - Samples totals, not just solution fraction - Destructive sample - Requires a soil water balance calculation to determine whether flow occurs
Suction Lysimeter	A porous ceramic tube is placed in the soil so soil solution samples can be collected and analyzed	+ Inexpensive, simple technique to implement - Extracts soil solution that is not mobile - Known to have large measurement variability - Requires a soil water balance calculation or correlation with soil moisture to determine whether flow occurs
Pan Lysimeter	A small collection pan (1-5 ft^2) is buried at a selected depth so that soil solution samples can be collected via gravity drainage for analysis. Side wall extending above the device may improve performance	+ Collects draining water during flow events + Provides a measure of both flow and water quality + Moderate variability among replicate samples - Relatively expensive installation costs - Some water flows around the top of the side wall - Side wall can cause preferential flow - Creates disturbed soil conditions
Basin Lysimeter	A large collection pan (50-400 ft^2) is constructed and covered with soil so that soil solution samples can be collected via gravity drainage for analysis	+ Samples draining water during flow events + Provides a measure of both flow and water quality - Installation creates disturbed soil conditions + Large sample decreases variability - Long-term installation generally done prior to starting a project
Wick Lysimeter	A porous wick designed to simulate the water retention characteristics of the soil is buried at a selected depth so that solution samples can be collected using a low negative pressure.	+ Collects soil solution at near zero water potential - Upper side wall can cause preferential flow - Creates disturbed soil conditions

10.4.4 Geophysical Surveys

Electromagnetic (EM) geophysical surveys can be used to obtain electrical conductance values for the shallow soil zone. While these surveys are not used as part of regular site monitoring, they can provide a useful snapshot of salinity on numerous transects across an entire site. They are far more economical than direct soil sampling for this purpose. The EM surveys can also be calibrated with results from direct soil samples at a few discreet locations. Where salinity is a major concern, EM surveys can be used at long term (5 to 10 year) intervals to measure trends in soil salinity or to compare soil salinity between sites.

10.4.5 Other In-Situ Vadose Measurement Techniques

Other in-situ vadose zone measurement techniques include soil aeration measurement, soil gas sampling, and direct soil-water parameters measurement using selective electrodes. These methods are customarily used for more research-oriented purposes than basic sprayfield monitoring; they are briefly mentioned here only for completeness.

Soil aeration status is measured to assess potential concerns related to organic BOD loading at land application sites. Analytical methods are summarized in available soils texts (American Society of Agronomy, 1986). The most common methods incorporate measuring air filled pore space or the resistance to oxygen movement in the soil.

Some soil-water parameters such as pH, oxidation-reduction potential (ORP), and specific constituents can be measured directly by selective electrodes placed in the soil. However, the selective electrodes typically have a short life span in field conditions.

Soil gas can be sampled using a probe and analyzed using a gas chromatograph or other gas-specific instrument. The gas concentrations can provide information helpful in determining the levels of microbial activity in the soil. Oxygen and carbon dioxide provide the most general information on aeration and soil microbial respiration. Nitrogen can be used to infer whether denitrification is occurring. At this time, soil gas sampling is primarily a research tool. Additional research into the development of inexpensive buried line-source samplers could be useful for moving soil gas sampling into a realm similar to lysimeters for use in test plots and as an adjunct in high intensity monitoring situations.

10.5 Groundwater Monitoring

The need for and scope of groundwater monitoring is dependent upon facility type and size, wastewater characteristics, management, loading rates, and aquifer and site characteristics. There are circumstances where groundwater quality monitoring may not be necessary, as in the case where wastewater constituent loading rates are below levels of regulatory concern (i.e., de minimus rates). A small facility with low-strength wastewater loaded at low discharge rates would have a limited potential to contaminate groundwater, therefore may not need as extensive a monitoring program as a larger and more complex facility that land-applies high-strength wastewater at high rates.

If required, groundwater monitoring will be in the MRP for the facility (Chapter 3). Groundwater monitoring programs, which include sampling frequency and the required analytical parameters, are established for a facility in direct consultation with the Regional Water Board. Details regarding the establishment of a program and methods for monitoring well construction, hydrogeologic evaluation and monitoring are in accordance with agency guidelines and industry standards (see Appendix D). Often, a facility will retain a professional hydrogeologist to assist them in developing an appropriate program, and/or will engage environmental consultants or technicians to conduct groundwater sampling. The general objectives of a groundwater monitoring program are:

- Develop a monitoring network to document background groundwater quality, depth to groundwater, and flow direction in the local area.

- Provide upgradient and downgradient groundwater monitoring locations so that potential facility impacts to groundwater can be assessed.
- Ensure that the waters of the state which would otherwise be useable are protected for existing and projected future beneficial uses.

There are no definitive regulatory guidelines for determining the number and configuration of monitoring wells needed for a facility's land application area. The number, locations and construction details for monitoring wells will depend on the size of the application area, loading rates and hydrogeologic conditions underlying the application site. Typically at least one upgradient and two downgradient wells are necessary, with a point of compliance near (within 150 feet of) the downgradient boundary of each contiguous land application area. An example of how monitoring wells should be positioned in relation to a land application area, assuming that the average groundwater gradient and flow direction are known, is shown in Figure 10-2. An example of how shallow monitoring wells should be screened relative to the water table is shown in Figure 10-3. Monitoring well screens should also be placed to accommodate fluctuations in the groundwater table.

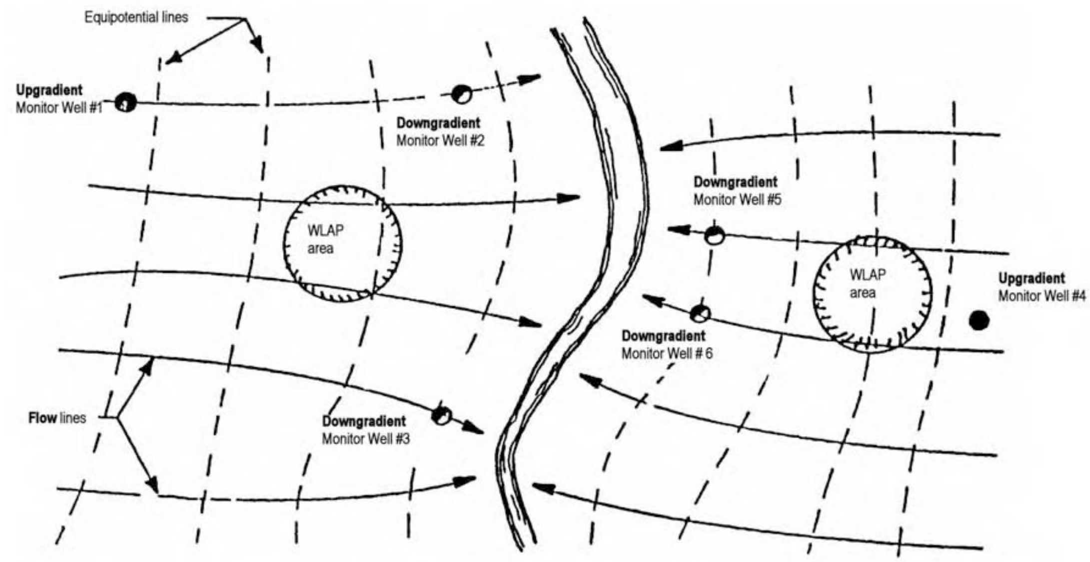
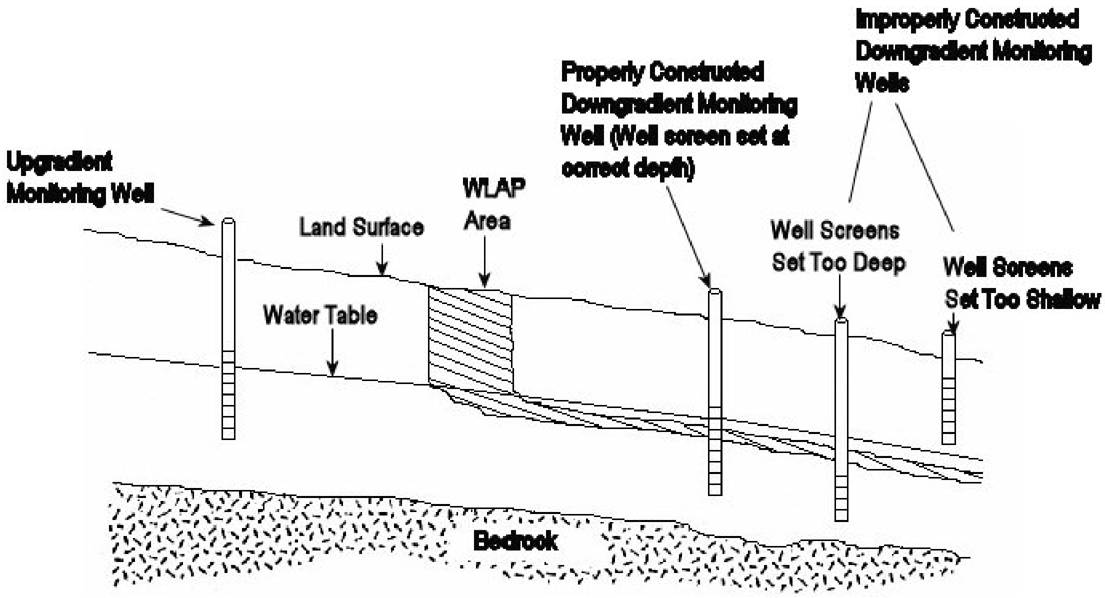


Figure 10-2. Improper (left) and Proper (right) Locations for Groundwater Monitoring Wells

Source: Idaho Department of Environmental Quality (2005)

As noted above, for situations where process/rinse water loading rates are low (lower than agronomic rates, for example), groundwater monitoring may not be necessary. For sites in sensitive areas (fragile groundwater resources, shallow water tables, etc.), monitoring wells will likely be mandatory. In cases where groundwater flow directions are not well understood, the first wells to be installed are sometimes used for initial establishment of groundwater gradients and flow directions. Based on data from these wells, additional, more appropriately located wells may be installed for ongoing monitoring.



Source: Idaho Department of Environmental Quality (2005)

Figure 10-3. Proper and Improper Placement of Screens for Monitoring Wells Completed into First Encountered Groundwater

When determining well locations, approximate groundwater elevations and grab samples collected via temporary push-sampling methods, such as Hydropunch™ or Geoprobe™, can provide useful information. Because the groundwater samples collected using these techniques are not considered fully reproducible, the results cannot be directly substituted for ongoing monitoring well sampling data; however, the grab samples can provide a useful indication of groundwater conditions to aid in decision-making and identification of appropriate well locations. The grab samples can also provide important information on the range and variability of preexisting or upgradient groundwater quality.

The suggested number of monitoring wells needed at an application site generally correlates with the water quality risk category for that site, as defined in Chapter 7; these guidelines are shown in Table 10-10. Once a monitoring well network has been installed, routine monitoring is straight forward. Sometimes initial monitoring results may indicate the need for an additional downgradient well to properly capture potential effects from the process/rinse water application site.

Table 10-11 provides a summary of monitoring recommendations. The Environmental Protection Agency has provided detailed guidance for sampling (USEPA, 1995B) and analysis methods (USEPA, 1983, 1982). The facility's sampling and analysis plan should cover groundwater sampling in specific detail. Equipment selection and preparation, sample handling procedures, and data management must be outlined to provide high quality data and comply with regulatory requirements.

Table 10-10. Groundwater Monitoring Well Guidelines by Risk Category		
Water Quality Risk Category	Typical Initial Requirements	Site Specific Considerations
1 (lowest)	No monitoring wells required	
2	1 upgradient well 2 downgradient wells	Augment w/reconnaissance survey (push-sampling) at larger sites to assess potential variability
3	1 upgradient well 2 to 3 downgradient wells	Augment w/reconnaissance survey (push-sampling) at larger sites to assess potential variability. For larger sites, one of the downgradient monitoring locations may include a well screened in the second encountered groundwater aquifer to provide vertical gradient data. Initial monitoring may indicated the need for additional wells.

Note: All downgradient monitoring wells should be at least 50 feet, but not more than 150 feet from the edge of an application area, if practicable. Upgradient wells should ideally be more than 100 feet from the edge of the application area, if practicable.

Table 10-11. Groundwater Monitoring Program Needs	
Issue	Considerations
Monitoring locations	Selected to assess effect of land application on water quality by comparing upgradient quality to downgradient water quality, depth to groundwater, and flow direction. Additional locations near potential sources such as storage ponds may be included.
Groundwater characterization	Examination of cores and cuttings during drilling for well installation provides information on subsurface conditions. Monthly water level and water quality sampling for one year is common. Special tests for aquifer flow properties may be included.
Routine sampling	Frequency: Quarterly is common initially; semi-annual is common thereafter. Equipment: pump or bailer, field measurement meters. Sample handling, and quality control are specified in Sampling and Analysis Plan.
Sample analysis[a]	Field measurement of water level, pH, EC, Temperature with portable equipment. Laboratory analysis as per MRP and sampling plan. Analysis for other constituents identified during characterization. Analysis of individual salt ions may be of value on an annual basis.
Data evaluation	Identification of possible erroneous values (due to lab error, unrepresentative sampling) to be resampled. Statistical calculation of average, standard deviation, compliance statistics for constituents. Examination of the data for trends using statistical and visual methods (EPA, 1995b).

[a] *Standard Methods or USEPA analytical procedures are most common.*

After the local area has been characterized using all available wells, it should be possible to decrease monitoring to include only those locations and parameters that provide useful information or meet reasonable regulatory requirements, as discussed above in Section 10.2.4. To have monitoring wells removed from a monitoring program once they have been installed, the local Regional Water Board staff must be consulted for approval.

10.5.1 Groundwater Age Analysis

For risk category 3 sites, it is often prudent to obtain data on average groundwater age. Average groundwater age can be estimated from tritium and helium 3 measurements and/or chlorofluorocarbon (CFC) concentrations. These constituents were introduced into the atmosphere within about the last 50 years, so their concentrations provide good indications of recent groundwater ages. While these tests are expensive, groundwater age information can be very useful for understanding the background hydrological conditions and natural background quality on the site. Groundwater age can also be useful when interpreting monitoring data to provide insight on the lag time between loadings on the land application site and potential impacts to groundwater quality constituent concentrations in monitoring wells. For best interpretation, groundwater age analysis is recommended at the first sampling of new monitoring wells and every five years thereafter.

10.5.2 Groundwater Data Evaluation

Although groundwater quality data typically forms the basis for permit compliance, the proper evaluation of groundwater quality data often is not simple. Establishing a cause and effect between process/rinse water loadings and groundwater quality results requires an understanding of transport conditions gained by watching trends of key parameters over time.

Background Groundwater Quality

Establishing "background" groundwater quality can be very important for both compliance purposes and for the proper interpretation of ongoing monitoring results. "Background" applies to groundwater that is representative of conditions in and around the site, but has not been affected by process/rinse water application on the site. Background samples can be collected solely from monitoring wells or from a combination of monitoring wells and push-samplers that are located either upgradient or sidegradient of the site. Alternatively, samples can be collected from any location within or surrounding the site if an adequate number of temporally independent samples can be collected prior to the application of process/rinse water to the site. Statistical procedures are used for establishment of the upper limit of background groundwater quality. Natural (pre-1968) background quality may also need to be differentiated if representative data are available. The investigation and establishment of background groundwater quality is usually best done by a professional hydrogeologist, engineer, or statistician in accordance with USEPA and California Title 27 methods. This is often done by calculating the upper prediction limit or upper tolerance limit of background groundwater quality values. See Section 7.6.3 for additional discussion of background groundwater quality as related to salinity.

Trends

Groundwater quality trends should be plotted over several years to determine if there are ongoing trends. Increasing concentrations of constituents of concern may indicate the need for changes in loading rates or operational practices. Seasonal trends in both groundwater elevation and quality should also be evaluated for water quality in shallow monitoring wells.

Permit Exceedances

Groundwater quality limitations violations occur when a compliance sample analysis result exceeds a level specified in the permit for a constituent. Permits may be written such that a first exceedance will not generate enforcement action or penalties. An exceedance may be treated as a warning signal that prompts further actions such as an acceleration of monitoring frequency, assessment of wastewater management practices, evaluation of the treatment capabilities and maintenance of the land application system, and assistance from qualified experts.

10.6 Crop Management and Biomass Removal

Crop management is a critical factor in operating and maintaining a land application system. A healthy and productive crop is required to remove nutrients and salts as part of soil-plant treatment of process/rinse water. Although it is of secondary importance, the value of crops harvested from the site may provide an additional incentive to assure that proper attention is paid to the land application fields.

Good plant vigor indicates adequate soil oxygen, although poor plant vigor may or may not indicate inadequate soil oxygen, depending upon other factors. Nutrient shortages, ion toxicity, and diseases may exhibit specific responses in plants that can be recognized by agronomists or experienced farmers. Attention to crop needs including irrigation water and nutrients will result in better management for agricultural production, process water treatment, and environmental protection objectives.

Much of crop management is accomplished in the same way for a land application site and conventional agricultural operations. Because process water supplies organic fertilizer, crop responses to process water irrigation differ from those in a conventional irrigation water/inorganic commercial fertilizer scenario. Recommendations for routine monitoring of crops are provided in Table 10-12. Daily visual observations are important for ongoing management activities and should be maintained in a field log for reference. The actual measurements required for crop monitoring are simple. These include biomass removal (harvest weight) and samples of the crop to determine the amount of constituents removed.

Table 10-12. Example Crop Monitoring Parameters

Parameter	Description
Crop management chronology	Dates of cropping activities should be logged including date of planting, date of harvest, dates of primary tillage operations, application of fertilizer, observations of crop health
Biomass removed	This can be accomplished by counting bales, bushels, trucks or other field-scale measurements. Water content should be determined so that data can be converted to a dry weight basis for constituent removal calculations.
Constituents removed	Test crops for TKN, NO_3-N and other nutrients by tissue analysis. Tissue samples should be composites of at least 10 equal-size samples of harvested portion of the crop, packaged to prevent moisture loss. Salts can be evaluated if appropriate for a specific site (by measuring salt ions or ash weight).

Because nutrient uptake is a primary function of the crop for land application purposes, analysis for nitrogen is recommended.. Total and available nitrogen in process/rinse water differ because the organic nitrogen is not entirely available to crops and some is lost in conversion processes (Crites et al., 2000; EPA, 2006). Available net nitrogen loading and crop uptake should be nearly equivalent, at least when averages over several years are being considered.

Inorganic salt management is receiving increased attention from Regional Water Board staff, so documentation of salt removal through monitoring is appropriate. The crop salt uptake can be incorporated into an overall salt balance and compared with planning assumptions.

For some crops, such as sudan grass and other forage crops, the nitrate and potassium content of the crop may be too high for a single-source feed to dairy cows or calves. It is recommended that tissue samples be taken for these two constituents prior to use of sudan grass as feed.

10.7 Routine Maintenance, Inspection and Record-Keeping

Routine monitoring, including thorough daily inspections, is recommended to identify operational problems at an early stage and gather data to make irrigation and cropping decisions. Each facility and process water manager should develop a customized inspection form. Table 10-13 provides an example inspection form useful for guiding daily inspections.

Table 10-13. Sample Routine Maintenance Inspection Checklist for Land Application Sites

Feature	Inspection	Observation & Recommended Action
Facility Discharge	Check primary screens for solids accumulation, amount of flow, evidence of unusual conditions	
Lagoon or Pond	Pond level, odor, scum on surface, presence of excessive solids	
Residuals Stockpile	Amount, need for land application, odor	
Main Pump Station	Current operations, flow, pressure, odor, leaks, mechanical concerns	
Transmission Piping	Leaks, odor, pressure at intermediate locations	
Booster Pumps	Current operations, flow pressure, odor, leaks, mechanical concerns	
Fields irrigated	For each field: list irrigation run times, process water or supplemental water supply, odor	
Fields condition	For each field: assess irrigation uniformity, runoff, erosion, irrigation system condition, duration of standing water after irrigation, odor, solids on surface	
Crop condition	For each field: general crop health, need for farming activities	
Samples Collected	List samples taken	

Routine inspection forms also commonly incorporate collection of meter readings, pressure checks, times that various activities take place, etc. This is an appropriate combination of tasks and should be encouraged. Because land application treatment is a biological process, it is inherently dependent on many variables, and observations used to adjust management according to actual field conditions are important. In addition, results and observations made during inspection are an appropriate topic at periodic facility staff meetings or informal meetings of field or maintenance personnel.

Inspection forms and other operational and compliance records associated with the monitoring activities described in this chapter should be maintained in a central file that allows for easy future reference. Careful record-keeping on an ongoing basis is critical to data evaluation, identification of short- and long-term trends, and operational fine-tuning, as discussed below. Facility files should also include process-related records, such as the volume of chemicals used for cleaning, energy consumption and other pertinent data.

10.8 Combined Data Evaluation

Data from each monitoring technique and all media should be evaluated as a whole to get a better picture of the overall effectiveness of the site for reuse and treatment of the constituents of concern. For risk category

1 and 2 sites, verifying loading rates, verifying good agronomic conditions, and watching trends are generally sufficient.

For risk category 3 sites, the effectiveness of the land application system should be periodically evaluated in greater detail. This could include estimations of deep percolation, fate of constituents in the vadose zone, transport of constituents to groundwater, and the rate of movement of groundwater. These values can then be used to evaluate the trends and changes seen in groundwater well monitoring results. Appendix F contains some technical approaches for estimating transport of constituents of concern. The WDRs for the site will usually specify the necessary evaluations and reports.

10.9 Operational Adjustments and Modifications

Changes should be considered when monitoring results show trends towards undesirable conditions. Some of the possible responses to undesirable conditions or trends are given in Table 10-14.

Table 10-14. Operational Adjustments

Condition	Possible Operation Adjustment or Other Change to Mitigate Condition
BOD or High Iron in Groundwater	• Check/repair monitoring well seal, construct berm to provide setback from process/rinse water flooding area. • Reduce BOD loadings • Reduce hydraulic loadings • Increase cycle and/or seasonal site resting time • Switch to sprinkler irrigation
Extended Ponding Duration	• Reduce amount applied per irrigation • Check soil chemistry and amend, if necessary • Dry and rip or scarify soil • Remove additional TSS in pretreatment • Re-level to eliminate depressions
Odors	• Remove additional TSS in pretreatment • Improve irrigation and solids application uniformity • Reduce BOD loading rates • Reduce ponding duration (see above) • Switch to sprinkler irrigation
Excess Soil Nitrate	• Plant crop with greater nitrogen uptake • Reduce nitrogen loadings • If flood irrigated, change irrigation/drainage cycle to optimize denitrification
Soil sodicity and swelling	• Switch from sodium based chemicals to potassium or calcium or magnesium • Apply gypsum or soil amendment
Excess soil salinity	• Use low salinity water for supplemental irrigation needs • Plant crops with greater salt tolerance and uptake • Develop and implement additional source control measures
Excess Nitrate in Groundwater	• Evaluate soil and groundwater nitrate trends • Plant crops with greater nitrogen uptake • Reduce nitrogen loadings • If flood irrigated, change irrigation/drainage cycle to optimize denitrification
Excess Salt in Groundwater	• Use low salinity water for supplemental irrigation needs • Plant crops with greater salt uptake • Develop and implement additional source control measures

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11. RESEARCH NEEDS

As indicated in Chapter 1, the manual was revised through a collaborative effort between CLFP, regulatory agency representatives and consultants. At the outset of this process, a list of known issues related to best practices for land application of process/rinse water was developed by the stakeholders group, and four working committees were formed to focus on specific topics (waiver development, BOD loading rate, point-of-compliance and soil monitoring). Many of the identified issues were resolved by the committees, and those results were incorporated in this manual; however, some points could not be adequately addressed within the timeframe allotted for revision of the manual because the existing literature was insufficient or inconclusive and/or further evaluation was deemed necessary. Specifically, these items include:

Category	Topic
Organics/BOD/ Nutrients	1. Determine soil aeration under various BOD loading rates. 2. Evaluate use of soil-gas testing to confirm soil aeration under various BOD loading rates. 3. Assess the correlation of BOD loading with TDS, alkalinity, dissolved iron and manganese, and arsenic in receiving groundwater. 4. Determine the minimum organic loading necessary to maintain and enhance soil health and fertility. 5. Determine the nitrogen mineralization rates of organic nitrogen for common process/rinse waters.
Salinity/TDS	1. Compare the salinity uptake by various cover crops, considering climate and applied water quality. 2. Identify best practicable treatment and control methods to minimize salinity impacts on groundwater. 3. Identify alternative methods for peeling fruit to minimize use of caustic. 4. Identify alternative cleaning products to minimize introduction of sodium. 5. Identify alternatives to water softener and boiler blowdown chemicals. 6. Determine if crops can be developed to remove specific ions, such as sodium and chloride. 7. Determine the management approach to long-term immobilization of salts by chemical precipitation in the soil mantle.

Category	Topic
Groundwater Protection	1. Evaluate the actual nature and extent of groundwater quality impacts at land application sites based on existing groundwater quality monitoring data. 2. Determine the protection from degradation of TDS afforded by using potassium in place of sodium in caustic and water softener regeneration.
Vadose Zone Monitoring	1. Assess the correlation between the thickness of vadose zone and treatment processes. 2. Define appropriate operational monitoring programs for land application sites to ensure that the systems are functioning as intended. Establish whether vadose zone monitoring by lysimeters can provide representative samples. 3. Compare intensive soil sampling versus lysimeters for operational monitoring.
Soil/ Site Selection	1. Investigate whether long-term wastewater application has an effect on soil buffering capacity. 2. Confirm that soil (and soil solution) is not adversely affected by wastewater with a pH in the range of 3 to 10.
Crop Irrigation	1. Determine whether the guidelines for land application of food process rinse water are applicable to the reuse of process wastewater for crop irrigation.

The list has not yet been prioritized, and the items differ widely in the level of research effort that would be required to reach satisfactory conclusions. It should be noted that many of the same issues are within the scope of other ongoing or planned research projects related to land application and salinity management. CLFP and the Wine Institute have discussed their intent to collaborate on preparing a detailed inventory of the objectives and timelines of these various active projects to avert duplicative efforts and facilitate prioritization of future research needs. Pilot testing on small plots associated with existing process/rinse water application systems could also help provide data to address research needs.

12. PLANNING AND DESIGN EXAMPLES

In trying to meet the objectives and needs of multiple target audiences for this manual, many of the chapters contain a depth of highly technical information. The purpose of this chapter is to provide examples to more clearly illustrate the application of the planning, design, and monitoring approaches presented in previous chapters. Initial planning calculations as illustrated in this chapter can be especially important in determining how much land to purchase or lease for a land application site.

12.1 Example 1 – Small Fresh Vegetable Washing Factory

This example is for an expansion of a small fresh vegetable washing factory to illustrate the approach for a low risk (Category 1) facility. The factory was initially small enough to discharge wastewater to a septic tank/leach field under county regulation. The factory now plans to expand well beyond what the county will allow for an onsite wastewater system.

12.1.1 Initial Characterization and Preliminary Calculations

Initial characterization of the process/rinse water from the current factory is shown in Table 12-1. The facility does not use chlorine or bromine for disinfection, so no THMs are created in the process. Expected flows from the expanded factory are also shown in Table 12-1.

Table 12-1. Process/Rinse Water Characteristics

Flow (mgd)	Operation (d/yr)	BOD[a] (mg/L)	Total N (mg/L)	FDS (mg/L)[b]
0.05	90	400	30	450

[a] *All values for BOD shown in this chapter refer to 5-day BOD unless otherwise indicated.*

[b] *mg/L is effectively the same as parts per million or ppm*

12.1.2 Site Investigation

A nearby 10-acre parcel has been identified for possible purchased as a process/rinse water land application and crop production site. The parcel has medium texture soil and moderate slope. An initial site investigation and characterization has been performed based on the guidelines in Chapters 4 and 7 of the manual. The results are shown in Table 12-2.

Table 12-2. Site Characteristics

Characteristic	Value	Unit
Soil Type	Loam	n/a
Slope	3	%
Depth to Restriction	8	ft
Depth to Groundwater	30	ft
Range of Local GW Irrigation Supply TDS	250 - 500	mg/L
Supplemental Water TDS	300	mg/L

12.1.3 Loading Rates

In this step, loading rates for water and constituents of concern are calculated and a target crop(s) and irrigated area are determined. It is best to start with the constituent that is expected to be the most limiting in terms of land area needs. If a different constituent is found to be limiting after the first round of loading rate calculations, it is then necessary to repeat calculations for the remainder of the constituents with an updated land area.

Since nitrogen loading rates will often be the most limiting for risk category 1 facilities, nitrogen loading rates will be calculated first in this example.

Nitrogen

For a Risk Category 1 system, the loading rate of nitrogen must be less than half of the agronomic use rate on an annual basis (see Table 7-3). The total annual nitrogen load is calculated as follows:

Total Annual Nitrogen Load = 0.05 mgal/d * 30 ppm * 8.34 lbs/gal * 90 d/yr = 1126 lb/yr

The agronomic nitrogen use rates of crops of interest for the site and the corresponding areas required to apply the process/rinse water at half the nitrogen use rates can then be calculated as shown in Table 12-3.

Table 12-3. Potential Crops and N Limiting Area

Crops of Interest	N Use (lb/ac*yr)	50% of N Use (lb/ac*yr)	Area[a] (ac)
Almonds	200	100	11.3
Wheat	175	88	12.9
Orchardgrass	300	150	7.5

[a] *Equals the total annual nitrogen load (1126 lb/yr) divided by 50% use rate.*

Based on the values in Table 12-3, the available area (10 acres), and general farming considerations, orchardgrass is selected as the preferred crop for this example. Nine out of the 10 acres are planted in orchardgrass, leaving a safety margin for loading rates and some room for possible future facilities.

BOD

Next, the organic loading rate should be compared with criteria. The total BOD loading rate is calculated as follows:

Total Daily BOD Load = 0.05 mgal/d • 400 ppm • 8.34 lb/gal = 167 lb/d

BOD Loading Rate = 167 / 9 = 19 lb/ac•d

The BOD loading rate is well below the 50 lb/ac•d loading rate criteria for risk category 1 shown in Table 7-5. The depth to groundwater is also sufficient for risk category 1. Therefore, the 9 acres is adequate for the anticipated organic loading rate.

It should also be noted that if there were several alternative sites under consideration, Equation 7-9 could be used to calculate the minimum necessary area based on BOD loading.

Hydraulic Loading

Surface irrigation would be very difficult on the 3 percent slope of the available land. Therefore, either solid set or periodic move sprinkler irrigation is preferred. The assumed hydraulic loading factors developed using the approach in Chapter 6 are shown in Table 12-4. The maximum and minimum irrigation needs of the crop are determined with Equation 7-5 using evapotranspiration (ET), effective rain (R_e), irrigation efficiency, and leaching ratio (LR). For this example, LR is determined based on irrigation season values. For sites that receive substantial amounts of rain and are planted to crops that are not very salt sensitive, target LR can optionally be estimated on an annual average basis that includes rainfall. For the purpose of this example, stored soil water will be ignored.

Table 12-4. Hydraulic Loading Factors

Factor	Value	Units
Peak month ET	9	in/mo
Min. month ET	6.6	in/mo
R_e during peak month flows	0	in/mo
Min. month R_e	0.6	in/mo
Efficiency	0.8	unitless
LR (from Figure 7-5)	0.07	unitless

$$I = (ET - R_e - W_s) \bullet (1+LR) / eff \quad (7\text{-}5)$$

Maximum Irrigation Rate = (0.3 – 0) in/mo • (1+0.07) / 0.8 = 12 in/mo

Minimum Irrigation Rate = (6.6 – 0.6) in/mo • (1+0.07) / 0.8 = 8.8 in/mo

The process/rinse water application rate is determined from the flow and land area as follows:

Rinse Water App. Rate = 0.05 mgal/d • 3.07 af/mgal • 12 in/ft / 9 ac • 30 d/mo

= 6.0 in/mo

The process/rinse water hydraulic loading rate will be less than both the maximum and minimum irrigation rates. Supplemental irrigation water will be needed during all months of process/rinse water generation. The 10 acre (net 9 acre) site is adequate for the hydraulic loading rate.

Salts

The FDS concentration in the process/rinse water (450 mg/L) is within the range of concentrations of TDS in irrigation water supply wells in the general area (250 – 500 mg/L). Therefore, the salt effects of fertilizer and the dilutive effects of supplemental irrigation water do not need to be considered for this to remain risk category 1.

12.1.4 Irrigation System Selection and Design Considerations

For size of the parcel identified, the preferred sprinkler system would probably be either solid set or hand-move aluminum lines, depending upon costs and labor availability. Information in Chapter 9 can be applied in developing design details. Setbacks from field borders should be used to prevent overspray off the site. Flushable ends should be included on the laterals to keep solids from accumulating in the pipes.

12.1.5 Other Considerations

Runoff containment and/or return facilities should be included so that no process/rinse water can leave the site. Monitoring should be performed in accordance with discharge requirements or waiver requirements, as prescribed. Typical monitoring recommendations and record keeping for risk category 1 facilities are described in Chapter 10.

12.2 Example 2 – Large Fruit Cannery, Sandy Loam Soil

This example is for a large fruit cannery. It illustrates the approach for a risk category 3 facility. Comparisons with risk category 2 criteria are also illustrated to provide examples of calculations associated with category 2 systems. In addition to the basic loading rate calculations presented in Example 1, this example demonstrates calculations used for:

- Nitrogen loss;
- Aeration capacity;
- Monthly water balance; and
- Average annual percolate salinity.

12.2.1 Initial Characterization and Preliminary Calculations

Initial characterization of the process/rinse water from a similar factory is shown in Table 12-5. Expected flows and operating days from the new factory are also shown in Table 12-5.

Table 12-5. Anticipated Process/Rinse Water Characteristics

Flow (mgd)	Operation (d/yr)	BOD_5 (mg/L)	TSS (mg/L)	Total N (mg/L)	FDS[a] (mg/L)	Total P (mg/L)	K (mg/L)
3	123	2000	800	70	900	15	60

[a] *Sum of major ions may be more appropriate for calculating C_d. FDS will be used throughout this example for simplicity.*

12.2.2. Site Investigation

A neighboring 400-acre parcel has been identified for possible purchase for process/rinse water land application and crop production. The parcel has moderately fine texture soil and little slope. An initial site investigation and characterization has been performed based on the guidelines in Chapters 4 and 7 of the manual. The results are shown in Table 12-6.

Table 12-6. Site Characteristics

Characteristic	Value	Units
Soil Type	Silt Loam	n/a
Slope	0.2	%
Depth to Groundwater	4	ft
Range of Local Groundwater Irrigation Supply TDS	250 – 400	mg/L
Supplemental Water TDS	400	mg/L
Background Shallow Groundwater TDS	1650[a]	mg/L

[a] *Established as discussed in Section 10.5.2.*

12.2.3 Loading Rates

In this step, loading rates for water and constituents of concern are calculated and a target crop(s) and irrigated area are determined. It is best to start with the constituent that is expected to be the most limiting in terms of land area needs. Since nitrogen loading rates will often be the most limiting for risk category 3 facilities, nitrogen loading rates will be calculated first in this example.

Nitrogen

The total annual nitrogen load is calculated as follows:

Total Annual Nitrogen Load = 3.0 mgal/d • 70 ppm • 8.34 lb/gal • 123 d/yr = 215400 lb/yr

The annual agronomic nitrogen use rates of crops of interest for the site and a comparison with category 2 criteria can then be calculated as shown in Table 12-7.

Table 12-7. Potential Crops and N Limiting Area

Crops of Interest	N Use[a] (lb/ac•yr)	150% of N Use (lb/ac•yr)	Min. Area for Category 2 (ac)
Corn	240	360	598
Alfalfa	480	720	299
Sorghum-sudan grass	325	488	442

[a] *From Western Fertilizer Handbook. Values can also be taken from chapter 6.*

Based on the values in Table 12-7, alfalfa could be planted to keep within guidelines for risk category 2. However, for the purposes of this example, it will be assumed that sorghum-sudan grass is the selected crop due to market conditions. Without additional land, this would place the system in risk category 3 because the nitrogen loading would be more than 150 percent of the crop uptake. Therefore nitrogen fate calculations will need to be performed.

The BOD:N ratio is 28:1, which would correspond to a C:N ratio of approximately 14:1. From Table 7-2, this would correspond to a loss factor of at least 0.5 for flood irrigation. Conservatively using the 0.5 loss factor, the total allowable loading would be calculated using equation 7-1:

$L_n = U/(1\text{-}f)$ (7-1)

Allowable N loading (flood irrigation) = 325 / (1 - 0.5) = 650 lb/ac

Assuming that 390 acres out of the 400 total were used for crop production, the actual loading rate on the 390 acres would be 550 lb/ac. This would be acceptable for flood irrigation.

BOD

Now checking the BOD loading rate;

Total Daily BOD Load = 3.0 mgal/d • 2000 ppm • 8.34 lb/gal = 50,000 lb/d

BOD Loading Rate = (50,000 lb/d) / 390 ac = 128 lb/ac•d

The BOD loading rate is above the 100 lb/ac•d loading rate criteria for risk category 2 shown in Table 7-5. In addition, the depth to groundwater is too shallow to qualify for risk category 2. If groundwater depth were not limiting and if the soil were well drained, sprinkler irrigation could enable a category 2 classification. The use of additional land to reduce loading rates could also enable a category 2 classification. The calculations for allowable organic loading rates for a category 3 system are given in equations 7.2 through 7.6.

Ultimate Biochemical Oxygen Demand = BOD_u = (1.4 • 2000 ppm) • 8.34 lb/gal) • 3 mgd / 390 ac = 180 lb/ac/d

Then the average oxygen flux can be calculated using Equation 7-2. The assumptions used for Equation 7-2 would be as follows:

Vapor phase concentration of O_2 = 300 ppm (sea level)

Fraction of air-filled porosity at field capacity = 0.16

7 day irrigation cycle, 2 days irrigation and drainage duration, t = 7 - 2 = 5 days

$$N_{O2} = 2(C_{O2}\text{-}Cp) \cdot [Dp\ t/\pi]^{1/2} \quad (7\text{-}2)$$

Total Oxygen Flux = 2 • (300 - 140) • $(0.6 \cdot 0.16 \cdot 1.62 \cdot 5 / 3.14)^{0.5}$ = 159 g/m2 = 1426 lb/ac

For the seven day total irrigation cycle, the average flux would be 204 lb/ac•d. This is greater than the 180 lb/ac•d total oxygen demand, therefore, the loading rate is acceptable. If the re-aeration had not been adequate, a shorter irrigation frequency and/or the use of sprinklers would have improved the average aeration rate (see Equations 7-4 and 7-6).

Hydraulic

A water balance was developed for the entire year, incorporating Equation 7-5 and water use calculations from Chapter 6. Assumptions are shown in Table 12-8. The water balance is shown in Table 12-9. The water balance enables the hydraulic loading factors to be checked for months of operation and for annual totals. For this example, the leaching requirement is ignored in the spring months prior to the process/rinse water irrigation season.

Table 12-8. Water Balance Assumptions

Irrigation Efficiency	0.75
Leaching Requirement (LR, from Figure 7-5)	0.11

Table 12-9. Water Balance								
	Nov – Apr	May	June	July	Aug	Sep	Oct	Totals
ET (in)	10	6	8	9	8	6	4	51.00
R_e (in)	13	0.5	0.2	0	0	0.2	0.6	14.50
W_s (in)	0	2	0	0	0	0	-2	0.00
LR	0	0	0	0.11	0.11	0.11	0.11	
Irrig. Needed (in)	0	4.67	10.40	13.32	11.84	8.58	7.99	56.80
Rinse Water (in)	0	0	0.00	8.78	8.78	8.50	8.78	34.86
Supplemental (in)	0	4.67	10.40	4.54	3.06	0.08	0.00	22.74
Deep Perc. (in)	3.00	1.17	2.60	4.32	3.84	2.78	3.38	21.10

Where,

ET = monthly crop evapotranspiration

R_e = effective rainfall

W_s = change in soil moisture

Irrig. Needed is calculated using Equation 7-5.

Rinse Water = (Flow • 3.07 ac•ft/mgal) / (12 in/ft • 390 ac) • 31 d/mo

Supplemental = Irrig. Needed – Rinse Water

Deep Perc. = Supplemental + Rinse Water + R_e + W_s - ET

As can be seen in Table 12-9, supplemental water is required through August, but the process/rinse water irrigation exceeds irrigation needs in October. As discussed in Chapter 7, this can be a reasonable approach during the shoulder months of an irrigation season as long as groundwater quality is still protected. It would be important to make sure crops and field conditions are appropriate for any fall harvesting or other operations that could be impacted by wet conditions in October. Otherwise, temporary storage or additional land may be needed.

The totals for supplemental irrigation water and deep percolation can be used in the calculation of the average salinity of applied water and the average salinity of deep percolate.

Salts

Based on comparability criteria in Table 7-7, the maximum acceptable irrigation water FDS concentration for a risk category 2 can be calculated as follows:

Max. Acceptable Comparable FDS = 400 mg/L + 320 mg/L = 720 mg/L

However, as shown in Table 7-7, this also cannot exceed 640 mg/L for a risk category 2. This means that the 640 mg/L is most limiting, and will therefore be used for comparison.

The average mineral dissolved solids of the applied irrigation water (using process/rinse water FDS and supplemental water TDS) for the entire year can be calculated by the following formula:

Average Comparative Mineral Salinity = (34.86 • 900 + 22.74 • 400) / (34.86 + 22.74) = 703 mg/L

The average irrigation water comparative mineral salinity (703 mg/L) is greater than the maximum allowable salinity for risk category 2 (640 mg/L). Therefore, the system is risk category 3 based on salinity (in addition to being risk category 3 based on BOD and nitrogen as shown previously).

For a category 3 system, one of the methods that could be used to assure protection of groundwater quality is to show that annual average C_d is less than background shallow groundwater quality. Using the annual irrigation and deep percolation values from the water balance in Table 12-9 and estimating a crop salt removal of 2000 lb/ac based on Table 6-9, the average annual C_d (in ppm) can be calculated as follows:

C_d = (Process Water Salt + Sup. Irrigation Water Salt – Crop Salt Uptake) / Mass of Annual Deep Percolate

On a per-acre basis, the calculation would be:

C_d = ((34.86 in • 900 ppm + 22.74 in • 400 ppm) • 0.232 Mlb/ac•in - 2000 lb/ac) / (21.1 in • 0.232 Mlb/ac•in)

= 1512 ppm

where ppm in liquid percolate is the same as mg/L

The calculated drainage water mineral salinity of 1512 mg/L compares favorably with the natural background shallow groundwater salinity upper limit of 1650 mg/L. Therefore, the salt loading rate is acceptable for the site under consideration.

Loading Rate Calculation Iterations

If a loading rate other than nitrogen had been found to be more limiting than nitrogen after the first round of loading rate calculations, it would have then been necessary to repeat all the loading rate calculations using an updated land area that satisfied the criteria for the most limiting loading rate factor.

12.2.4 Irrigation System Selection and Design

The system will be relatively high frequency for surface irrigation. The process/rinse water also has a relatively high concentration of TSS. Recommendations in Chapter 9 should be followed for distribution system design. Short runs, the use corrugations or furrows, and relatively high application rates should all be considered to help distribute the TSS more uniformly across each field.

12.2.5 Other Considerations

Other nutrients such as phosphorus and potassium should be checked against crop needs. A tailwater return system with good velocity should be considered to help minimize ponding durations. Fields should be laser leveled to provide good uniformity and eliminate low spots. Monitoring should be consistent with the guidelines for category 3 systems provided in Chapter 10.

APPENDIX A

Glossary of Terms

GLOSSARY OF TERMS, ABBREVIATIONS, SYMBOLS, AND CONVERSATION FACTORS

TERMS

Adsorption. A process in which soluble substances are attracted to and held at the surface of soil particles.

Aerosol. A suspension of fine solid or liquid particles in air or gas.

Alkali soil. A soil with a high degree of alkalinity (pH of 8. 5 or higher) or with a high exchangeable sodium content (15 percent or more of the exchange capacity), or both.

Application rate. The rate at which a liquid is dosed to the land (in./hr, ft/yr, etc.).

Aquifer. A geologic formation or stratum that contains water and transmits it from one point to another in quantities sufficient to permit economic development.

Border strip method. Application of water over the surface of the soil. Water is applied at the upper end of the long, relatively narrow strip.

Conductivity. Quality or capability of transmitting and receiving. Normally used with respect to electrical conductivity (EC).

Consumptive use. Synonymous with evapotranspiration.

Contour check method. Surface application by flooding. Dikes constructed atcontour intervals to hold the water.

Conventional wastewater treatment. Reduction of pollutant concentrations in wastewater by physical, chemical, or biological means.

Drainability. Ability of the soil system to accept and transmit water by infiltration and percolation.

Evapotranspiration. The unit amount of water used on a given area in transpiration, building of plant tissue, and evaporation from adjacent soil, snow, or intercepted precipitation in any specified time.

Field area. Total area of treatment for a large land-application system including the wetted area.

Fixation. A combination of physical and chemical mechanisms in the soil that act to retain wastewater constituents within the soil, including adsorption, chemical precipitation, and ion exchange.

Flooding. A method of surface application of water which includes border strip, contour check, and spreading methods.

Grass filtration. See overland flow.

Groundwater. The body of water that is retained in the saturated zone which tends to move by hydraulic gradient to lower levels.

Groundwater table. The free surface elevation of the groundwater; this level will rise and fall with additions or withdrawals.

Infiltration. The entrance of applied water into the soil through the soil-water interface.

Infiltration-percolation. An approach to land application in which large volume of wastewater are applied to the land, infiltrate the surface, and percolate through the soil pores.

Irrigation. Application of water to the land to meet the growth needs of plants.

Land application. The discharge of wastewater onto the soil for treatment or reuse.

Lithology. The study of rocks; primarily mineral composition.

Loading rate. The average amount of liquid or solids applied to the land over fixed time period, taking into account periodic resting.

Lysimeter. A device for measuring percolation and leaching losses from a column of soil. Also a device for collecting soil water in the field.

Micronutrient. A chemical element necessary in only small amounts (less than 1 mg/l) for microorganism and plant growth.

Mineralization. The conversion of an element from an organic form to an inorganic form as a result of microbial decomposition.

Overland flow. Wastewater treatment by spray-runoff (also known as "grass filtration" and "spray runoff") in which wastewater is sprayed onto gently slopping, relatively impermeable soil that has been planted to vegetation. Biologic oxidation occurs as the wastewater flows over the ground and contacts the biota in the vegetative litter.

Pathogenic organisms. Microorganisms that can transmit diseases.

Percolation. The movement of water beneath the ground surface both vertically and horizontally, but above the groundwater table.

Permeability. The ability of a substance (soil) to allow appreciable movement of water through it when saturated and actuated by a hydrostatic pressure.

Phytotoxic. Toxic to plants.

Primary effluent. Wastewater that has been treated by screening and sedimentation.

Ridge and furrow method. The surface application of water to the land through formed furrows; wastewater flows down the furrows and plants may be grown on the ridges.

Saline soil. A nonalkali soil containing sufficient soluble salts to impair its productivity.

Secondary treatment. Treatment of wastewater which meets the standards set forth in 40 CFR 133.

Sewage farming. Originally involved the transporting of sewage to rural areas for land disposal. Later practice included reusing the water for irrigation and fertilization of crops.

Soil texture. The relative proportions of the various soil separates - sand, silt, and clay.

Soil water. That water present in the soil pores in an unsaturated zone above the groundwater table.

Spraying. Application of water to the land by means of stationary or moving sprinklers.

Spray-runoff. See overland flow.

Tilth. The physical condition of a soil as related to its ease of cultivation.

Transpiration. The net quantity of water absorbed through plant roots that is used directly in building plant tissue, or given off to the atmosphere.

Viruses. Submicroscopic biological structures containing all the information necessary for their for their own reproduction.

Wetted area. Area within the spray diameter of the sprinklers.

ABBREVIATIONS

BOD - biochemical oxygen demand

BPT - best practicable treatment technology

cm - centimeter

COD - chemical oxygen demand

cu. m - cubic meter

deg C - degree Centigrade

deg F - degree Fahrenheit

EC - electrical conductivity

ECdw - maximum EC of drainage water permissible for plant growth

ECe - EC of saturation extract (from soil)

ECw - EC of irrigation water

ENRCC - Engineering News-Record construction cost (index)

FDA - Food and Drug Administration

fps - feet per second

ft - foot

gal. - gallon

gpm - gallons per minute

ha - hectare

hr - hour

in. - inch

kg - kilogram

l - liter

lb - pound

m - meter

max -maximum

mgd - million gallons per day

mg/l - milligrams per liter

min - minute

ml - milliliter

mm - millimeter

mmho/cm - millimhos per centimeter

MPN -most probable number

NRCS – Natural Resources Conservation Service ppm - parts per million

psi - pounds per square inch

SAR - sodium adsorption ratio

SCS - Soil Conservation Service

sec - second

sq ft - square foot

SS - suspended solids

STPCC - sewage treatment plant construction cost (index)

TOC - total organic carbon

TDS - total dissolved solids

USDA - U. S. Department of Agriculture

USGS - U. S. Geological Survey

wk - week

yr - year

SYMBOLS

B - boron

Ca - calcium

Cu - copper

K - potassium

Fe - iron

Mg - magnesium

Mn - manganese

N - nitrogen

Na - sodium

NH_3 - ammonia

NO_3 - nitrate

P - phosphorus

S - sulfur

Zn - zinc

> - greater than

< - less than

μ - micro

CONVERSION FACTORS

million gallons x 3.06 = acre-feet

acre-inch x 27,154 = gallons

mg/l x ft/yr x 2.7 = lb/acre/yr

APPENDIX B

State Water Board Policy 68-16

STATE WATER RESOURCES CONTROL BOARD
RESOLUTION NO. 68-16
STATEMENT OF POLICY WITH RESPECT TO MAINTAINING HIGH QUALITY OF WATERS IN CALIFORNIA

WHEREAS the California Legislature has declared that it is the policy of the State that the granting of permits and licenses for unappropriated water and the disposal of wastes into the waters of the State shall be so regulated as to achieve highest water quality consistent with maximum benefit to the people of the State and shall be controlled so as to promote the peace, health, safety and welfare of the people of the State; and

WHEREAS water quality control policies have been and are being adopted for waters of the State; and

WHEREAS the quality of some waters of the State is higher than that established by the adopted policies and it is the intent and purpose of this Board that such higher quality shall be maintained to the maximum extent possible consistent with the declaration of the Legislature;

NOW, THEREFORE, BE IT RESOLVED:

1. Whenever the existing quality of water is better than the quality established in policies as of the date on which such policies become effective, such existing high quality will be maintained until it has been demonstrated to the State that any change will be consistent with maximum benefit to the people of the State, will not unreasonably affect present and anticipated beneficial use of such water and will not result in water quality less than that prescribed in the policies.

2. Any activity which produces or may produce a waste or increased volume or concentration of waste and which discharges or proposes to discharge to existing high quality waters will be required to meet waste discharge requirements which will result in the best practicable treatment or control of the discharge necessary to assure that (a) a pollution or nuisance will not occur and (b) the highest water quality consistent with maximum benefit to the people of the State will be maintained.

3. In implementing this policy, the Secretary of the Interior will be kept advised and will be provided with such information as he will need to discharge his responsibilities under the Federal Water Pollution Control Act.

BE IT FURTHER RESOLVED that a copy of this resolution be forwarded to the Secretary of the Interior as part of California's water quality control policy submission.

CERTIFICATION

The undersigned, Executive Officer of the State Water Resources Control Board, does hereby certify that the foregoing is a full, true, and correct copy of a resolution duly and regularly adopted at a meeting of the State Water Resources Control Board held on October 24, 1968.

Dated: October 28, 1968

Kerry W. Mulligan
Executive Officer
State Water Resources Control Board

APPENDIX C

Form 200 and Information Needs for RWD

INTRODUCTION

This application package constitutes a Report of Waste Discharge (ROWD) pursuant to California Water Code Section 13260. Section 13260 states that persons discharging or proposing to discharge waste that could affect the quality of the waters of the State, other than into a community sewer system, shall file a ROWD containing information which may be required by the appropriate Regional Water Quality Control Board (RWQCB).

This package is to be used to start the application process for all waste discharge requirements (WDRs) and National Pollutant Discharge Elimination System (NPDES) permits* issued by a RWQCB except:

a) Those landfill facilities that must use a joint Solid Waste Facility Permit Application Form, California Integrated Waste Management Board Form E-1-77; and
b) General WDRs or general NPDES permits that use a Notice of Intent to comply or specify the use of an alternative application form designed for that permit.

This application package contains:

1. Application/General Information Form for WDRs and NPDES Permits [Form 200 (10/97)].
2. Application/General Information Instructions.

Instructions

Instructions are provided to assist you with completion of the application. If you are unable to find the answers to your questions or need assistance with the completion of the application package, please contact your RWQCB representative. *The RWQCBs strongly recommend that you make initial telephone or personal contact with RWQCB regulatory staff to discuss a proposed new discharge before submitting your application.* The RWQCB representative will be able to answer procedural and annual fee related questions that you may have. (See map and telephone numbers inside of application cover.)

All dischargers regulated under WDRs and NPDES permits must pay an annual fee, except dairies, which pay a filing fee only. The RWQCB will notify you of your annual fee based on an evaluation of your proposed discharge. Please do NOT submit a check for your first annual fee or filing fee until requested to do so by a RWQCB representative. Dischargers applying for reissuance (renewal) of an existing NPDES permit or update of an existing WDR will be billed through the annual fee billing system and are therefore requested NOT to submit a check with their application. Checks should be made payable to the State Water Resources Control Board.

Additional Information Requirements

A RWQCB representative will notify you within 30 days of receipt of the application form and any supplemental documents whether your application is complete. If your application is incomplete, the RWQCB representative will send you a detailed list of discharge specific information necessary to complete the application process. The completion date of your application is normally the date when all required information, including the correct fee, is received by the RWQCB.

*** NPDES PERMITS:** If you are applying for a permit to discharge to surface water, you will need an NPDES permit which is issued under both State and Federal law and may be required to complete one or more of the following Federal NPDES permit application forms: Short Form A, Standard Form A, Forms 1, 2B, 2C, 2D, 2E, and 2F. These forms may be obtained at a RWQCB office or can be ordered from the National Center for Environmental Publications and Information at (513) 891-6561.

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

State of California
Regional Water Quality Control Board

APPLICATION/REPORT OF WASTE DISCHARGE GENERAL INFORMATION FORM FOR WASTE DISCHARGE REQUIREMENTS OR NPDES PERMIT

INSTRUCTIONS

FOR COMPLETING THE APPLICATION/REPORT OF WASTE DISCHARGE GENERAL INFORMATION FORM FOR: WASTE DISCHARGE REQUIREMENTS/NPDES PERMIT

If you have any questions on the completion of any part of the application, please contact your RWQCB representative. A map of RWQCB locations, addresses, and telephone numbers is located on the reverse side of the application cover.

I. FACILITY INFORMATION

You must provide the factual information listed below for ALL owners, operators, and locations and, where appropriate, for ALL general partners and lease holders.

A. FACILITY:
Legal name, physical address including the county, person to contact, and phone number at the facility. (**NO P.O. Box numbers!** If no address exists, use street and nearest cross street.)

B. FACILITY OWNER:
Legal owner, address, person to contact, and phone number. Also include the owner's Federal Tax Identification Number.

OWNER TYPE:
Check the appropriate Owner Type. The legal owner will be named in the WDRs/NPDES permit.

C. FACILITY OPERATOR (The agency or business, not the person):
If applicable, the name, address, person to contact, and telephone number for the facility operator. Check the appropriate Operator Type. If identical to B. above, enter "same as owner".

D. OWNER OF THE LAND:
Legal owner of the land(s) where the facility is located, address, person to contact, and phone number. Check the appropriate Owner Type. If identical to B. above, enter "same as owner".

E. ADDRESS WHERE LEGAL NOTICE MAY BE SERVED:
Address where legal notice may be served, person to contact, and phone number. If identical to B. above, enter "same as owner".

F. BILLING ADDRESS
Address where annual fee invoices should be sent, person to contact, and phone number. If identical to B. above, enter "same as owner".

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

State of California
Regional Water Quality Control Board

APPLICATION/REPORT OF WASTE DISCHARGE GENERAL INFORMATION FORM FOR WASTE DISCHARGE REQUIREMENTS OR NPDES PERMIT

II. TYPE OF DISCHARGE

Check the appropriate box to describe whether the waste will be discharged to: A. Land, or B. Surface Water.

Check the appropriate box(es) which best describe the activities at your facility.

Hazardous Waste - **If you check the Hazardous Waste box,** STOP **and contact a representative of the RWQCB for further instructions.**

Landfills - **A separate form, APPLICATION FOR SOLID WASTE FACILITY PERMIT/WASTE DISCHARGE REQUIREMENTS, California Integrated Waste Management Board Form E-1-77, may be required. Contact a RWQCB representative to help determine the appropriate form for your discharge.**

III. LOCATION OF THE FACILITY

1. Enter the Assessor's Parcel Number(s) (APN), which is located on the property tax bill. The number can also be obtained from the County Assessor's Office. Indicate the APN for both the facility and the discharge point.

2. Enter the Latitude of the entrance to the proposed/existing facility and of the discharge point. Latitude and longitude information can be obtained from a U.S. Geological Survey quadrangle topographic map. Other maps may also contain this information.

3. Enter the Longitude of the entrance to the proposed/existing facility and of the discharge point.

IV. REASON FOR FILING

NEW DISCHARGE OR FACILITY:
A discharge or facility that is proposed but does not now exist, or that does not yet have WDRs or an NPDES permit.

CHANGE IN DESIGN OR OPERATION:
A material change in design or operation from existing discharge requirements. Final determination of whether the reported change is material will be made by the RWQCB.

CHANGE IN QUANTITY/TYPE OF DISCHARGE:
A material change in characteristics of the waste from existing discharge requirements. Final determination of whether the reported change would have a significant effect will be made by the RWQCB.

CHANGE IN OWNERSHIP/OPERATOR:
Change of legal owner of the facility. Complete Parts I, III, and IV only and contact the RWQCB to determine if additional information is required.

WASTE DISCHARGE REQUIREMENTS UPDATE OR NPDES PERMIT REISSUANCE:
WDRs must be updated periodically to reflect changing technology standards and conditions. A new application is required to reissue an NPDES permit which has expired.

OTHER:
If there is a reason other than the ones listed, please describe the reason on the space provided. (If more space is needed, attach a separate sheet.)

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

State of California
Regional Water Quality Control Board

APPLICATION/REPORT OF WASTE DISCHARGE GENERAL INFORMATION FORM FOR WASTE DISCHARGE REQUIREMENTS OR NPDES PERMIT

V. CALIFORNIA ENVIRONMENTAL QUALITY ACT (CEQA)

It should be emphasized that communication with the appropriate RWQCB staff is vital before starting the CEQA documentation, and is recommended before completing this application. There are Basin Plan issues which may complicate the CEQA effort, and RWQCB staff may be able to help in providing the needed information to complete the CEQA documentation.

Name the Lead Agency responsible for completion of CEQA requirements for the project, i.e., completion and certification of CEQA documentation.

Check YES or NO. Has a public agency determined that the proposed project is exempt from CEQA?
If the answer is YES, state the basis for the exemption and the name of the agency supplying the exemption on the space provided. (Remember that, if extra space is needed, use an extra sheet of paper, but be sure to indicate the attached sheet under Section VII. Other.)

Check YES or NO. Has the "Notice of Determination" been filed under CEQA? If YES, give the date the notice was filed and enclose a copy of the Notice of Determination and the Initial Study, Environmental Impact Report, or Negative Declaration. If NO, check the box of the expected type of CEQA document for this project, and include the expected date of completion using the timelines given under CEQA. The date of completion should be taken as the date that the Notice of Determination will be submitted. (If not known, write "Unknown")

VI. OTHER REQUIRED INFORMATION

To be approved, your application MUST include a COMPLETE characterization of the discharge. If the characterization is found to be incomplete, RWQCB staff will contact you and request that additional specific information be submitted.

This application MUST be accompanied by a site map. A USGS 7.5' Quadrangle map or a street map, if more appropriate, is sufficient for most applications.

VII. OTHER

If any of the answers on your application form need further explanation, attach a separate sheet. Please list any attachments with the titles and dates on the space provided.

VIII. CERTIFICATION

Certification by the owner of the facility or the operator of the facility, if the operator is different from the owner, is required. The appropriate person must sign the application form.
Acceptable signatures are:

1. **for a corporation,** a principal executive officer of at least the level of senior vice-president;
2. **for a partnership or individual (sole proprietorship),** a general partner or the proprietor;
3. **for a governmental or public agency,** either a principal executive officer or ranking elected/appointed official.

DISCHARGE SPECIFIC INFORMATION

In most cases, a request to supply additional discharge specific information will be sent to you by a representative of the RWQCB. If the RWQCB determines that additional discharge specific information is not needed to process your application, you will be so notified.

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

State of California
Regional Water Quality Control Board

APPLICATION/REPORT OF WASTE DISCHARGE GENERAL INFORMATION FORM FOR WASTE DISCHARGE REQUIREMENTS OR NPDES PERMIT

I. FACILITY INFORMATION

A. Facility:

Name:			
Address:			
City:	County:	State:	Zip Code:
Contact Person:		Telephone Number:	

B. Facility Owner:

Name:			Owner Type (Check One) 1. ☐ Individual 2. ☐ Corporation 3. ☐ Governmental Agency 4. ☐ Partnership 5. ☐ Other: ______
Address:			
City:	State:	Zip Code:	
Contact Person:		Telephone Number:	Federal Tax ID:

C. Facility Operator (The agency or business, not the person):

Name:			Operator Type (Check One) 1. ☐ Individual 2. ☐ Corporation 3. ☐ Governmental Agency 4. ☐ Partnership 5. ☐ Other: ______
Address:			
City:	State:	Zip Code:	
Contact Person:		Telephone Number:	

D. Owner of the Land:

Name:			Owner Type (Check One) 1. ☐ Individual 2. ☐ Corporation 3. ☐ Governmental Agency 4. ☐ Partnership 5. ☐ Other: ______
Address:			
City:	State:	Zip Code:	
Contact Person:		Telephone Number:	

E. Address Where Legal Notice May Be Served:

Address:		
City:	State:	Zip Code:
Contact Person:		Telephone Number:

F. Billing Address:

Address:		
City:	State:	Zip Code:
Contact Person:		Telephone Number:

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

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APPLICATION/REPORT OF WASTE DISCHARGE GENERAL INFORMATION FORM FOR WASTE DISCHARGE REQUIREMENTS OR NPDES PERMIT

II. TYPE OF DISCHARGE

Check Type of Discharge(s) Described in this Application (A or B):

☐ **A. WASTE DISCHARGE TO LAND** ☐ **B. WASTE DISCHARGE TO SURFACE WATER**

Check all that apply:

☐ Domestic/Municipal Wastewater Treatment and Disposal
☐ Cooling Water
☐ Mining
☐ Waste Pile
☐ Wastewater Reclamation
☐ Animal Waste Solids
☐ Land Treatment Unit
☐ Dredge Material Disposal
☐ Surface Impoundment
☐ Industrial Process Wastewater
☐ Animal or Aquacultural Wastewater
☐ Biosolids/Residual
☐ Hazardous Waste (see instructions)
☐ Landfill (see instructions)
☐ Storm Water
☐ Other, please describe: ____________________

III. LOCATION OF THE FACILITY

Describe the physical location of the facility.

1. Assessor's Parcel Number(s)	2. Latitude	3. Longitude
Facility:	Facility:	Facility:
Discharge Point:	Discharge Point:	Discharge Point:

IV. REASON FOR FILING

☐ New Discharge or Facility
☐ Change in Design or Operation
☐ Change in Quantity/Type of Discharge
☐ Changes in Ownership/Operator (see instructions)
☐ Waste Discharge Requirements Update or NPDES Permit Reissuance
☐ Other: ____________________

V. CALIFORNIA ENVIRONMENTAL QUALITY ACT (CEQA)

Name of Lead Agency: ____________________

Has a public agency determined that the proposed project is exempt from CEQA? ☐ **Yes** ☐ **No**

If Yes, state the basis for the exemption and the name of the agency supplying the exemption on the line below.

Basis for Exemption/Agency: ____________________

Has a "Notice of Determination" been filed under CEQA? ☐ **Yes** ☐ **No**

If Yes, enclose a copy of the CEQA document, Environmental Impact Report, or Negative Declaration. If no, identify the expected type of CEQA document and expected date of completion.

Expected CEQA Documents:

☐ **EIR** ☐ **Negative Declaration**

Expected CEQA Completion Date: ____________________

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

State of California
Regional Water Quality Control Board

APPLICATION/REPORT OF WASTE DISCHARGE GENERAL INFORMATION FORM FOR WASTE DISCHARGE REQUIREMENTS OR NPDES PERMIT

VI. OTHER REQUIRED INFORMATION

Please provide a COMPLETE characterization of your discharge. A complete characterization includes, but is not limited to, design and actual flows, a list of constituents and the discharge concentration of each constituent, a list of other appropriate waste discharge characteristics, a description and schematic drawing of all treatment processes, a description of any Best Management Practices (BMPs) used, and a description of disposal methods.

Also include a site map showing the location of the facility and, if you are submitting this application for an NPDES permit, identify the surface water to which you propose to discharge. Please try to limit your maps to a scale of 1:24,000 (7.5' USGS Quadrangle) or a street map, if more appropriate.

VII. OTHER

Attach additional sheets to explain any responses which need clarification. List attachments with titles and dates below:

____

____

____

You will be notified by a representative of the RWQCB within 30 days of receipt of your application. The notice will state if your application is complete or if there is additional information you must submit to complete your Application/Report of Waste Discharge, pursuant to Division 7, Section 13260 of the California Water Code.

VIII. CERTIFICATION

"I certify under penalty of law that this document, including all attachments and supplemental information, were prepared under my direction and supervision in accordance with a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment."

Print Name: ____________________ Title: ____________________

Signature: ____________________ Date: ____________________

FOR OFFICE USE ONLY

Date Form 200 Received:	Letter to Discharger:	Fee Amount Received:	Check #:

California Environmental Protection Agency
Bill of Rights for Environmental Permit Applicants

California Environmental Protection Agency (Cal/EPA) recognizes that many complex issues must be addressed when pursuing reforms of environmental permits and that significant challenges remain. We have initiated reforms and intend to continue the effort to make environmental permitting more efficient, less costly, and to ensure that those seeking permits receive timely responses from the boards and departments of the Cal/EPA. To further this goal, Cal/EPA endorses the following precepts that form the basis of a permit applicant's "Bill of Rights."

1. Permit applicants have the right to assistance in understanding regulatory and permit requirements. All Cal/EPA programs maintain an Ombudsman to work directly with applicants. Permit Assistance Centers located throughout California have permit specialists from all the State, regional, and local agencies to identify permit requirements and assist in permit processing.

2. Permit applicants have the right to know the projected fees for review of applications, how any costs will be determined and billed, and procedures for resolving any disputes over fee billings.

3. Permit applicants have the right of access to complete and clearly written guidance documents that explain the regulatory requirements. Agencies must publish a list of all information required in a permit application and of criteria used to determine whether the submitted information is adequate.

4. Permit applicants have the right of timely completeness determinations for their applications. In general, agencies notify the applicant within 30 days of any deficiencies or determine that the application is complete. California Environmental Quality Act (CEQA) and public hearing requests may require additional information.

5. Permit applicants have the right to know exactly how their applications are deficient and what further information is needed to make their applications complete. Pursuant to California Government code Section 65944, after an application is accepted as complete, an agency may not request any new or additional information that was not specified in the original application.

6. Permit applicants have the right of a timely decision on their permit application. The agencies are required to establish time limits for permit reviews.

7. Permit applicants have the right to appeal permit review time limits by statute or administratively that have been violated without good cause. For state environmental agencies, appeals are made directly to the Cal/EPA Secretary or to a specific board. For local environmental agencies, appeals are generally made to the local governing board or, under certain circumstances, to Cal/EPA. Through this appeal, applicants may obtain a set date for a decision on their permit and, in some cases, a refund of all application fees (ask boards and departments for details).

8. Permit applicants have the right to work with a single lead agency where multiple environmental approvals are needed. For multiple permits, all agency actions can be consolidated under a lead agency. For site remediation, all applicable laws can be administered through a single agency.

9. Permit applicants have the right to know who will be reviewing their application and the time required to complete the full review process.

Linda S. Adams
Secretary for Environmental Protection

California Regional Water Quality Control Board
Central Valley Region
Robert Schneider, Chair

Fresno Branch Office
1685 E Street, Fresno, California 93706
(559) 445-5116 • Fax (559) 445-5910
http://www.waterboards.ca.gov/centralvalley

Arnold Schwarzenegger
Governor

INFORMATION NEEDS FOR LIQUID WASTE DISPOSAL TO LAND

A report of waste discharge consists of a complete State Form 200 and a technical report that thoroughly characterizes the discharge. The technical report must be signed and certified by a registered civil engineer. To accommodate our filing system, the technical report should be indexed, unbound, and provide at least a 1-inch top margin. Information Needs for liquid waste disposal to land are:

1. Facility Description. Describe the facility in terms of what is accepted, how it is processed, and what is produced. The description should quantify what is produced on a daily basis. Briefly describe significant plant equipment (e.g., boilers, evaporators, ion exchange units, reverse osmosis units) and its function within the process. Provide the hours of operation and any seasonal variations in the operation of the facility.

2. Waste Characteristics. Describe the quality of each component of the waste stream proposed to be discharged to land (i.e., process wastewater, wash water, boiler blowdown, etc). Describe any pretreatment the wastewater receives prior to discharge and the removal efficiencies. The description should include maximum and average flow and concentrations of BOD, suspended matter, minerals analysis,[1] and total nitrogen of the discharge following pretreatment. Describe daily or seasonal variations in the volume and/or quality of the discharge, how such parameters are monitored, and how the flow rate of the discharge is measured.

3. Process Flow Diagram. Provide a flow process diagram for the facility and its discharge. Indicate sources and volumes of intake water, operations contributing wastewater to the effluent, and treatment units. Construct a water balance indicating average daily and maximum daily flows (mgd) between intakes, operations, treatment units, and outfalls.

4. Chemical Usage. Provide a detailed accounting of the chemical usage at the facility for all chemicals that enter the process stream (e.g., acids, bases, and salts) and a description of how and where in the process stream they enter. Estimate the amount of chemical used on an annual basis and describe any seasonal variability in chemical usage. Further, report any hazardous wastes that may be generated at the facility and certify that all hazardous wastes will be disposed of in accordance with California Code of Regulation (CCR), Title 23, Chapter 15 and will not be commingled with process wastewater.

5. Vicinity Map. Provide a scale map based on the appropriate USGS 7 ½ Quadrangle map (or its equivalent) showing the location and acreage of the wastewater application area. The map must indicate all topographical features, the direction of groundwater flow, all domestic and irrigation wells within 500 feet of the site, the direction of prevailing wind, all residences within 1/2-mile of the site, and land use in the vicinity of the site.

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[1] Minerals Analysis as referred to in this document shall include alkalinity, bicarbonate, calcium, carbonate, chloride, conductivity, copper, hardness, hydroxide, iron, magnesium, manganese, nitrate, pH, potassium, sodium, sulfate, total dissolved solids, zinc, and all major anions and cations. Analyses should be accompanied by an anion-cation balance demonstrating that analyses are complete.

6. Site Map. Provide a scale map of the site showing the location and dimensions of all major buildings, roads and parking areas, process and wastewater treatment structures, drainage control structures, on-site wells, ponds, and wastewater application areas.

7. Treatment and Holding Ponds. Ponds must be designed to contain total annual precipitation using a rainfall return period of 100 years without exceeding two feet of freeboard unless you can provide certification by a California registered civil engineer, or geotechnical engineer, or engineering geologist that the integrity of the levees will be assured at lesser freeboard. Provide a description of the pond(s) including dimension, separation between groundwater and the pond invert, the presence or absence of a liner, and holding capacity. If a liner will be present, describe proposed materials and construction specifications. Provide calculations demonstrating that two feet of freeboard will be maintained under the conditions described above or lesser freeboard if certified as adequate to prevent overtopping, overflows, and levee failures. Describe how the ponds will be managed and maintained (e.g., sludge removal).

8. Soils. Provide information on soil types underlying ponds and/or wastewater application areas from the ground surface to the saturated zone. Soils information should include data from on-site borings, logged by a California registered geologist or civil engineer, and may include referenced data from published sources.

9. Groundwater. Provide information on the depth to first groundwater and its gradient and direction of flow for each area, based on data from wells of known construction which are perforated in the upper aquifer. If such data is not available, provide an estimate based on referenced data from published sources.

10. Surface Water. Provide slope and direction of surface drainage at the proposed facility and disposal area. Provide name and location of nearest surface water bodies (i.e., streams, lakes, storm water basins) that would receive storm water drainage from the proposed facility and disposal areas. Provide average annual precipitation and evaporation data, and the source of the data.

11. Source Water. Provide water quality and quantity information, and describe the source of water for the facility (e.g., on-site wells, canals, municipal supply). At a minimum, run a standard minerals[1] analysis of facility source water.

12. Waste Management Plan. Provide a wastewater management plan that:

   a) discusses wastewater application in terms of
      (i) acreage and description of individual daily application areas
      (ii) irrigation type (e.g., sprinkler, furrow irrigation, etc.)
      (iii) furrow length and spacing or sprinkler type
      (iv) crops to be grown and harvested and season of cropping
      (v) frequency the application area(s) is/are scraped, disked, or ripped
      (vi) depth of application (inches)
      (vii) drying time (days)
   b) calculates wastewater loading of the application area in terms of (include supporting calculations)
      (i) hydraulic loading (gpd, inches/month)
      (ii) maximum and average BOD_5 loadings (lbs/acre/day) using actual acreage and wastewater volumes applied on each day of discharge
      (iii) nitrogen loading (lbs/acre/year) assuming no denitrification

   (iv) nitrogen loading (lbs/acre/year) assuming a specified denitrification rate
   (v) the use of any commercial fertilizers
c) calculates a water and nutrient balance in terms of (include supporting calculations)
   (i) a monthly water balance using a rainfall return period of 100 years
   (ii) an annual nitrogen balance

The plan must demonstrate that wastewater application at the design flow can be accomplished in accordance with accepted irrigation practices, and without contributing additional nitrogen to ground water. The plan must include contingencies for wastewater disposal for periods when the application area is saturated (i.e., during rainfall events) and for supplemental water if the wastewater is insufficient for irrigation. The plan must also describe methods to prevent runoff of tail water into streams, drainage courses, and/or onto properties owned by others, and to prevent the occurrence of nuisance vectors and odors.

13. Solids Handling. Describe all solid wastes generated at the facility and discuss how they are handled and disposed of. Volumes, chemical and physical characteristics, and final disposition of each waste stream (e.g., land application, compost, landfill) needs to be described. If solid wastes are treated or disposed of on-site, a waste management plan for those wastes needs to be included.

14. Monitoring and Reporting. Describe proposed monitoring activities during discharge operations to determine the accuracy and variance of the information requirements described in Items 2, 3, and 4. Describe a proposed monitoring plan to demonstrate that the waste management plans described in Item 12, is being implemented, and that includes periodic confirmation (e.g., through frequent sampling) that the loading described in Item 12, is being adhered to. Describe a proposed monitoring plan to demonstrate that water quality is not degraded by the discharge. Water quality monitoring should include groundwater monitoring wells, surface water monitoring and soils monitoring as appropriate.

15. Contact Information. Provide the name, address, and phone number of the person(s) responsible for operating and maintaining the production facility and wastewater application area.

Linda S. Adams
Secretary for Environmental Protection

California Regional Water Quality Control Board
Central Valley Region

Robert Schneider, Chair

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INFORMATION NEEDS FOR LIQUID WASTE DISPOSAL TO LAND

A report of waste discharge consists of a complete State Form 200 and a technical report that thoroughly characterizes the discharge. The technical report must be signed and certified by a registered civil engineer. To accommodate our filing system, the technical report should be indexed, unbound, and provide at least a 1-inch top margin. Information Needs for liquid waste disposal to land are:

1. Facility Description. Describe the facility in terms of what is accepted, how it is processed, and what is produced. The description should quantify what is produced on a daily basis. Briefly describe significant plant equipment (e.g., boilers, evaporators, ion exchange units, reverse osmosis units) and its function within the process. Provide the hours of operation and any seasonal variations in the operation of the facility.

2. Waste Characteristics. Describe the quality of each component of the waste stream proposed to be discharged to land (i.e., process wastewater, wash water, boiler blowdown, etc). Describe any pretreatment the wastewater receives prior to discharge and the removal efficiencies. The description should include maximum and average flow and concentrations of BOD, suspended matter, minerals analysis,[1] and total nitrogen of the discharge following pretreatment. Describe daily or seasonal variations in the volume and/or quality of the discharge, how such parameters are monitored, and how the flow rate of the discharge is measured.

3. Process Flow Diagram. Provide a flow process diagram for the facility and its discharge. Indicate sources and volumes of intake water, operations contributing wastewater to the effluent, and treatment units. Construct a water balance indicating average daily and maximum daily flows (mgd) between intakes, operations, treatment units, and outfalls.

4. Chemical Usage. Provide a detailed accounting of the chemical usage at the facility for all chemicals that enter the process stream (e.g., acids, bases, and salts) and a description of how and where in the process stream they enter. Estimate the amount of chemical used on an annual basis and describe any seasonal variability in chemical usage. Further, report any hazardous wastes that may be generated at the facility and certify that all hazardous wastes will be disposed of in accordance with California Code of Regulation (CCR), Title 23, Chapter 15 and will not be commingled with process wastewater.

5. Vicinity Map. Provide a scale map based on the appropriate USGS 7 ½ Quadrangle map (or its equivalent) showing the location and acreage of the wastewater application area. The map must indicate all topographical features, the direction of groundwater flow, all domestic and irrigation wells within 500 feet of the site, the direction of prevailing wind, all residences within 1/2-mile of the site, and land use in the vicinity of the site.

[1] Minerals Analysis as referred to in this document shall include alkalinity, bicarbonate, calcium, carbonate, chloride, conductivity, copper, hardness, hydroxide, iron, magnesium, manganese, nitrate, pH, potassium, sodium, sulfate, total dissolved solids, zinc, and all major anions and cations. Analyses should be accompanied by an anion-cation balance demonstrating that analyses are complete.

6. Site Map. Provide a scale map of the site showing the location and dimensions of all major buildings, roads and parking areas, process and wastewater treatment structures, drainage control structures, on-site wells, ponds, and wastewater application areas.

7. Treatment and Holding Ponds. Ponds must be designed to contain total annual precipitation using a rainfall return period of 100 years without exceeding two feet of freeboard unless you can provide certification by a California registered civil engineer, or geotechnical engineer, or engineering geologist that the integrity of the levees will be assured at lesser freeboard. Provide a description of the pond(s) including dimension, separation between groundwater and the pond invert, the presence or absence of a liner, and holding capacity. If a liner will be present, describe proposed materials and construction specifications. Provide calculations demonstrating that two feet of freeboard will be maintained under the conditions described above or lesser freeboard if certified as adequate to prevent overtopping, overflows, and levee failures. Describe how the ponds will be managed and maintained (e.g., sludge removal).

8. Soils. Provide information on soil types underlying ponds and/or wastewater application areas from the ground surface to the saturated zone. Soils information should include data from on-site borings, logged by a California registered geologist or civil engineer, and may include referenced data from published sources.

9. Groundwater. Provide information on the depth to first groundwater and its gradient and direction of flow for each area, based on data from wells of known construction which are perforated in the upper aquifer. If such data is not available, provide an estimate based on referenced data from published sources.

10. Surface Water. Provide slope and direction of surface drainage at the proposed facility and disposal area. Provide name and location of nearest surface water bodies (i.e., streams, lakes, storm water basins) that would receive storm water drainage from the proposed facility and disposal areas. Provide average annual precipitation and evaporation data, and the source of the data.

11. Source Water. Provide water quality and quantity information, and describe the source of water for the facility (e.g., on-site wells, canals, municipal supply). At a minimum, run a standard minerals[1] analysis of facility source water.

12. Waste Management Plan. Provide a wastewater management plan that:

   a) discusses wastewater application in terms of
      (i) acreage and description of individual daily application areas
      (ii) irrigation type (e.g., sprinkler, furrow irrigation, etc.)
      (iii) furrow length and spacing or sprinkler type
      (iv) crops to be grown and harvested and season of cropping
      (v) frequency the application area(s) is/are scraped, disked, or ripped
      (vi) depth of application (inches)
      (vii) drying time (days)
   b) calculates wastewater loading of the application area in terms of (include supporting calculations)
      (i) hydraulic loading (gpd, inches/month)
      (ii) maximum and average BOD_5 loadings (lbs/acre/day) using actual acreage and wastewater volumes applied on each day of discharge
      (iii) nitrogen loading (lbs/acre/year) assuming no denitrification
      (iv) nitrogen loading (lbs/acre/year) assuming a specified denitrification rate

(v) the use of any commercial fertilizers

c) calculates a water and nutrient balance in terms of (include supporting calculations)
   (i) a monthly water balance using a rainfall return period of 100 years
   (ii) an annual nitrogen balance

The plan must demonstrate that wastewater application at the design flow can be accomplished in accordance with accepted irrigation practices, and without contributing additional nitrogen to ground water. The plan must include contingencies for wastewater disposal for periods when the application area is saturated (i.e., during rainfall events) and for supplemental water if the wastewater is insufficient for irrigation. The plan must also describe methods to prevent runoff of tail water into streams, drainage courses, and/or onto properties owned by others, and to prevent the occurrence of nuisance vectors and odors.

13. <u>Solids Handling</u>. Describe all solid wastes generated at the facility and discuss how they are handled and disposed of. Volumes, chemical and physical characteristics, and final disposition of each waste stream (e.g., land application, compost, landfill) needs to be described. If solid wastes are treated or disposed of on-site, a waste management plan for those wastes needs to be included.

14. <u>Monitoring and Reporting</u>. Describe proposed monitoring activities during discharge operations to determine the accuracy and variance of the information requirements described in Items 2, 3, and 4. Describe a proposed monitoring plan to demonstrate that the waste management plans described in Item 12, is being implemented, and that includes periodic confirmation (e.g., through frequent sampling) that the loading described in Item 12, is being adhered to. Describe a proposed monitoring plan to demonstrate that water quality is not degraded by the discharge. Water quality monitoring should include groundwater monitoring wells, surface water monitoring and soils monitoring as appropriate.

15. <u>Contact Information</u>. Provide the name, address, and phone number of the person(s) responsible for operating and maintaining the production facility and wastewater application area.

APPENDIX D

Standard Requirements for Monitoring Well Installation Reports

MONITORING WELL WORKPLAN AND MONITORING WELL
INSTALLATION REPORT REQUIREMENTS

Prior to installation of groundwater monitoring wells, the Discharger shall submit a workplan containing the minimum listed information. Wells may be installed after staff approves the workplan. Upon installation of the monitoring wells, the Discharger shall submit a report of results, as described below. All workplans and reports must be signed by a registered geologist, certified engineering geologist, or civil engineer registered or certified by the State of California.

SECTION 1 - Monitoring Well Installation Workplan

A. General Information:
- Purpose of well installation project
- Copies of County Well Construction Permits (to be submitted after workplan review)
- Monitoring well locations and rationale
- Survey details
- Equipment decontamination procedures
- Health and safety plan
- Topographic map showing any existing wells, proposed wells, waste handling facilities, utilities, and other major physical and man-made features.

B. Drilling Details:
- Describe drilling technique
- Sampling intervals, and logging methods

C. Monitoring Well Design:
- Casing diameter and centralizer spacing (if needed)
- Borehole diameter
- Depth of surface seal
- Well construction materials
- Diagram of proposed well construction details
- Type of well cap, bottom cap either screw on or secured with stainless steel screws
- Size of perforations and rationale
- Grain size of sand pack and rationale
- Thickness and position of bentonite seal and sand pack
- Depth of well, length and position of perforated interval

D. Well Development:
- Method of development to be used
- Method of determining when development is complete
- Parameters to be monitored during development
- Method of development water storage and disposal

E. Well Survey:
- Identify the Licensed Land Surveyor or Civil Engineer that will perform the survey
- Describe what well features will be surveyed (i.e. top of casing, horizontal and vertical coordinates, etc.)
- Vertical accuracy shall be to at least 0.01 foot

G. Well Sampling:
- Minimum time after development before sampling (48 hours)

Well purging method and amount of purge water
Sample containers, collection method, and preservation method
Table describing sample volumes, sample containers, preservation agents, and hold times
QA/QC procedures

H. Water Level Measurement:
The elevation reference point at each monitoring well shall be within 0.01 foot. Ground surface elevation at each monitoring well shall be within 0.01 foot.
Method and time of water level measurement shall be specified.

I. Proposed time schedule for work.

SECTION 2 – Groundwater Sampling and Analysis Plan

A. General Information:
Site Location
Monitoring well locations
Monitoring well construction details including elevation, well depth, casing material and size, and screen interval
Equipment decontamination procedures
Health and safety plan
Topographic map showing any existing wells, proposed wells, waste handling facilities, utilities, and other major physical and man-made features.

B. Water Level Measurement:
Ground surface elevation at each monitoring well shall be within 0.01 foot.
Method and time of water level measurement shall be specified
Water level in well shall be allowed to equilibrate prior to measuring the depth to water

C. Well Sampling:
Well purging method and amount of purge water, purge water storage
Sample containers, collection method, and preservation method
Table describing sample volumes, sample containers, preservation agents, and hold times
Identification of analytical laboratory
Chain of custody procedures
QA/QC procedures

D. Proposed time schedule for work.

SECTION 3 - Monitoring Well Installation Report

A. Well Construction:
Number and depth of wells drilled
Date(s) wells drilled and completed
Description of drilling and construction
Scaled map of facility site features including monitoring wells, buildings, storage ponds, waste piles, etc.
A well construction diagram for each well must be included in the report, and must contain the following details:

Drilling Contractor and driller name
Depth of open hole (same as total depth drilled if no caving occurs)
Method and materials of grouting excess borehole
Footage of hole collapsed
Length of slotted casing installed
Depth of bottom of casing
Depth to top of sand pack
Thickness of sand pack
Depth to top of bentonite seal
Thickness of bentonite seal
Thickness of concrete grout
Boring diameter
Casing diameter
Casing material
Size of perforations
Well elevation at top of casing
Stabilized depth to groundwater
Date of water level measurement
Monitoring well number
Date drilled
Location

B. Well Development:

Date(s) of development of each well
Method of development
Volume of water purged from well
How well development completion was determined
Method of effluent disposal
Field notes from well development should be included in report.

C. Well Survey:

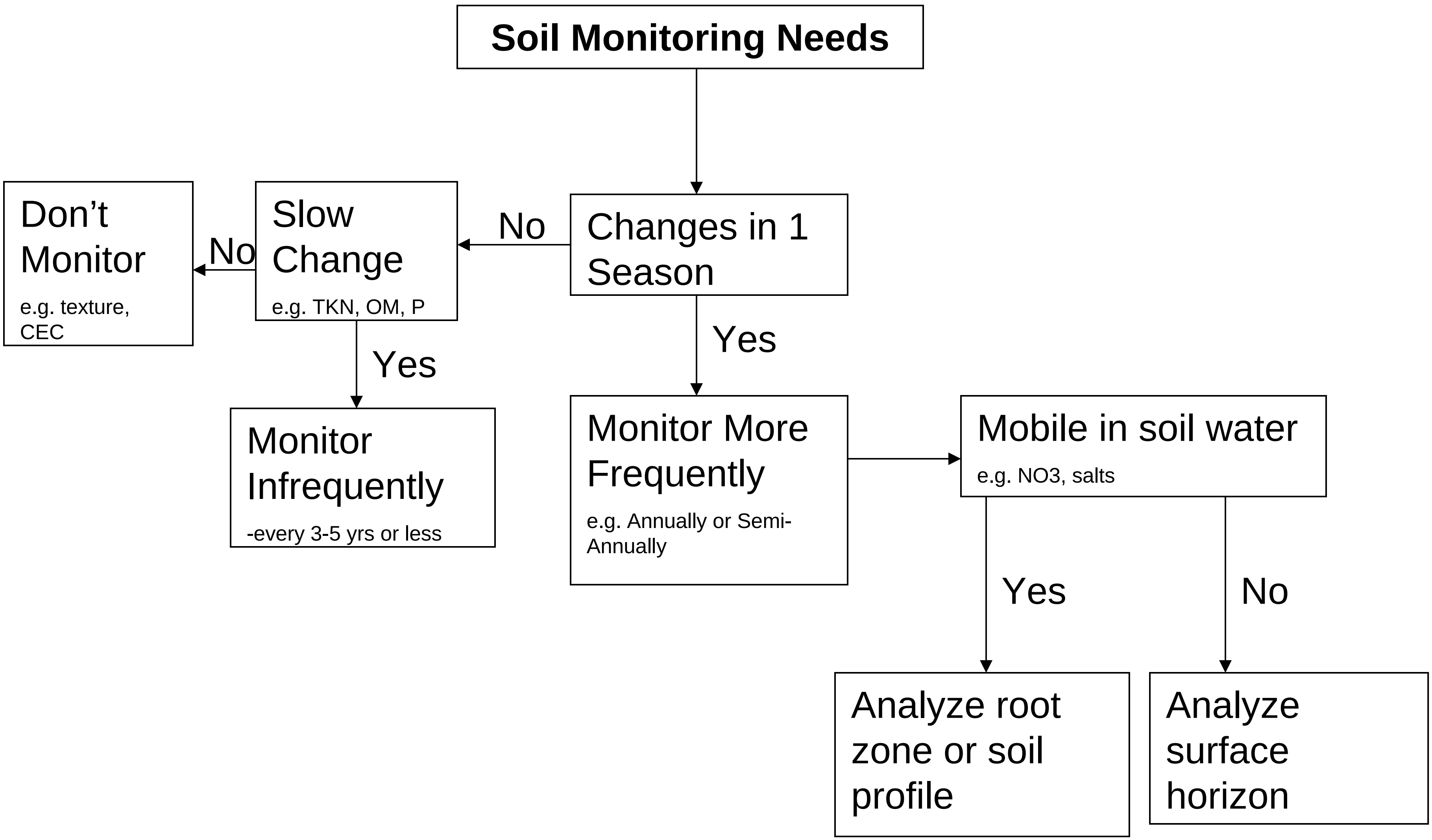
Identify the coordinate system or reference points
Survey the well casing with the cap removed (horizontal and vertical coordinates)
Registered Engineer or Licensed Surveyor's report and field notes in appendix
Describe the measuring points (i.e. ground surface, top of casing, etc.)
Tabular survey data

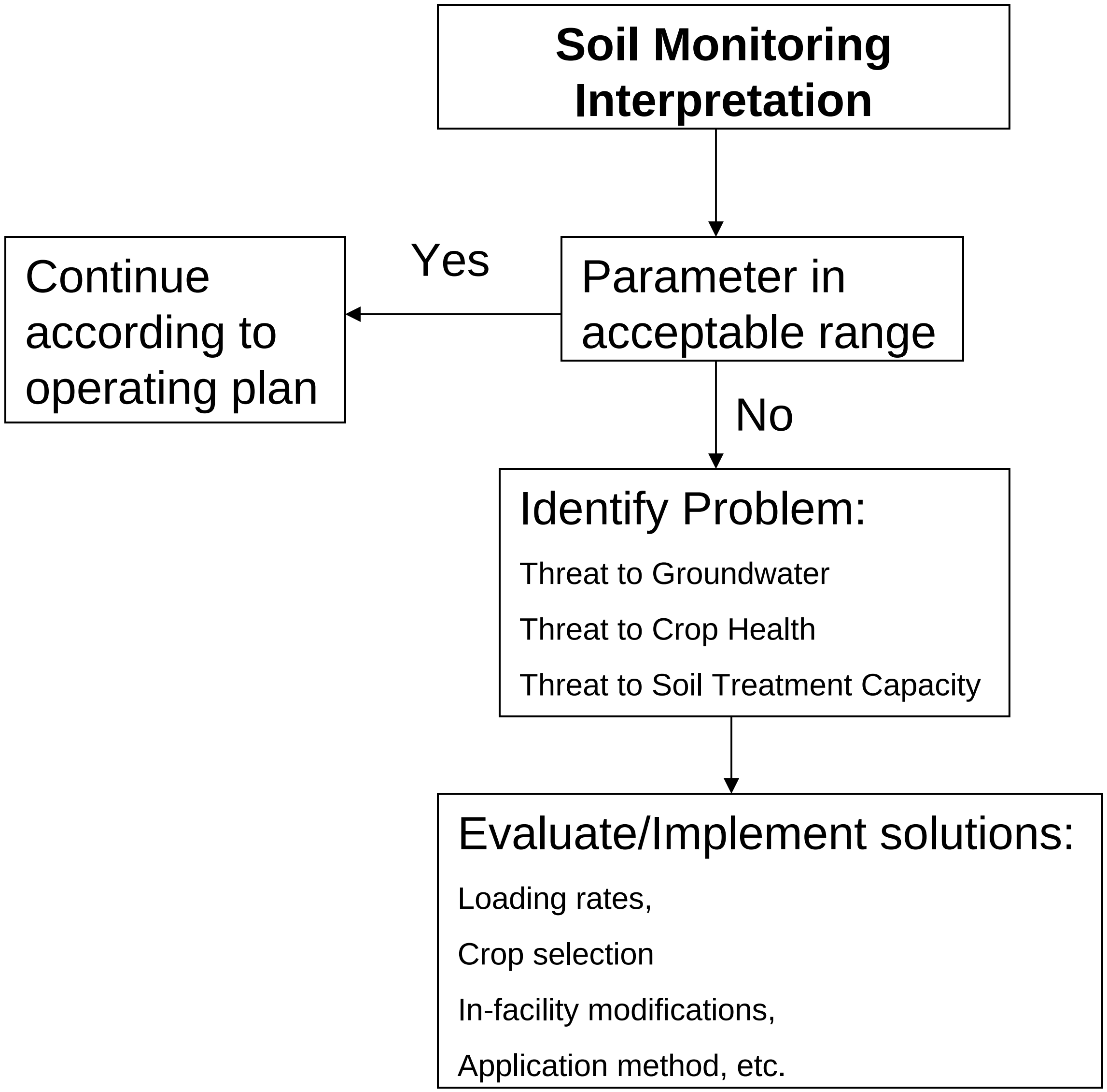
APPENDIX E

Decision Trees for Soils Evaluations

Manual of Good Practices Subcommittee #4

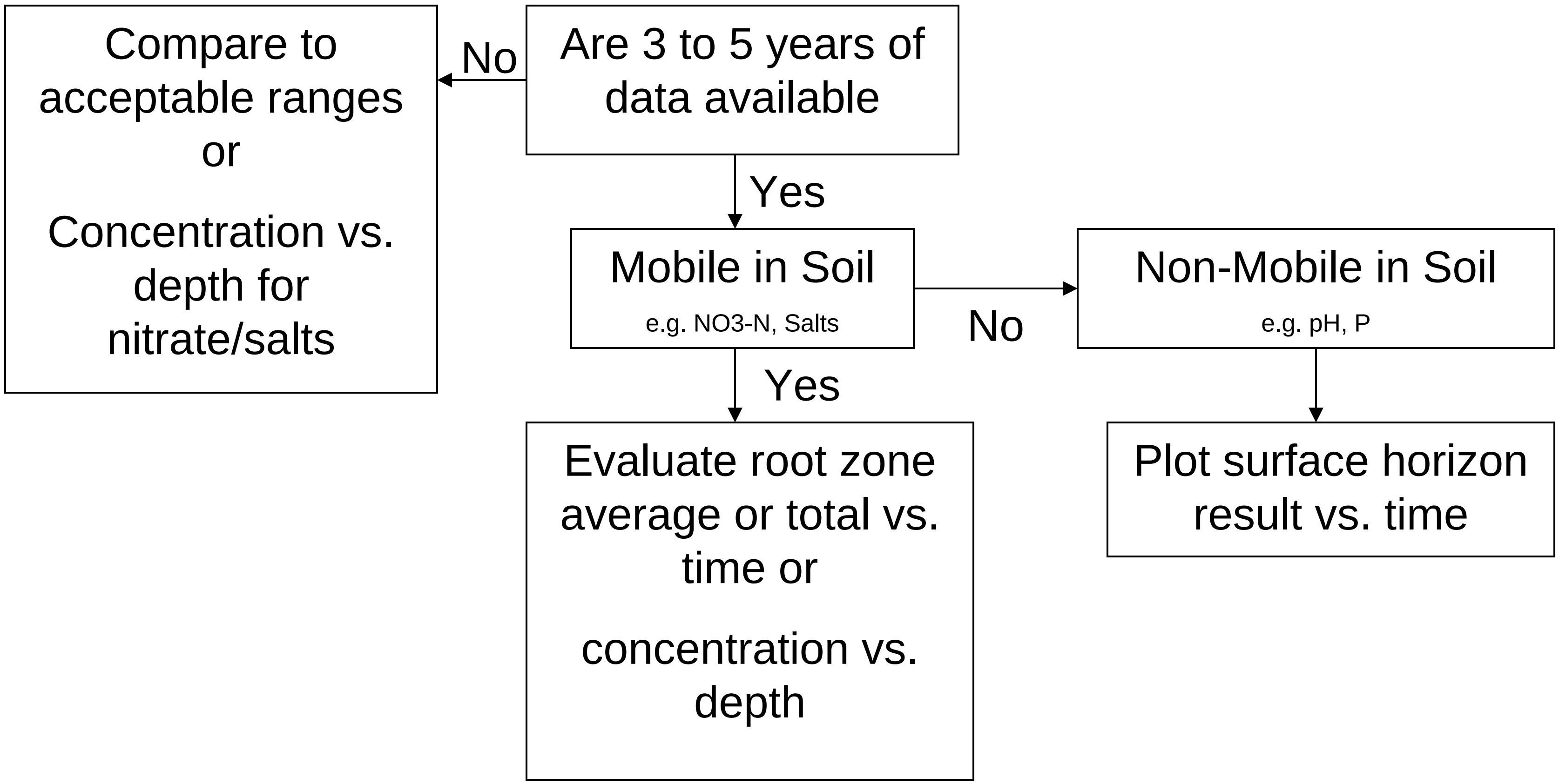
Soil Monitoring Considerations


Soil Monitoring Needs
Changes in 1 Season
No
Slow Change
e.g. TKN, OM, P
No
Don't Monitor
e.g. texture, CEC
Yes
Monitor Infrequently
-every 3-5 yrs or less
Yes
Monitor More Frequently
e.g. Annually or Semi-Annually
Mobile in soil water
e.g. NO3, salts
Yes
No
Analyze root zone or soil profile
Analyze surface horizon


Soil Monitoring Interpretation
Parameter in acceptable range
Yes
Continue according to operating plan
No
Identify Problem:
Threat to Groundwater
Threat to Crop Health
Threat to Soil Treatment Capacity
Evaluate/Implement solutions:
Loading rates,
Crop selection
In-facility modifications,
Application method, etc.

Soil Monitoring Interpretations

Trend Analysis



The purpose of trend analysis is to identify process water management practices over time as reflected in changes in soil chemistry and quality over time.

APPENDIX F

Transport of Constituents in Groundwater

The following text is taken from the Guidance for Reclamation and Reuse of Municipal and Industrial Wastewater by the Idaho Department of Environmental Quality. Example calculations are provided for evaluating the transport of constituents to groundwater and mixing with groundwater based on guidelines from the USEPA and other sources. More sophisticated transport modeling can be accomplished using transport model computer programs.

7.7.5.2.2 Estimation of Ground Water Impact

The potential impact to the underlying ground water can be estimated using constituent mass flux information from lysimeter sampling and basic aquifer characteristics. One important simplifying assumption made here is that there is no sorption, denitrification, precipitation or other constituent losses or sequestration between the bottom of the crop root zone and ground water. All of these treatment processes are possible, which makes this assumption conservative.

Continuing with the same example, the potential ground water impacts at the down gradient boundary of the source area can be estimated using the EPA aquifer-mixing model (EPA, 1981).

$$C_{mix} = \frac{C_p Q_p + C_{gw} Q_{gw}}{Q_p + Q_{gw}}$$

Equation 7-4. EPA aquifer-mixing equation .

Where:

C_{mix} = constituent concentration in percolate and ground water mixture.

C_p = constituent concentration in percolate.

Q_p = percolate flow.

C_{gw} = constituent concentration in up gradient ground water.

Q_{gw} = ground water flow (volume/time).

Q_{gw} is calculated as shown:

$$Q_{gw} = kiA$$

Equation 7-5. Calculation of ground water flow, (Q_{gw}).

Where:

k = hydraulic conductivity (in ft/day)

i = gradient (ft/ft)

A = cross sectional area of down gradient boundary perpendicular to ground water flow, and is calculated by:

$$A = L * d$$

Equation 7-6. Calculation of down gradient cross sectional area perpendicular to ground water flow (A).

Where:

L = the length of the down gradient boundary perpendicular to ground water flow

d = the depth of the mixing zone. (special note: do depth calculations in metric units (meters), then convert to feet for remainder of the mixing zone calculations. This is calculated by:

$$d = d_{\alpha v} + d_{Iv}$$

Equation 7-7. Calculation of ground water mixing zone depth (d).
(Source: eq. 44, page 45. EPA/540/R-95/128 May 1996. Soil Screening Guidance: Technical Background Document)

Where:

$d_{\alpha v}$ = depth of mixing due to vertical dispersivity, or

$$d_{\alpha v} = (2\alpha_v L)^{0.5}$$

d_{Iv} = depth of mixing due to downward velocity of infiltrating water (Source: eq. 38, page 44. EPA/540/R-95/128 May 1996. Soil Screening Guidance: Technical Background Document)

$$d_{Iv} = d_a\{1 - \exp[(-LI)/(V_s n_e d_a)]\}$$

Where:

α_v = vertical dispersivity (m)

$$a_v = 0.01\alpha_L$$

α_L = longitudinal dispersivity

$$\alpha_L = 0.82(\log_{10} L)^{2.446}$$

(Source: eq. 14b, page 907. Xu, M. and Eckstein, Y. 1995. Ground Water Vol. 33, No. 6; as corrected by Al-Suwaiyan, M.S., 1996, Ground Water Vol. 34 No. 4, page 578.)

Where:

L = length of source parallel to GW flow (meters)
n_e = effective aquifer porosity
d_a = aquifer depth (meters)
I = leachate infiltration rate (meters/yr)
V_s = ground water seepage velocity; (meters/year)

$$V_s = Ki/n_e$$

For this example, we are given the following:

For mixing zone depth calculations:

L = 2087 ft or 636.3 m
n_e = 0.30
d_a = 30 meters
I = 19.03 in/EP * 1 EP/2.25 yr * 1 ft/12 in * 1 m/3.28 ft = 0.218 m/yr
(note EP = evaluation period = 2.25 years in this example)
$\alpha_L = 0.82(\log_{10} 636.3 \text{ m})^{2.446} = 10.2$
α_v = 0.102
k = 100 ft/day;
i = 0.0015 ft/ft (7.92 ft/mile); and
$V_s = ki/n_e$ = (100 ft/day)*(0.0015 ft/ft)/0.3 * 365 day/yr * 3.28 m/ft = 55.6 m/yr

d_{Iv} = 30*{1 – exp[(-(636.3 * 0.218))/(55.6 * 0.3 * 30)]} = 7.2

$d_{\alpha v}$ = (2 * 0.102 * 636.3)$^{0.5}$ = 11.4

d = 11.4 + 7.2 = 18.2 meters or 61 ft

Site dimensions: square site of 100 acres (2087 ft by 2087 ft).

In our example,

Q_{gw} = kiA =(100 ft/day)*(0.0015 ft/ft)*(61 ft)*(2087 ft)
= 19096 ft^3/day, or
= (19096 ft^3/day)*(365 days/year)*(1 acre-ft/43,560 ft^3)
= 160 acre-ft/year discharging from the down gradient boundary,
or, for the volume during the evaluation period (EP)
= 160 acre-ft/yr * 2.25 yr/EP = 360 ac-ft/EP

Q_p is 19.03 in/EP (from Table 7-21). Converting to acre-feet we have:

Q_p = (19.03 in/[EP acre-year])*(100 acres)*(1 acre-feet/12 acre-inches)
Q_p = 158.6 acre-ft/EP

C_p = 16.93 mg/L (from Table 7-21).

C_{gw} = 3 mg/L

Putting these values into the EPA mixing zone equation introduced above we have:

$$C_{mix} = \frac{(16.93\text{ mg/L})*(158.6\text{ ac-ft/EP}) + (3.0\text{ mg/L})*(360\text{ ac-ft/EP})}{158.6\text{ ac-ft/EP} + 360\text{ ac-ft/EP}}$$

Solving for C_{mix}, the units acre-ft/year cancel to give units of mg/L, or

C_{mix} = 7.26 mg/L

The final ground water NO_3-N concentration is estimated to be 7.26 mg/L when the system achieves steady state conditions (which may or may not occur within the evaluation period). This result indicates that while the ground water standard for nitrate will not be exceeded, it does indicate the ground water concentration for nitrate-nitrogen is estimated to increase from 3.0 mg/L to 7.26 mg/L. Although most of the quarterly lysimeter samples exceeded the Maximum Contaminant Level, the ground water standard was not modeled to exceed the ground water standard. Beneficial uses may or may not be impacted, depending upon this modeled change in ground water quality is determined significant by DEQ in the site-specific circumstances.

As discussed at the beginning of 7.3, a maximum percolate constituent concentration (given a constant percolation rate) that will comply with site specific permit conditions can be determined. For example, if a down gradient ground water concentration limit (Cmix) is set at 10 mg/L at the down gradient boundary of the source area, and retaining other values assumed above, we can utilize the mixing zone equation and solve for percolate concentration (Cp).

$$C_p = \frac{\left[C_{mix} * \left(Q_p + Q_{gw}\right)\right] - \left(C_{gw} * Q_{gw}\right)}{Q_p}$$

$$C_p = \frac{[10 \text{ mg/L} * (158.6 \text{ ac-ft/EP} + 360 \text{ ac-ft/EP})] - (3.0 \text{ mg/L} * 360 \text{ ac-ft/EP})}{158.6 \text{ ac-ft/yr}}$$

C_p = 25.9 mg/L

Given the assumptions above, the percolate could have a value of less than 25.9 mg/L and theoretically not cause exceedance of the ground water standard of 10 mg/L.

7.7.5.2.3 Depth to Water/Travel Time

As discussed in Section 7.1, the estimated travel time of percolate to ground water and other critical factors should be evaluated to help determine whether vadose zone or ground water monitoring would be more practical and appropriate.

Differences in the thickness and composition of the vadose zone affects travel times and for certain constituents the attenuation of constituents percolating through this zone. For example, fractured basalt, if few or thin interbeds are present, provides rapid travel times and negligible treatment. In this case ground water monitoring may still be warranted, even in areas where the vadose zone thickness is substantial.

There are several computer models which may be utilized to characterize unsaturated flow. A simple method of estimating travel time through the vadose zone employs the unit gradient *Lumped Time of Travel Model* (c.f. Guymon, G.L., 1994 pp 103-104). In this model the system is: 1) assumed to be at steady-state with a uniform moisture content, 2) the vadose zone is unlayered, with uniform hydraulic characteristics, and 3) the hydraulic gradient is equal to unity. Under these conditions the hydraulic conductivity is equal to the net percolation rate (Guymon, 1994). The pore velocity (V) can then be estimated with:

$$V = P_o / \theta$$

Equation 7-8. Calculation of pore velocity (V).

Where:

P_o = net percolation rate (amount of water per unit time; typically expressed in terms such as feet/yr). This variable represents the net amount of water that may be expected to move below the crop root zone. (An example of how P_o may be calculated is found in Guymon, G.L. [1994] pp 81-83.)

θ = soil moisture content (volume of water/total soil volume) and is expressed in dimensionless terms as a decimal fraction. θ may be obtained indirectly from tensiometer data, given a soil-specific relationship between θ and soil tension (soil water characteristic curve), from gravimetric analysis of soil cores taken below the root zone soon after an irrigation event, or may be estimated from the use of unsaturated flow computer models. Also, θ may be estimated by use of Gardener's equations (Gardner 1958) (Eq. Equation 7-9 and Equation7-10) if ψ >= -1 atm of pressure head in the vadose zone. If the latter condition does not hold, other methods should be used (c.f. Guymon 1994 p. 70 ff.)

Guymon also references W.R. Gardner's equations in this model. Using these equations to estimate θ, one must first obtain an estimate of ψ, the pressure head in the vadose zone by using:

$$K(\Psi) = \frac{K_s}{A_k|\Psi|^{\beta} + 1}$$

Equation 7-9. Gardner equation for unsaturated hydraulic conductivity K(ψ).

Where:

K_s = the saturated hydraulic conductivity; and A_k and β, best fit parameters; are found in Guymon, (1994) p. 70, and are reproduced in Table 7-22.

K(ψ), the hydraulic conductivity at a given pressure head is taken to be equal to P_o.

Equation 7-9 is rearranged to solve for ψ.

$$|\Psi| = e^{\{\ln[(K_s - Po)/AkPo]/\beta\}}$$

Equation7-10. Solving Equation 9 for soil pressure head (Ψ).

Table 7-22. Approximate Gardner's Parameters for Calculating Unsaturated Hydraulic Conductivity

Soil Texture	Ks (cm· h^-1^)	Ak (ψ in cm of water)	β
Sand (dirty)	3.75	$0.132 \cdot 10^{-2}$	2.576
Sandy Loam	1.17	$0.127 \cdot 10^{-4}$	3.731
Silt Loam	0.30	$0.132 \cdot 10^{-4}$	3.135

From Gardner 1958.

Solving for ψ, this value is substituted into Equation 7-11 to obtain θ.

$$\theta = \frac{\theta_s}{A_w|\Psi|^{\alpha} + 1}$$

Equation 7-11. Gardner equation for calculating soil moisture content (θ).

Where:

θ_s = soil porosity expressed as a decimal. A_w and α, best fit parameters, are found in Guymon (1994) p. 51, and are reproduced in Tabe 7-24.

Table 7-23. Gardner Parameters for Soils

Soil Texture	Θ_s	A_w	α
Sand	0.36	0.0787	0.614
Sandy Loam	0.42	0.0149	0.743
Loam	0.50	0.0121	0.720
Silty Loam	0.46	0.0024	1.079
Clay Loam	0.39	0.0420	0.418
Silty Clay Loam	0.43	0.0128	0.488
Clay	0.44	0.0002	1.007

[a]Values are approximate and are primarily for ranges of pressure head between zero and -1 atm. Pore-water pressure units are in cm of water. From Gardner 1958

Travel time (T) is then estimated by:

$$T = \frac{X}{V}$$

Equation7-12. Calculation of travel time (T).

Where:

X = thickness of the vadose zone (units of length).

V = pore velocity as defined previously

For example, if a rapid infiltration basin receives 85 inches of wastewater during a year's time and 80 inches is lost to deep drainage then:

$$P_o = K(\psi) = 80 \text{ inches/yr, or } 2.32 \text{ E-2 cm/hr}$$

If the vadose zone is composed of uniform sandy materials, we utilize Equation 7-10. Obtaining A_k = 0.132 E-2, β = 2.576, and K_s = 3.75 from Table A-10 (Guymon, 1994 p. 70), we solve for ψ:

$$|\Psi| = e^{\{\ln[(3.75 - 2.32 \cdot 10^{-2})/0.132 \cdot 10^{-2} * 2.32 \cdot 10^{-2}]/2.576\}} = 94.2 \text{ cm}$$

Next we utilize Equation 7-11, substituting ψ obtained from Equation A-10, obtaining θ_s = 0.36, A_w = 0.0787 and α = 0.614 from Guymon (1994) p. 51. This expression is then solved for θ:

$$\theta = \frac{0.36}{0.0787 \cdot 94.2^{0.614} + 1} = 0.16$$

Substituting P_o = 80 in/yr and θ = 0.16 into Equation 7-8, we obtain the pore velocity under steady-state conditions:

$$V = 80/0.16 = 500 \text{ in/yr or } 42 \text{ ft/yr}$$

If the vadose zone thickness were 50 feet then, using Equation 7-12, the travel time to ground water would be:

$$T = \frac{50}{42} = 1.2 \text{ yr}$$

APPENDIX G

Measurement of Salinity and Organics

Measurement of Salinity and Organics in Process/Rinse Water and Groundwater

Robert Beggs, Brown and Caldwell
Joe Drago, Kennedy/Jenks Consultants
November 2006

Introduction

The purpose of this information paper is to compare analytical methods and discuss the interpretation of analytical results for the characterization of salinity and organics in food process/rinse water and groundwater.

Salinity

Salinity is a term commonly used to describe the concentration or electrical conductivity (EC) effects of mineral salts dissolved in water. According to the American Heritage Dictionary, something described as saline means it is:

1. Of, relating to, or containing salt; salty.
2. Of or relating to chemical salts.

In the discussion in Standard Methods (2520 Salinity), the test for measuring salinity was "originally conceived as a measure of the mass of dissolved salts in a given mass of solution." However, Standard Methods goes on to describe electrical conductivity (EC) and density methods as the most appropriate indirect methods for measuring total salinity.

The purpose of salinity objectives for drinking water is normally to protect the aesthetic qualities of water. The purpose of salinity objectives for irrigation water is normally to keep the osmotic potential of soil-water within a reasonable range for plant growth. These objectives are applied to groundwater that could be extracted for the respective uses.

Salinity Related Analytical Methods and Their Interpretation

Total Dissolved Solids (TDS)

TDS is typically measured using Standard Methods 2540C. In this test, the sample is filtered to remove suspended solids greater than about 1.4 microns, evaporated at 180 ± 2 degrees C, and then remaining solids are weighed. The TDS test measures the mass of mineral salts, fine colloids, most of the dissolved organic matter, and some waters of hydration bound to mineral salts (e.g., $CaSO_4 \bullet 2H_2O$). In addition, bicarbonates in the original sample associated with hardness (calcium and magnesium) are converted to carbonates while bicarbonates associated with sodium and potassium may only be partially converted to carbonates. Approximately half of the bicarbonate mass is lost to water vapor and carbon dioxide as it is converted to carbonate by the following reactions:

$$Ca^{2+} + 2\ HCO_3^- \rightarrow CaCO_3 + H_2O + CO_2$$
$$Mg^{2+} + 2\ HCO_3^- \rightarrow MgCO_3 + H_2O + CO_2$$

$$2\ Na^+ + 2\ HCO_3^- \rightarrow Na_2CO_3 + H_2O + CO_2$$

$$2\ K^+ + 2\ HCO_3^- \rightarrow K_2CO_3 + H_2O + CO_2$$

Fixed Dissolved Solids (FDS)

FDS is measured using Standard Methods 2540E. In this test, the solids residue from the TDS test is fired at 550 degree C, and the remaining solids weighed. The FDS test essentially measures only the mass of mineral salts and fine mineral colloids from the original sample. Remaining sodium and potassium bicarbonate in the original TDS sample are lost to water vapor and carbon dioxide as they are converted to carbonates. In addition, some carbonates may be converted to oxides by the following reactions:

$$Na_2CO_3 \rightarrow Na_2O + CO_2$$
$$K_2CO_3 \rightarrow K_2O + CO_2$$
$$CaCO_3 \rightarrow CaO + CO_2$$

Waters of hydration are water held in crystalline structures with mineral salts. Some of these waters are held tightly enough that they are not lost until a sample is heated above 180 degrees C. Some examples are:

CaSO4 ·2H2O (gypsum), which loses 21% of its mass as it dehydrates.
MgSO4 ·7H2O (Epsom salt), which loses 51% of its mass as it dehydrates.

Volatile Dissolved Solids (VDS)

VDS is calculated as the difference between TDS and FDS. VDS represents most of the organics, some of the mass of original bicarbonate, all of the waters of hydration lost over 180 degrees C, and volatile colloids. Therefore, the mass of VDS will often be far greater than the mass of dissolved organics, especially at lower concentrations of organics.

Electrical Conductivity (EC)

EC is an indirect measure of total salinity that can be obtained using a simple meter. EC is affected by the presence of ionized organic acids, which may not completely be accounted for by the total alkalinity measurement. EC is not affected by some organics, such as sugars. EC is affected by temperature, so it is stated at a standard of 25 °C.

Measurement of Salinity in Process/Rinse Water

Process/rinse water often has high concentrations of non-ionized organics that are broken down in the upper soil layer to carbon dioxide and water. With adequate soil aeration, the carbon dioxide escapes to the atmosphere over time. Therefore, only the mineral salts in the process/rinse water are of interest in protecting groundwater salinity.

The most accurate method for measuring total mineral salinity in process/rinse water is to measure and sum the concentrations of all the major mineral ions. However, this procedure is relatively expensive for frequent use. The best measure for salinity of process/rinse water on a routine or frequent basis is FDS. As discussed above, mineral waters of hydration and a portion of the mass of original bicarbonate are lost in the FDS test, meaning that FDS slightly understates total mineral salinity. The relationship between FDS and the sum of major minerals can be derived from a few samples. Then FDS measurements can be multiplied by a correction factor to obtain a good estimate of total mineral salinity. An example of salinity and organic measurements from food process/rinse water samples is shown in Table 1.

EC can be useful as a "quick" measure of total salinity for comparative operational monitoring purposes for food process/rinse water, and average relationships between EC and the sum of the major minerals and/or FDS can also be derived. The use of EC directly for comparison with water quality objectives can overstate mineral salinity because of the presence of organic acids in process/rinse water. EC typically does provide a better indication of mineral salinity of food process/rinse water than the TDS test.

<u>Recommendation: Use the sum of ions and FDS.</u>

Table 1. Comparison of Salinity and Organic Measurements for Process/Rinse Water from Site A

Date	EC (µmhos/cm)	TDS (mg/L)	FDS (mg/L)	VDS (mg/L)	Sum of Minerals (mg/L)	TSS (mg/L)	BOD (mg/L)	COD (mg/L)
8/10/2005	1700	1500	1100	400	1250	11000	630	1300
9/14/2005	790	640	430	210	460	61	190	510

*Includes PO_4, NO_3, Cl, SO_4, Ca, Mg, Na, K, NH_4, and ALK*0.6 (as per SM 1030F), Concentrations of other ions are typically negligible.

Measurement of Organics in Food Process/Rinse Water

Food process/rinse water organic constituents that are easily biodegradable are traditionally measured using five-day biochemical oxygen demand (BOD). Chemical oxygen demand (COD) results can be obtained more quickly than BOD and can provide a better estimate of total ultimate oxygen demand if potential chloride interferences are addressed. COD tends to somewhat overstate ultimate biological oxygen demand. Total organic carbon (TOC) is rarely used to measure organics in food process/rinse water because of the high cost of the test and the fact that it is not specific to the biodegradable portion of the organics.

<u>Recommendation: Use BOD and (if needed) COD.</u>

Measurement of Salinity in Groundwater

The best measures of total salinity in groundwater samples are TDS and EC. FDS can be measured for comparison with the FDS of applied process/rinse water, but it will typically be somewhat less than TDS because it will not fully measure bicarbonates/carbonates and mineral waters of hydration as discussed previously. This is illustrated in Tables 2 and 3.

<u>Recommendation: Use TDS and EC.</u>

Table 2. Comparison of Organic and Solids Data for Groundwater Monitoring Well Sample from Actual Food Process/Rinse Sites

Site	Date	BOD	COD	EC	TDS	FDS	TOC	VDS
		(mg/L)	(mg/L)	(umhos/cm)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
A	3/27/2006	0	-	900	580	440	1.2	140
B	9/13/2005	0	14	5600	3700	2900	1.6	800

Table 3. Sum of Ions for Groundwater Monitoring Well Sample from Actual Food Process/Rinse Sites

Site	Date	ALKB* (mg/L $CaCO_3$)	Ca (mg/L)	Cl (mg/L)	K (mg/L)	Mg (mg/L)	Na (mg/L)	P (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)	Sum (mg/L)
A	3/27/2006	330	68	30	0	35	91		51	32	505
B	9/13/2005	550	130	1300	0	280	790	0	810	0	3640

*Bicarbonate Alkalinity from lab expressed as $CaCO_3$. Sum includes 0.6 x ALKB, as suggested by SM 1030F.

Measurement of Organics in Groundwater

Organics are usually found in very low concentrations in groundwater. BOD found in a sample from a groundwater monitoring well often can be an indication of short-circuiting of water from the surface through a broken well seal, animal holes, etc. COD can be used as an indicator of organics, but anecdotally COD has been found to increase along with increasing groundwater salinity even when no significant organic carbon is present in the groundwater, probably due to chloride or other interferences. TOC is the best test for organic compounds in groundwater, although it tends to be more expensive. VDS is not recommended for measuring organics in groundwater because the interference effects of bicarbonates and mineral waters of hydration typically overwhelm the organics actually in the groundwater. Examples of high VDS in groundwater that are due almost entirely to bicarbonate and waters of hydration are shown above in Tables 2 and 3.

<u>Recommendation: Use TOC and BOD.</u>

APPENDIX H

Salinity Removal by Crops

SALINITY REMOVAL BY CROPS

Crop Uptake of Salinity

The salinity uptake of crops can be measured by determining the ash content of the plant tissue. Values of crop uptake are presented in Tables H-1 and H-2. The procedure used to determine the ash (mineral) content of plant tissue is presented following the tables.

Table H-1. Values of Crop Uptake of Salinity
Del Monte Kingsburg Site, 2001-2006

Crop	Year	Yield, tons/acre	Ash,%	Salinity uptake, lb/ton	Salinity uptake, lb/acre
Winter wheat (grain plus straw)	2001	5.2	12.7	254	1321
	2002	1.5	7.9	158	237
	2004	0.85	11.8	236	201
Winter wheat/barley mix (grain plus straw)	2005	2.69	22.3	446	1200
	2006	4.66	13.66	273	1272
Triticale (grain plus straw)	2003	0.9	9.0	180	162
Field corn (grain plus stover)	2001	11.7	7.5	150	1755
Silage corn	2003	9.6	7.1	142	1363
Sorghum-sudan grass	2002	1.5	12.7	254	381
	2003	0.9	11.8	236	212
	2004	0.47	11.8	236	111
	2005	1.33	6.72	135	180
	2006	0.79	11.46	229	181
Bermuda grass hay	2006	6.8	8.19	164	1115

Ash content using Method TMECC-0302 B

Table H-2. Values of Crop Uptake of Salinity
Del Monte Caldwell, Idaho Site, 1993-1997

Crop	Year	Yield, lb/acre	Ash, %	Salinity uptake, lb/ton	Salinity uptake, lb/acre
Tall fescue	1996	7.94	13.05	261	2076
	1997	8.78	11.9	238	2091
Alfalfa	1996	4.82	16.2	326	1569
	1997	8.90	11.24	225	2000
Barley	1996	3.67	7.65	153	560
	1997	4.09	11.7	234	959

Test Method: Ash. Three Methods.							**Units:** % g g^{-1} dw	
Test Method Applications								
Process Management							**Product Attributes**	
Step 1: Feedstock Recovery	*Step 2:* Feedstock Preparation	*Step 3:* Composting	*Step 4:* Odor Treatment	*Step 5:* Compost Curing	*Step 6:* Compost Screening and Refining	*Step 7:* Compost Storing and Packaging	*Safety Standards*	*Market Attributes*
	03.02-A	03.02-A		03.02-A		03.02-A		
				03.02-B		03.02-B		
								03.02-C

03.02 ASH

DISCLAIMERS

(1) The methodologies described in TMECC do not purport to address all safety concerns associated with their use. It is the responsibility of the user of these methods to establish appropriate safety and health practices, and to determine the applicability of regulatory limitations prior to their use.

(2) All methods and sampling protocols provided in TMECC are subject to revision and update to correct any errors or omissions, and to accommodate new widely accepted advances in techniques and methods. Please report omissions and errors to the U.S. Composting Council Research and Education Foundation. An on-line submission form and instructions are provided on the TMECC web site, http://www.tmecc.org.

(3) Process alternatives, trade names, or commercial products as mentioned in TMECC are only examples and are not endorsed or recommended by the U.S. Department of Agriculture or the U.S. Composting Council Research and Education Foundation. Alternatives may exist or may be developed.

1. Scope

1.1 This section covers the measurement of ash content and volatile solids content for compost materials and feedstocks.

1.1.1 *Method 03.02-A Unmilled Material Ignited at 550°C without Inerts Removal.*

1.1.2 *Method 03.02-B Milled Material Ignited at 550°C with Inerts Removal.*

1.1.3 *Method 03.02-C Unmilled Material Ignited at 550°C with Inerts Removal.*

1.2 Values stated in SI units are to be regarded as the standard. Values given in parentheses are provided for information only.

2. Referenced Documents

2.1 *TMECC:*

Method 03.09-A Total Solids and Moisture.

Method 05.01 Biodegradable Volatile Solids.

Method 05.07-A Loss-on-Ignition Organic Matter.

2.2 *Other References:*

Cohen, I.R. 1973. Laboratory Procedure for the Preparation of Solid Waste Related Materials for Analysis. *In* Methods of Solid Waste Testing, EPA-6700-73-01. US EPA, Cincinnati, OH.

Methods for the Evaluation of Water and Wastewater, EPA 0600/4-79-020, US EPA, Environmental Monitoring and Support Laboratory, Cincinnati, OH 45268.

SM 2540-E, Fixed and Volatile Solids Ignited at 500°C. *In* Standard Methods for the Examination of Water and Wastewater. Part 2000. Physical and Aggregate Properties. 18th edition. 1992.

US EPA Method 600/4-79-020, adapted by physical removal of volatile solids that are not readily biodegradable.

3. Terminology

3.1 *ash, n*—The inorganic matter, or mineral residue of total solids that remains when a compost or feedstock is combusted at 550°C in the presence of excess air; equivalent to *fixed solids*, % g g^{-1}.

3.2 *biodegradable volatile solids, n*—The organic matter fraction; the biodegradable portion of total solids that volatilizes to carbon dioxide and other gasses when a compost or feedstock is combusted at 550°C in the presence of excess air, % g g^{-1}.

3.3 *fixed solids, n*—The inorganic matter, or mineral residue of total solids that remains when a compost or feedstock is combusted at 550°C in the presence of excess air; equivalent to *ash*, % g g^{-1}.

3.4 *moisture content, n*—The liquid fraction (percentage) of a compost or feedstock that evaporates at 70±5°C, % g g^{-1}.

3.5 *total solids, n*—The solid fraction (percentage) of a compost or feedstock that does not evaporate at 70±5°C, which consists of fixed solids, biodegradable volatile solids, and volatile solids that are not readily biodegradable, % g g^{-1}.

3.6 *volatile solids, n*—The sum of biodegradable materials, non-biodegradable materials, and biodegradable materials that do not degrade during the retention time allowed for composting, that volatilize to carbon dioxide and other gasses when a compost or feedstock is combusted at 550°C in the presence of excess air, % g g^{-1}.

4. Summary of Test Methods

4.1 *Method 03.02-A Unmilled Material Ignited at 550°C without Inerts Removal*—Quick-Test to determine moisture and total solids content at 70±5°C, and total ash and volatile solids content by combustion at 550°C in the presence of excess air and reported on an oven dried basis of an unsieved, as-received finished or in-process compost or feedstock sample.

4.1.1 This test is recommended for samples where no consideration need be given to inert materials and biodegradable materials that do not degrade during the retention time allowed for composting.

4.2 *Method 03.02-B Milled Material Ignited at 550°C with Inerts Removal*—Analytical test to determine biodegradable volatile solids contents (organic matter) by combustion at 550°C in the presence of excess air and reported on an oven-dried basis from an air-dried (36°C), sieved and milled compost sample from which non-biodegradable or biodegradable materials that do not readily humify have been removed.

4.2.1 This test method provides an estimate of biodegradable volatile solids. Compeusation for inert materials and biodegradable materials that do not degrade during the retention time for composting prior to combustion is accomplished by their removal through sample preparation prior to performing this test.

4.3 *Method 03.02-C Unmilled Material Ignited at 550°C with Inerts Removal*—A test to determine moisture and total solids content at 70±5°C, biodegradable volatile solids content (organic matter) by combustion at 550°C in the presence of excess air and reported on an oven-dried basis of a sieved, as-received finished or in-process compost, or feedstock sample.

4.3.1 The test employs a calculated weighting method to compensate for inert materials and for biodegradable materials that do not degrade during the retention time allowed for composing.

5. Significance and Use

5.1 Carbon dioxide and other gasses are evolved when the biodegradable volatile solids portion (organic matter) of material is combusted at 550°C. The ash residue is mineral fraction of compost that remains in the fixed solids, or inorganic content of total solids.

5.2 Biodegradable volatile solids (organic matter) and ash content in feedstock and compost are two of three material categories in total solids, or dry matter. Total solids, or dry matter include:

5.2.1 Organic Matter (OM), which is occasionally referred to as Biodegradable Volatile Solids (BVS);

5.2.2 Ash or fixed solids (Ash, inorganic matter, or minerals); and

5.2.3 Volatile Solids that are not readily biodegradable (VS).

6. Interference and Limitations

6.1 Biodegradable volatile solids (organic matter) is determined on a compost sample that is sieved and whose inert contaminants are removed, i.e., during inert classification. Samples must be thoroughly blended and properly split (subdivided) prior to drying, milling and inert removal. Unmilled coarse samples are almost always more variable than finely milled samples. A small aliquot of milled material will more closely resemble the bulk milled sample than will a small aliquot of unmilled coarse material.

6.1.1 The presence of materials that are not readily biodegradable such as wood chips and man-made inerts such as plastics cause over estimation of the sample biodegradable volatile solids.

6.1.2 The presence of man-made inerts such as metal and glass cause over estimation of the sample ash content.

6.2 Volatile residues may accumulate on glass surfaces when ashing temperatures are too low (<500°C) and/or the duration of the ashing process is too short. If volatile residnes accumulate on the ashing vessel, the volatile solids determination will be low.

6.3 A sample is oven dried at 70±5°C rather than 105°C, to minimize volatile loss of carbon compounds during determinations of total solids. The significance of this error increases with increasingly mature materials where the relative volatile solids measure diminishes to less than ten percent the total solids.

6.4 Negative errors in volatile solids can be produced through the loss of volatile matter from samples that require prolonged drying at relatively high temperatures. This error may become significant with feedstock where total solids is very high relative to volatile solids. If this condition exists, consider measuring for quantities of suspect volatile components by another test, such as the total organic carbon test (Method 04.01).

7. Sample Handling

7.1 *Method 03.02-A Unmilled Material Ignited at 550°C without Inerts Removal*—Perfonn this test on a feedstocks, in-process and finished composts. The material may contain unclassified inert material. This test should be implemented as the standard for the Volatile Solids Reduction test (Test Method 05.10-A).

7.1.1 *Compost Samples*—This test is best performed in conjunction with the total solids and moisture test. Use the same sample for volatile solids determination (50 cm^3 aliquot of prepared material).

7.1.2 *Feedstocks Samples*—Increase sample size to 400 cm^3 for feedstock sample analysis. This test is best performed in conjunction with the total solids moisture test. Use the same sample for volatile solids determination (400 cm^3 aliquot of prepared material).

7.2 *Method 03.02-B Milled Material Ignited at 550°C with Inerts Removal*—Perform this test with a 250 cm^3 aliquot of material screened through a 9.5-mm sieve, air-dried at 36°C, with man-made inerts >2 mm and materials >2 mm not readily biodegradable removed from the sieved material, and milled to a fine powder texture.

7.2.1 Material for this test should conform to the marketing specifications established for compost product distribution.

7.3 *Method 03.02-C Unmilled Material Ignited at 550°C with Inerts Removal*—Perform this test on 50 cm^3 aliquot of material screened through a 9.5 mm sieve, oven-dried at 70±5°C, with man-made inerts and materials not readily biodegradable removed from the sieved material.

7.3.1 Material for this test should conform to the marketing specifications established for compost product distribution.

Test Method: Ash. Unmilled Material Ignited at 550°C without Inerts Removal							**Units:** % g g^{-1} dw	
Test Method Applications								
Process Management							**Product Attributes**	
Step 1: Feedstock Recovery	*Step 2:* Feedstock Preparation	*Step 3:* Composting	*Step 4:* Odor Treatment	*Step 5:* Compost Curing	*Step 6:* Compost Screening and Refining	*Step 7:* Compost Storing and Packaging	*Safety Standards*	*Market Attributes*
	03.02-A	03.02-A		03.02-A		03.02-A		

03.02-A UNMILLED MATERIAL IGNITED AT 550°C WITHOUT INERTS REMOVAL

LOOK—Interference and Limitations, and Sampling Handling issues are presented as part of the introduction to this section.

8. Apparatus for Method A

8.1 *Balance*—analytical, with accuracy of ±0.001 g.

8.2 *Furnace*—forced air muffle, set at 550°C.

8.3 *Evaporation Dish*—Pyrex beaker, use 150-mL beaker with compost samples, and 500-mL beakers with feedstocks.

8.4 *Watch Glass*—2.5 cm (2 in.) diameter for compost, or 5 cm (4 in.) diameter for feedstock.

8.5 *Desiccator Cabinet*—vacuum with desiccant tray containing a color indicator of moisture concentration or an instrument indicator.

9. Reagents and Materials for Method A

9.1 *None required.*

10. Procedure for Method A

10.1 *Preparation of Evaporating Dish:*

10.1.1 Heat a clean beaker or crucible to 105°C for 0.5 h to 1.0 h to drive off all hygroscopic moisture.

10.1.2 Place heated beaker in desiccator cabinet to keep it dry, and allow to cool to approximately 27°C.

10.1.3 Record tare weight immediately prior to use.

10.2 *Determine Initial Sample Weight:*

10.2.1 Place sample beaker in forced-air oven set at 70±5°C for approximately 18 h – 24 h, until weight change and moisture loss diminishes to nil.

10.2.2 Transfer 50 cm^3 of oven-dried compost to the 150-mL beaker. For feedstocks, transfer approximately 400 cm^3 of oven-dried material to a 500-mL beaker.

10.2.2.1 Disregard the mass of inerts when using this method.

10.2.3 Weigh and record gross weight of beaker and sample, subtract beaker weight from gross weight to determine net weight of the oven-dried sample (dw).

10.3 *Ash Weight:*

10.3.1 Place the watch glass, concave side facing up, on top of the beaker and transfer it to the forced-air muffle furnace; slowly ramp furnace temperature to 550°C, ash at 550°C for 2 h, and then slowly ramp furnace temperature to approximately 200°C.

10.3.2 Transfer beakers containing ashed samples to a desiccator and cool to approximately 27°C.

10.3.3 Weigh and record gross weight of beaker and sample (AshW).

10.4 *Calculations*—determine ash content (fixed solids) and volatile solids content.

11. Calculations for Method A

11.1 *Calculate Total Solids and Moisture content as percentages as-received wet weight basis:*

$$TS = (dw \div ARW) \times 100 \qquad \textit{Equation 11.1.1}$$

$$M = [1 - (dw \div ARW)] \times 100 \qquad \textit{Equation 11.1.2}$$

where:

TS = total solids, % g g^{-1},
M = percent moisture, % g g^{-1},
dw = sample net oven-dried weight determined at 70±5°C, ±0.001 g, and
ARW = sample net weight at as-received moisture, ±0.001 g.

11.2 *Calculate organic matter (OM) and ash (Ash) content as percentages of total solids on an oven dry weight basis:*

$$Ash = (AshW \div dw) \times 100 \qquad \textit{Equation 11.2.1}$$

$$VS = [1 - (AshW \div dw)] \times 100 \qquad \textit{Equation 11.2.2}$$

where:

Ash = percentage of solids at 550°C, % g g^{-1},
VS = percentage of solids volatilized at 550°C, % g g^{-1},
dw = net oven-dry weight at 70±5°C, ±0.001 g, and
AshW = net ash weight at 550°C, ±0.001 g.

COMMENT—As compost becomes increasingly humified (biological degradation), the relative content of biodegradable volatile solids approaches zero.

Test Method: Ash. Milled Material Ignited at 550°C with Inerts Removal							Units: % g g^{-1} dw	
Test Method Applications								
Process Management							Product Attributes	
Step 1: Feedstock Recovery	*Step 2:* Feedstock Preparation	*Step 3:* Composting	*Step 4:* Odor Treatment	*Step 5:* Compost Curing	*Step 6:* Compost Screening and Refining	*Step 7:* Compost Storing and Packaging	*Safety Standards*	*Market Attributes*
				03.02-B		03.02-B		

03.02-B MILLED MATERIAL IGNITED AT 550°C WITH INERTS REMOVAL

LOOK—Interference and Limitations, and Sampling Handling issues are presented as part of the introduction to this section.

12. Apparatus for Method B

12.1 *Analytical Balance,* with of ±0.001 g accuracy.

12.2 *Crucibles*—high-form ceramic with cover, 20-mL.

12.3 *Desiccator Cabinet*—vacuum with desiccant tray containing color indicator of moisture concentration or an instrument indicator.

12.4 *Forced-Air Drying Oven,* for operation at 70±5°C.

12.5 *Muffle Furnace*—forced-air for operation at 550°C.

13. Reagents and Materials for Method B

13.1 *None required.*

14. Procedure for Method B

14.1 *Preparation of Evaporating Crucible:*

14.1.1 Heat a crucible to 105°C for 0.5-1.0 h to drive off all hygroscopic moisture.

14.1.2 Place heated crucible in desiccator cabinet to keep it dry, and allow to cool to approximately 27°C.

14.1.3 Record tare weight immediately prior to use, ±0.001 g.

14.2 *Sample Aliquot*—Transfer 10 cm^3 aliquot of prepared, (air-dried), material to a dry, tared crucible.

14.3 *Initial Weight*—Weigh and record gross weight of crucible and sample, subtract crucible weight from gross to determine net air-dried weight (inert-free sample would be air-dried at 36°C).

14.4 *Determine Oven Dry Weight (dw):*

14.4.1 Place sample crucible in forced-air oven set at 70±5°C for approximately 18 h – 24 h, until weight change and moisture loss diminishes to nil.

14.4.2 Place sample crucible in desiccator and cool to approximately 27°C.

14.4.3 Weigh and record gross weight of crucible and sample.

14.4.4 Subtract crucible weight from gross to determine net oven-dried weight (dw) of sample.

14.5 *Determine Ash Weight:*

14.5.1 Place the capped crucible to the forced air muffle furnace; slowly ramp furnace temperature to 550°C, ash at 550°C for 2 h, and then slowly ramp furnace temperature to approximately 200°C.

14.5.2 Place the crucible and ashed sample in a desiccator and cool to approximately 27°C.

14.5.3 Weigh and record gross weight of crucible and sample.

14.5.4 Subtract crucible weight from gross to determine net ash weight.

14.6 Perform Calculations.

15. Calculations for Method B

15.1 *Calculate organic matter (OM) and ash (Ash) content as percentages of total solids on an oven dry weight basis:*

$$Ash = (AshW \div dw) \times 100 \quad \textit{Equation 15.1.1}$$

$$OM = [1 - (AshW \div dw)] \times 100 \quad \textit{Equation 15.1.2}$$

where:

Ash = percentage of fixed solids remaining after combustion at 550°C, % g g^{-1},
BVS = the organic matter fraction of solids, percentage of readily biodegradable solids volatilized at 550°C, % g g^{-1},
dw = oven-dry weight of the test sample aliquot, g
OM = BVS = LOI organic matter, and
AshW = net ash weight at 550°C, g.

Test Method: Ash. Unmilled Material Ignited at 550°C with Inerts Removal							Units: % g g^{-1} dw	
Test Method Applications								
Process Management							Product Attributes	
Step 1: Feedstock Recovery	*Step 2:* Feedstock Preparation	*Step 3:* Composting	*Step 4:* Odor Treatment	*Step 5:* Compost Curing	*Step 6:* Compost Screening and Refining	*Step 7:* Compost Storing and Packaging	*Safety Standards*	*Market Attributes*
								03.02-C

03.02-C UNMILLED MATERIAL IGNITED AT 550°C WITH INERTS REMOVAL

LOOK—Interference and Limitations, and Sampling Handling issues are presented as part of the introduction to this section.

16. Apparatus for Method C

16.1 *Evaporating Dish*—Pyrex beaker of 150-mL capacity.

16.2 *Watch Glass*—Pyrex, 5 cm (2 in.) diameter.

16.3 *Forced-Air Drying Oven,* for operation at 70±5°C.

16.4 *Muffle Furnace,* for operation at 550°C.

16.5 *Desiccator Cabinet*—With a desiccant containing a color indicator of moisture concentration or an instrument indicator.

16.6 *Sieve*—#5 mesh (4 mm).

16.7 *Analytical Balance*—capable of weighing to 100 g, with ±0.1 mg accuracy.

17. Reagents and Materials for Method C

17.1 *None required.*

18. Procedure for Method C

18.1 *Preparation of Evaporating Dish:*

18.1.1 Heat a clean beaker to 105°C for 0.5 h - 1.0 h to drive off all hygroscopic moisture.

18.1.2 Place heated beaker in desiccator cabinet to keep it dry, and allow to cool to approximately 27°C.

18.1.3 Record tare weight of dry beaker immediately prior to nse.

18.2 *Preparation of Sample:*

18.2.1 Transfer 50 cm^3 of as received sample material as received to a tared Pyrex beaker. Obtain and record total as-received weight of sample in beaker, ±0.001 g.

18.2.2 Place beaker with sample into forced-air drying oven set at 36°C and dry for 24 h - 48 h.

18.2.3 Remove beaker and cool in desiccator for minimum of 1 h. Record dry weight of beaker contents.

18.2.4 Empty the air-dried sample onto a #5 sieve (4-mm) and remove stones and manufactured inert material, such as metal fragments, glass shards, sharps, leather, textiles, hard and film plastics, and all material that will not biologically degrade, or oversized biodegradable material such as wood chips and twigs that will not degrade during the retention time of the composting process.

18.2.4.1 Using a soft spatula, scrape the remaining material across the sieve, and collect the sieve accepts (4 mm and under).

18.2.4.2 Oven dry the hand-sorted trash at 70±5°C for 18 h - 24 h until sample weight change due to moisture loss diminishes to nil. Weigh and record the mass of inert material removed (T_R) from the air-dry >4-mm sample.

18.2.5 Recombine the sieve accepts (under 4 mm) and oversized (over 4 mm) biodegradable material. Weigh and record weight of recombined compost sample.

18.2.6 Place the beaker with recombined compost in a forced-air drying oven set at 70±5°C and dry for 18-24 h until sample weight change due to moisture loss diminishes to nil.

18.2.7 Remove the beaker and cool in a desiccator for a minimum of 1 h. Determine oven-dried weight of beaker contents, (dw).

18.3 *Sample Analysis:*

18.3.1 Transfer the recombined oven-dried sample with inert material removed into a tared 150-mL tared Pyrex beaker.

18.3.1.1 Weigh and record gross weight of sample and beaker. Determine compost sample net weight.

18.3.2 Place the watch glass, concave side facing up, on top of the beaker and transfer it to the forced-air muffle furnace; slowly ramp furnace temperature to 550°C, ash at 550°C for 2 h, and then slowly ramp furnace temperature to approximately 200°C.

18.3.2.1 Transfer beakers containing ashed samples to a desiccator and cool to approximately 27°C.

18.3.2.2 Weigh and record gross weight of the ashed sample plus beaker. Determine sample net weight, (AshW).

18.3.3 Sieve the beaker contents through a #20 mesh (4-mm sieve) with a wire brush; weigh the over #20 mesh material and record net weight of any small trash fragments that escaped removal in step 18.2.4. This trash consists of stones and other inerts not volatilized at 550°C, (T_A).

19. Calculation for Method C

19.1 Calculate ash content as a percentage of total solids, i.e., dry matter on an oven dry weight basis:

$$Ash = [AshW - T_A] \div [dw + T_R] \times 100 \qquad \textit{Equation 19.1}$$

where:

Ash = fixed solids of biodegradable fraction remaining after combustion at 550°C, % g g^{-1},

AshW = net ash weight including fine trash (T_A), combusted at 550°C, g,

dw = net oven-dried weight of recombined sample at 70±5°C, g,

T_A = net weight of trash remaining after ashing, over #20 mesh materials, g, and

T_R = net oven-dried weight of trash removed prior to ashing, hand-sorted and removed, g.

19.2 Calculate the organic matter (OM, biodegradable volatile solids) as a percentage of total solids, i.e., dry matter on an oven dry weight basis:

$$OM = [100 - Ash] \qquad \textit{Equation 19.2}$$

where:

OM = organic matter fraction, biodegradable volatile solids evolved at 550°C, % g g^{-1}, and

Ash = fixed solids remaining after combustion at 550°C, from Equation 19.1, % g g^{-1}.

03.02 Methods Summary

20. Report

20.1 *Report the Following Information:*

20.1.1 Express results for Organic Matter (OM, %) and Biodegradable Volatile Solids (BVS, %) as a percentage for the ratio, mass of volatilized compost per mass of oven-dried compost, % g g^{-1}.

20.1.2 Express results for percent ash (Ash, %) as a percentage for the ratio, unit mass of ash per unit mass of compost on an oven-dried basis, % g g^{-1}.

20.1.3 Report test method number.

20.2 *Minimum Detection Limit*—Record unit mass to an accuracy of ±0.005 g.

21. Precision and Bias

21.1 *Percent Ash and Biodegradable Volatile Solids:*

21.1.1 *Test Method 03.02-A Unmilled Material Ignited at 550°C without Inerts Removal:*

21.1.1.1 *Feedstocks, In-Process Materials, Finished Compost* —The precision and bias of these tests have not been determined. Data are being sought for use in developing a precision and bias statement.

21.1.2 *Method 03.02-B Milled Material Ignited at 550°C with Inerts Removal*—The precision and bias of this test have not been determined. Data are being sought for use in developing a precision and bias statement.

21.1.3 *Method 03.02-C Unmilled Material Ignited at 550°C with Inerts Removal*—The precision of this test were determined by the Research Analytical Laboratory, Department of Soil, Water, and Climate; University of Minnesota for the MN-OEA CUP Project, 1993-1994. St. Paul, MN. Bias of this test has not been determined. Data are being sought for use in developing a bias statement.

21.1.3.1 Precision was determined using 10 subsamples taken from one field composite sample for each of three locations and two months (1993).

Table 03.02-C1 Percent Ash, %. Variability is expressed as percent relative standard deviation, % CV.

Median	*Std Dev*	*% CV*	*Number of Samples*
54.0	3.36	6.3	10
82.5	1.35	1.6	10
59.4	4.10	6.9	10
38.6	1.45	3.7	10
53.4	0.77	1.5	10
40.6	4.64	11.9	10

Table 03.02-C2 Biodegradable Volatile Solids, %. Variability is expressed as percent relative standard deviation, CV.

Median	*Std Dev*	*% CV*	*Number of Samples*
46.0	3.36	7.2	10
17.5	1.35	7.7	10
40.6	4.10	10.1	10
61.4	1.45	2.4	10
46.6	0.77	1.6	10
59.4	4.64	7.6	10

NOTE 1C—Coefficient of Variation, %CV = Standard Deviation ÷ Mean × 100.

22. Keywords

22.1 ash; biodegradable volatile solids; fixed solids; moisture content; total solids; volatile solids

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Process Design Manual

Land Treatment of Municipal Wastewater Effluents

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National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio

Chapter 2
Wastewater Constituents and Removal Mechanisms

An understanding of the basic interactions between the wastewater constituents of concern and the soil treatment system is essential for the determination of the limiting design parameter (LDP) for a particular system. These interactions are generally the same for all of the land treatment processes and are therefore discussed together in this chapter.

2.1 Biochemical Oxygen Demand

All land treatment processes are very efficient at removal of biodegradable organics, typically characterized as biochemical oxygen demand (BOD_5). Removal mechanisms include filtration, absorption, adsorption, and biological reduction and oxidation. Most of the responses in slow rate (SR) and soil aquifer treatment (SAT) occur at the soil surface or in the near-surface soils where microbial activity is most intense. Treatment oxidation-reduction reactions generally occur in the upper 1/3 of the slope on the OF sites. Intermittent or cyclic wastewater application on these systems is necessary to allow the restoration of aerobic conditions in the soil profile and maintenance of the infiltration capacity at the soil surface.

2.1.1 BOD Loading Rates

To establish a basis for the amount of degradable organic matter that can be land applied, the BOD loading rate is calculated. The BOD loading rate is defined as follows:

L_{BOD} = (kg of BOD applied/day) / (area loaded per day) (cycle time)

(2-1)

Where

L_{BOD}	= kg/ha-d
Kg of BOD applied per day	= concentration, mg/L x flow, m^3/d x 1000 L/1 m^{3}x 0.001 kg/g x 1 g/1000 mg
Area loaded	= total wetted area receiving wastewater per day, ha
Cycle time	= time between subsequent applications to a given subplot (days of application plus days of drying), days

Example 2.1	BOD Loading Rates
Conditions:	Wastewater with a BOD of 250 mg/L. Slow rate land treatment field area of application of 2 ha/day. Flow of 1000 m^3/d. Cycle time of 7 days between wastewater applications.
Find:	Cycle-average BOD loading rate
Solution:	1. Calculate the kg of BOD applied per day
	Kg of BOD applied = 250 mg/L x 1,000 m^3/d x 0.001 kg/g = 250" kg/d
	2. Calculate the BOD loading rate using Eq. 2-1
	L = 250 kg/d / (2 ha/d)(7 d) = 17.9 kg/ha-d

The BOD is a 5-day test of the oxygen demand required by microorganisms to biodegradable organics. Other quicker tests, often more reliable, include the chemical oxygen demand (COD) which is always larger than the BOD and the total organic carbon (TOC) test, which ranges from greater than the BOD for untreated wastewater to less than the BOD for treated effluent (Tchobanoglous et al., 2002). The treatment of BOD occurs throughout the loading (application period), drainage, and the reaeration (drying or resting) period or cycle. To maintain aerobic conditions in the soil, the rate of reaeration in a given cycle should match or exceed the rate of BOD exertion. A "rational" model that predicts the rate of reaeration depending on soil conditions, the depth of application and the reaeration period has been developed (Smith and Crites, 2001) and is presented in Chapter 8. Typical BOD loading rates for the three processes are presented in Table 2-1.

Table 2-1. Typical Organic Loading Rates for Land Treatment Systems (adapted from Reed et al., 1995)

Process	BOD loading (kg BOD_5/ha•d)[a,b]
Slow Rate (SR)	50 – 500
Soil Aquifer Treatment (SAT)	145 – 1000
Overland Flow (OF)	40 – 110

[a]kg/ha•d x 0.89 = lb BOD_5/ac•d

[b]Lower end of range is typical of municipal systems and upper end is typical of industrial strength wastewater.

Essentially all of the treatment in overland flow systems (OF) occurs at or near the soil surface or in the mat of plant litter and microbial material. Settling of most particulate matter occurs rapidly in OF systems as the applied wastewater flows in a thin film down the slope. Algae removal is an exception since the detention time on the slope may not be sufficient to permit complete removal by physical settling (Witherow and Bledsoe, 1983). The biological material and slimes which develop on the OF slope are primarily responsible for ultimate pollutant removal. These materials are similar to those found in other fixed film processes, such as trickling filters, and the presence of aerobic zones and anaerobic microsites within the slime layer is to be expected. In a properly managed system, with acceptable loadings, the aerobic zones dominate. However, there are still numerous anaerobic sites that contribute to the breakdown of the more refractory organics (Crites et al., 2000).

2.1.2 BOD Removal

A few examples of removal of BOD by land treatment processes receiving municipal wastewater are summarized in Table 2-2. Long-term effects studies (US EPA, 1979; Hossner et al., 1978; Koerner and Haws, 1979; Leach et al., 1980; and US EPA, 1978) generated much of the available data. Because the basic treatment mechanism is biological, all three processes have a continually renewable capacity for BOD5 removal as long as the loading rate and cycle allows for preservation and/or restoration of aerobic conditions in the system. Laboratory studies in 1998 with soil columns indicated that BOD5 removal to low "background" levels was independent of the level of pretreatment, independent of soil type, and essentially independent of infiltration rate (ASU et al., 1998). These responses confirm the results presented in Table 2-2 and also confirm the fact that high levels of preapplication treatment are not necessary for effective BOD5 removal in municipal land treatment systems.

2.2 Total Suspended Solids

Total suspended solids (TSS) are generally not an LDP in the design of municipal land treatment systems. SR and SAT systems are very effective for removal of suspended solids. Filtration through the soil profile is the principal removal mechanism. OF systems depend on sedimentation and entrapment in the vegetative litter or on the biological slimes and are typically less efficient than SR or SAT. However, OF systems can produce better than secondary effluent quality for total suspended solids when either screened wastewater or primary effluent is applied.

TSS removal at a number of land treatment systems receiving municipal wastewaters is summarized in Table 2-3. Suspended solids removal in OF systems receiving facultative lagoon effluents is not always effective due to the variability of algal species present and the short detention time on the slope. The seasonal variation in performance of the Davis, CA system, shown in Table 2-3, clearly illustrates this problem. See Chapter 9 for additional information on this issue.

2.3 Oil and Grease

Oil and grease, also known as fats, oil, and grease (FOG), should not be a factor for land treatment of typical municipal wastewaters unless there is a spill somewhere in the municipal collection system. There is

Table 2-2. BOD_5 Removal at Typical Land Treatment Systems (adapted from Crites et al., 2000)

Process/Location	Hydraulic Loading (m/yr[a])	BOD_5 Applied (mg/L)	BOD_5 Soil Water Drainage (mg/L)	Sample Depth (m[b])
SR				
Hanover, NH	1.2 –7.6	40-92	0.9-1.7	1.5
San Angelo, TX	3	89	1.0	7.6
Yarmouth, MA[c]	1	85	<2.0	1.0
SAT				
Lake George, NY	43	38	1.2	3.2
Phoenix, AZ	110	15	1.0	9
Hollister, CA	15	220	8.0	7.6
OF				
Hanover, NH	7.6	72	9	--
Easley, SC	8.2	200	23	--
Davis, CA	12.5	112	10	--

[a]m/yr x 3.28 = ft/yr.
[b]m x 3.28 = ft.
[c]Giggey et al., 1989.

Potassium (K)

IMPORTANCE

Potassium (K) deficiency in California vineyards is considered third in overall importance, following that of nitrogen and zinc. This is somewhat surprising, because the potassium needs of the grapevine are relatively high and are comparable to the demand for nitrogen. The reasons are, in part, the greater initial supply of K in most California soils and resistance of K to losses from leaching. K deficiency is usually confined to small areas in a vineyard—seldom larger than 1 to 3 acres. When vines are deficient, however, the poorer vine growth and lower crop yields can be dramatic.

K-deficient areas in San Joaquin Valley vineyards probably total no more than several thousand acres. The deficiency has not been found in Kern County vineyards and is rare in Tulare County, where it may be found only in scattered areas between Kingsburg and Orosi. Fresno County has scattered areas of localized deficiency, mostly east of Dickenson Avenue north of Fresno and east of Highway 41 south of Fresno. In a tissue analysis survey of 120 vineyards throughout Fresno County, only one vineyard was found to be deficient in K, further demonstrating the infrequency and localization of the problem. K deficiency is rare in Madera County. Merced and Stanislaus counties have scattered deficient areas centering around Ballico, Cressey, and Delhi, and around Keyes and Ceres. In San Joaquin County, deficiency is occasionally found in the vineyard areas around Manteca, Ripon, and Escalon.

SOURCES IN THE SOIL

Most K in soils is derived from minerals, notably micas and feldspars. These minerals are only slightly soluble and are usually found as large-size particles. Under the influence of various weathering factors, K is gradually solubilized and becomes available to plants as positively charged ions, which become attached to clay colloids or to organic matter in the soil.

A comparatively large quantity of K is found in soils, but most of it is present in relatively insoluble compounds. Thus, the available K level in the root zone is a more important consideration than the total supply. The ordinary range of total K in minerals ranges from 0.15 percent in sands to 4 percent and higher in clay soils.

When K fertilizer is applied to the soil, part is fixed in slowly available compounds. The extent of fixation is proportional to the amounts and kinds of colloids in the soil, being greatest in clays and clay loams and smallest in sands. K fixation or holding by the soil is important, because it serves as a check against rapid leaching and provides a more continuous supply of available K. Even when K fertilizer dissolves in the soil moisture, it is soon attracted to the surfaces of the colloidal complex and replaces sodium, calcium, or some other element associated with the colloidal soil particles. K so fixed may move slowly in the soil, the rate dependent on the amount and nature of the colloidal complex.

The K cycle is fairly simple. It is fixed by the soil; removed by crops and, to a minor extent, by drainage water; exported by harvested crops; and returned to the land in crop residues, manures, or K fertilizers.

K levels are generally highest in the topsoil. Hence, deficiency is most likely to occur in cut areas from land leveling where the less fertile subsoil is exposed. K deficiency is also more common in sandier soils.

ROLE AND UTILIZATION

Not much is really known about the function of K in grapevines. Much more is known about what happens to vine growth and crop yields when this element is deficient.

Plants need K for the formation of sugars and starches, for the synthesis of proteins, and for cell division. K also neutralizes organic acids, regulates the activity of other mineral nutrients in plants, activates certain enzymes, and helps to adjust water relationships. It increases the oil content of certain fruits, and contributes to cold hardiness. Even though it is considered essential for the formation of carbohydrates and is somehow involved in other processes, it is not usually found as a part of organic compounds. About 1 to 4 percent of a plant by dry weight is K.

The demand for K is highest in midsummer to late summer, when greater amounts accumulate in the ripening fruit. Thus, temporary K deficiencies are sometimes associated with overcropping.

DIAGNOSIS OF DEFICIENCY

The ability to recognize and identify symptoms of K deficiency is extremely important; response to K fertilization has been obtained only in vineyard areas with visible symptoms of deficiency. Fertilizer trials in vineyards with low, but not deficient, levels of K in leaf tissue have not shown a yield or growth response.

Symptoms

Leaf symptoms usually begin to show in early summer and typically are seen first on leaves on the middle portions of the shoots. A fading or yellowing of leaf color begins at the margin or outer edge of the leaf.

As the season progresses, the yellowing continues to progress into the areas between the main veins, leaving a central island of green extending somewhat along the main veins. (See fig. 3a.) The yellowed leaf areas of colored grape varieties may bronze or redden (fig. 3b). In all varieties, marginal burning and curling, either upward or downward, usually follows. Leaves above and below the midshoot section become affected as the season advances, until many of the leaves show some symptoms by harvest time.

When K deficiency is severe, shoot growth is markedly reduced, and symptoms may be present on nearly all of the leaves before blossoming time. Leaves may drop prematurely, especially if the vines are carrying a heavy crop or are stressed for moisture. If leaf drop is extensive, the fruit may fail to develop full color or to ripen normally.

Symptoms of a mild K deficiency do not appear until late summer, approaching harvest. Here, symptoms may appear on many of the leaves on lateral or secondary shoots. In Thompson Seedless, the late symptoms produce a more blotchy or irregular pattern of chlorosis, particularly on the leaves near the ends of lateral shoots.

Vines severely deficient in K tend to have fewer and smaller, tight clusters with unevenly colored, small berries. With Thompson Seedless the lower portion of the bunch may collapse by midsummer, resulting in raisined, immature berries by harvest. (See fig. 4.)

Much of the effect of K deficiency on the fruit is the result of reduced vine growth and premature leaf fall, and accounts for lower vine yields and fruit maturity. Fruit symptoms alone are not always distinctive enough to be used in diagnosis; other factors, such as moisture stress, water berry, or red berry, can affect the fruit in a somewhat similar manner.

K deficiency symptoms may be confused with those caused by midsummer moisture stress during hot weather. Moisture stress, however, causes a general leaf burn of an irregular pattern that is most prominent on the older, basal leaves. The gradual fading or yellowing pattern, characteristic of K deficiency, is not seen.

A high water table during the spring and early summer may induce typical K deficiency symptoms. In fact, many other conditions that substantially reduce the effectiveness of the root system may also cause deficiency symptoms to appear. The diagnostic procedure should include digging and careful examination of the vine root system for the presence of phylloxera, nematodes, or unfavorable soil conditons.

Vineyard areas showing deficiency symptoms should be marked during the growing season. This will pinpoint the vines to be treated during the dormant season.

Using laboratory analysis

Even though keen observers may readily identify K deficiency by means of leaf symptoms, laboratory analysis of a properly collected sample of petioles may verify the diagnosis or help clear up confusion with other disorders. Based on fertilizer trials and field observations, tissue potassium values may be interpreted to determine whether the vines have an adequate level.

Soil analysis is not a reliable means of determining whether a vineyard requires K treatment. Too many variables are involved: the wide range of soil depths; the varying concentrations of K in the soil profile; the many different grape varieties and rootstocks used; and the many factors influencing root health and thus K uptake.

A note of caution: the K level in the vines may be influenced by other conditions that reduce the effectiveness of the roots—overcropping, shallow-rooting, high water table, inadequate irrigation, or heavy nematode or phylloxera feeding. The application of K fertilizer cannot be expected to give a positive vine response under such conditions.

FERTILIZER PRACTICE

Research results in California for both fruit trees and vines have shown that, when a deficiency exists, massive rates of K fertilizer are necessary to obtain vine or tree recovery and yield response. Large amounts of fertilizer are needed to overcome the high fixation of K in most California soils. Fertilizer mixes or complete fertilizers are not recommended, because they have a relatively low K content and hence would be needed in unreasonably large amounts to supply enough K.

Materials

The symbol "K," used for the element, is from the Latin word for potassium—*Kalium*. When expressed as a plant food by the fertilizer industry, potassium is usually reported in terms of the oxide, K_2O, also called potash.

Potassium fertilizer is commonly available in three forms, each with a different potassium content:

- Potassium chloride (KCl, muriate of potash)—52 percent K (62 percent K_2O)
- Potassium sulfate (K_2SO_4, sulfate of potash)—44 percent K (53 percent K_2O)
- Potassium nitrate (KNO_3)—37 percent K (44 percent K_2O) plus 13 percent total nitrogen

Studies in Fresno County vineyards have shown that one fertilizer form offers no advantage over another in terms of vine response, provided that equal amounts of actual K are used. Thus, the choice will depend on relative cost and availability of the materials and on soil and vine conditions.

Currently, potassium chloride is the most economical source of K. It must be used with caution, however, because its chloride content might contribute to salt injury of vines under some conditions. For example, potassium chloride should not be applied to vineyard soils with an existing salinity condition, nor should it be used on shallow or poorly drained soils. It is best used during the dormant season and should be avoided during spring and summer. Only a low to moderate rate applied during the winter is safe for young vines.

Potassium chloride can be used safely on well-drained soils without a salinity problem. One or two heavy furrow irrigations directly over the area treated are recommended as the best means of reducing the concentration of chloride fertilizer. It is somewhat dangerous to rely on rainfall alone to move the fertilizer, because rainfall amounts are not likely to be adequate. Light rain might be expected to leave a slightly dispersed, but still concentrated fertilizer band in the root zone. To leach the chlorides in sprinkler-irrigated vineyards, one should also provide some irrigation in excess of the grapevines' water needs.

The relatively high cost of potassium nitrate all but eliminates its use in vineyards as a soil treatment. Potassium sulfate is slightly more expensive than potassium chloride, and is safe to use during the dormant season. However, it should be used with some caution during the growing season, especially on young vines, because experience with this form is limited. Thus, from a practical standpoint, the choice of a potash fertilizer narrows to either potassium sulfate or potassium chloride.

Rates

A high rate is needed to overcome the high K-fixing power of most San Joaquin Valley soils. (See table 3.) The quickest response by far can be achieved by applying the fertilizer in a single heavy application rather than in small amounts applied annually. In general, the speed and degree of vine recovery, as well as the length of effectiveness, improve as rates are increased.

TABLE 3. SUGGESTED POTASSIUM APPLICATION RATES, BASED ON SEVERITY OF DEFICIENCY

Vine deficiency	Application rate			
	Per vine		Per acre equivalent*	
	KCl	K_2SO_4	KCl	K_2SO_4
	lb	*lb*	*lb*	*lb*
Severe	4 - 4½	5 - 6	1,800 - 2,000	2,300 - 2,700
Moderate	3½	4	1,600	1,800
Mild	2½	3	1,150	1,350

*Pounds per acre equivalent is based on 454 vines per acre (8' × 12' spacing).

Application methods

Deep placement of K fertilizer in a concentrated band close to the vine is recommended for most soils. This places the fertilizer near the root zone and also is the best means of overcoming soil fixation.

The fertilizer can be applied by hand or banded with a fertilizer applicator into the bottom of 6- to 8-inch-deep furrows opened about 18 to 24 inches from the vine on each side of the row. Many growers have found a 1-pound coffee can a convenient measure for applying K fertilizer by hand. A level, full can holds almost exactly 3 pounds of potassium sulfate.

Open French (row) plow furrows can also be used. In either case, the furrows should be left open to allow rainfall and irrigation water to move the fertilizer. The first irrigation should be made in these furrows to ensure deeper movement.

On sandy soils, surface banding of 2½ pounds of potassium sulfate on each side of the vine row (total of 5 pounds per vine) was successful in limited studies in Fresno County vineyards; movement into the soil depends on winter rainfall. The vines responded fairly rapidly after surface applications, presumably because of a good concentration of actively growing roots near the soil surface in the spring. Use of this method should be limited until more experience is gained; only high rates of potassium sulfate have been evaluated.

When subsoiling is done reasonably close to the vine rows, K fertilizer may be placed in the subsoiler slots. Good vine responses have been observed following such applications.

Foliar sprays. Potassium nitrate applied in foliar sprays in extensive Fresno County trials has shown no promise in correcting deficiency. During the growing season, repeated sprays at 4 to 5 pounds of potassium nitrate per 100 gallons of water did not measurably increase tissue K levels or reduce deficiency symptoms over a 3-year test period. Higher rates could not be used because of toxicity to young leaves.

Time of treatment

The late fall or early winter is a good time to treat, allowing maximum exposure to winter rainfall to help move the fertilizer into the soil. At the latest, the fertilizer should be applied before the first irrigation in early spring, before bud break. Some growers have found that an application in the fall is convenient, because deficient areas can still be defined by the presence of leaf symptoms.

Symptoms are not corrected immediately after fertilizer application in the winter. A partial improvement in leaf color or in vine growth may not appear until midsummer; a full response usually is not attained until the second growing season, or even the third, after fertilizer treatment.

Treatment longevity

A single application of K fertilizer at a recommended high rate will sustain an adequate K tissue level and eliminate leaf symptoms for 5 years, at least. Typically, the treatment loses effectiveness after about 8 years. Higher rates than those in table 3 can last for 10 years and beyond. If soil pests, such as nematodes or phylloxera, are causing root problems, the longevity of any treatment can be expected to be shortened.

It would be prudent to observe the treatment area closely for reappearance of foliar symptoms and to monitor the tissue level of K by collecting petiole samples for laboratory analysis. This procedure will be helpful in anticipating the time when a follow-up fertilizer treatment may be necessary.