Manual of Good Practice for Land Application of Food Processing/Rinse Water

Prepared for

California League of Food Producers

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Chapter 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. The purpose of this 2024 edition is to update the 2007 edition, not to revise the entire manual.

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).

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 of process/rinse water use is presented in Chapter 2 along with key conclusions from the Peer Reviewers. 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. 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. Chapter 11 describes areas that have been identified for future research and demonstration. 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. Other appendices are introduced in subsequent chapters.

1.5 Acknowledgments

Development of this revised document was led by Ms. Trudi Hughes of the California League of Food Producers. Her collaborative approach, leadership and perseverance are all greatly appreciated. The revised manual was prepared by a team from Brown and Caldwell (BC) 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 Dr. Robert Beggs and Mr. Ryan Beil of Brown and Caldwell, and Mr. Robert Chrobak, Dr. Stuart Childs, Ms. Margaret Wild, and Mr. Gary Carlton of K/J.

1.6 References

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Chapter 2

Beneficial Use of Food Processing/Rinse Water

Food processing is one of the largest industrial sectors in the California economy. There are hundreds of companies who collectively employ about 198,000 full-time and part-time workers, and there are thousands more workers employed in trucking, packaging, energy, equipment and other related businesses that depend on the food processing industry (California League of Food Producers, 2023). Food processing adds $220 billion in total output annually to the California economy and contributes $8.2 billion in state and local tax revenue. Many farmers across the state rely on food companies to purchase their harvests for processing. In a number of rural counties and disadvantaged communities, food processing is a primary engine of local economic prosperity.

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 for processing alone is presented in Table 2-1. This does not include the amount of water used for crop production.

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.

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

Food type	Food production tons/year	Water use gallons/ton	Annual flow	
			Million gallons	Acre-feet
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

Source: CLFP, 1999

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; US EPA, 2006). 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, triticale, milo, and pasture grass. In central and southern California, it is common to grow two crops per year to take advantage of year-round process/rinse water availability. The CLFP estimates 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 by Sustainable Conservation (Crites et al., 2006; 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), and a similar project in Central California treats and reuses winery wastewater (SOA Inc., 1998).

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, based on a nationwide dataset (USEPA, 1977). 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

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

Source: USEPA, 1977

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 the soil bacteria, or taken up by crops which serves 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) and natural systems are also effective in treatment (Crites et al., 2006).

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 Peer Review Process

As part of updating the 2007 version of the manual, the CLFP contracted with three scientists/engineers to review the draft manual revisions.

- Daniel J. Howes, Ph.D., P.E. California Polytechnic University and Irrigation Training and Research Center. San Luis Obispo, CA. Professor.
- Harold L Leverenz, Ph.D., P.E. University of California, Department of Civil and Environmental Engineering. Davis, CA. Research Engineer.
- Christopher W. Simmons, Ph.D. University of California, Department of Food Science and Technology. Davis, CA. Professor.

The 2024 update to the Manual of Good Practice for Land Application of Process/Rinse Water began with Brown and Caldwell and Kennedy/Jenks Consultants reviewing the 2007 chapters and developing outlines for modifications. The modifications were primarily to provide updates since 2007 and provide better coordination among chapters. Once the authors prepared drafts for each chapter in the Manual, the draft chapters were provided to the peer reviewers after a group meeting with the authors and peer reviewers.

The reviewers then provided comments on all chapters of the Manual. These were returned to the authors as three separate documents. The peer review documents were immediately valuable because the reviewers provided different perspectives that resulted in new insights that helped the authors improve the revised version of the Manual. Improvements included a) identification of topics that were missed or inadequately discussed, b) relationships among the Manual chapters that could be strengthened, and c) methods of evaluation that would be more appropriate for the intended audience.

To improve readability of the Manual, the authors provided references to provide detailed information in the Manual so that the text could remain at a readable level for a broad audience. The authors incorporated peer review comments into second drafts and then, in a group session, discussed each peer review comment. The chapters were revised and were sent to the peer reviewers for a second review. The new peer review comments were incorporated into the manual and forwarded to CLFP for review and finalization.

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Chapter 3

Regulatory Overview

This chapter provides an overview of federal, state, regional, and local regulatory programs that are relevant to establishing, permitting, and operating a land application system. These regulations and policies have been condensed and summarized for this overview. For the most current information, a discharger should 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.

In California, application of process/rinse water to land is regulated at the state level by the State Water Resources Control Board (State Water Board; *www.Waterboards.ca.gov*). The mission of the State Water Board is to ensure the highest reasonable quality for waters of the State and maintaining an optimum balance of beneficial uses of water. The State Water Board has the 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 1972 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.). The CWA is intended to restore and maintain the integrity of the country's surface waters and encourages water reuse and recycling. 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 implementation of the CWA to California and the State Water Board, and the Regional Water Boards are responsible for enforcement and implementation of the programs. The Code of Federal Regulations (Title 40, CFR) and USEPA guidance documents provide direction for implementation of the CWA.

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. Three key statutes and regulations in California are 1) the 1970 Porter-Cologne Water Quality Control Act (California Water Code (CWC) Division 1, Chapter 2, Article 3, sections 13000 et seq.), 2) Water Quality Control Plans (Basin Plans) for each management basin in California (Section 13240 of the CWC), and 3) the State Water Resources Control Board's Antidegradation Policy (State Water Board, 1968; see Appendix B).

The impact of these laws and policies on the regulation of land application systems is described 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 under the Porter-Cologne Water Quality Control Act. 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 Board, which develops statewide policies and regulations, and the Regional Water Boards, which implement water quality policies on a regional basis. Contact information for the State Water Board and each of the nine Regional Water Boards is shown as Figure 3-1 and available at the following link:

https://www.waterboards.ca.gov/waterboards_map.html.

In accordance with the CWC, most discharges to land require a permit because they have potential to impact underlying groundwater. Permits regulating the discharge of food process/rinse water to land are issued in the form of Waste Discharge Requirements (WDRs), which are granted by the applicable Regional Water Board following submission of the permit application known as State Form 200 and a Report of Waste Discharge (RWD) that provides details and an analysis of the proposed discharge. 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 CWC 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 CWC Section 13240. Each of the nine Regional Water Boards is responsible for adopting and periodically updating the Basin Plan for areas in its region. Copies of the basin plans may be obtained on State Water Board or Regional Water Board websites (http://www.swrcb.ca.gov) or contacting the State Water Board or Regional Water Board offices.

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 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 specific beneficial uses or water bodies, permits have included water quality limitations based on external references.

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 established by the California Department of Drinking Water (DDW, https://www.waterboards.ca.gov/drinking_water/programs/), a division of the State Water Board, generally follow Federal drinking water standards, and can be found in Title 22, California Code of Regulations, for a number of organic and inorganic constituents. Secondary standards are not established based on human health, but set limits that address aesthetics including water taste, odor, and appearance considerations.

In cases where the natural background concentration of a particular constituent exceeds an applicable water quality objective in the basin plan, the higher background concentration is generally used as the discharge concentration limit.

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, water quality exemptions are seldom granted because it requires documentation by the person seeking the exception. In addition, this process requires a Basin Plan Amendment that both the Regional Water Boards and State Water Board must conduct public hearings for, and then the California Office of Administrative Law must approve the exemption.

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 (State Water Board, 1968; see Appendix B). This policy applies to water bodies with water quality characteristics that are better than the basin plan requirements for protection of beneficial uses. It establishes a goal to preserve that level of quality to the maximum extent possible. However, the antidegradation policy is not a zero-discharge policy. Where the existing water quality is better than the water quality objectives, some reduction of water quality may 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 CWC.

CWC 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: a) past, present and probable future uses of water; b) environmental characteristics of the hydrographic unit; c) water quality conditions reasonably achievable through coordinated control of all factors; d) economic considerations; and e) 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 discharge process/rinse water to land in an area where it could have an effect 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 CWC 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 CWC 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. Chapter 8 of this manual describes an approach for evaluating facility operations and identifying appropriate methods to reduce process/rinse water generation and strength.

For food processors, a minimum BPTC should address source reduction efforts for target constituents, segregation of high-strength wastes, and pretreatment and treatment practices employed. The Antidegradation Policy also notes that a project that has an impact on groundwater but does not exceed water quality objectives should also consider whether the benefits of the project are in the best interests of people of the state.

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 3-1 and Figure 3-2. 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 3-2). Figure 3-2 is Chart B that is referenced in Figure 3-1. Ignore the footnotes in the yellow diamonds on Figure 3-2. 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.

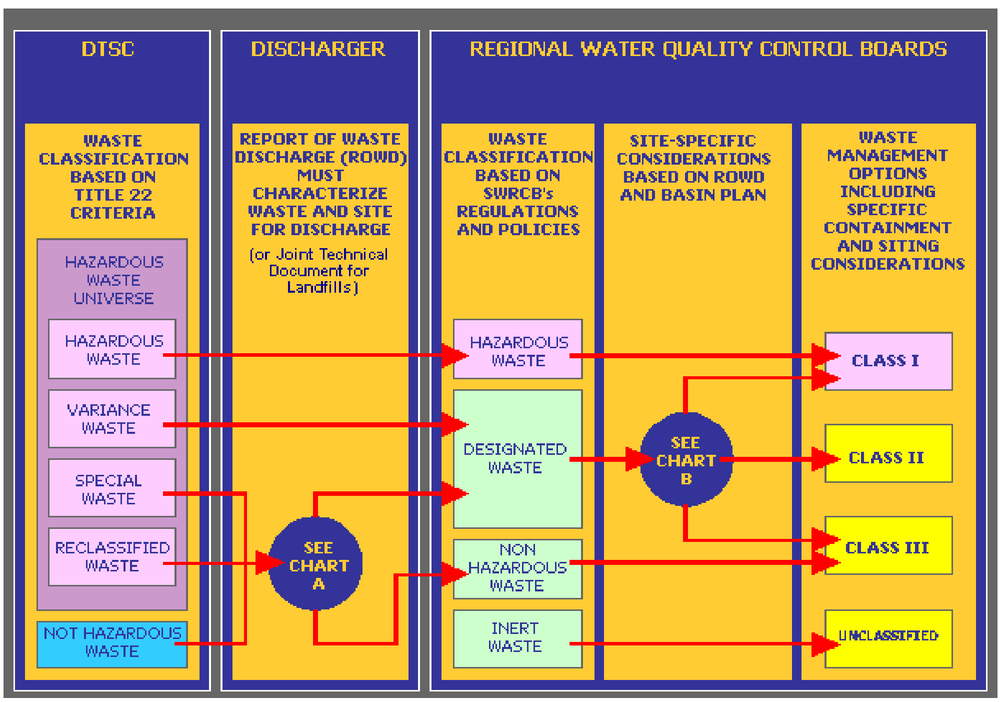

Figure 3 1. Water Board flowchart 1 for waste classification and management

Title 27 represents a consolidation of existing waste disposal to land regulations of the State 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, CWC 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.

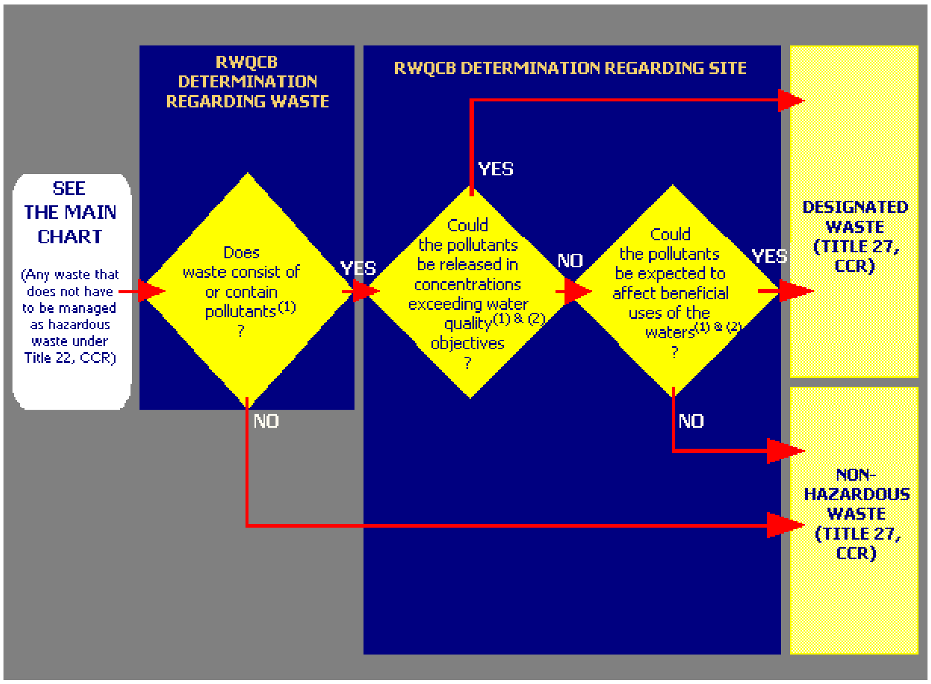

Figure 3 2. State Water Board flowchart 2 for waste classification and management

3.1.5 Waste Discharge Requirements (WDR) Permits

The applicable Regional Water Board issues 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. 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 issued under specific circumstances, as detailed in Section 3.1.6 below.

To obtain new or updated WDRs, the discharger must submit a permit application to the appropriate Regional Water Board office (https://www.waterboards.ca.gov/waterboards_map.html). 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 a California Registered Civil Engineer. The Regional Water Board recommends submitting the RWD at least 9 to 12 months prior to the date of the proposed discharge to allow adequate time for staff review and approval, preparation of tentative WDRs, a period of public review, and a hearing before the Regional Water Quality Control Board. 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 California Environmental Quality Act (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 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 and address the Antidegradation Policy.

Collection of information for the RWD requires process/rinse water sampling, flow measurement, and treatment 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 collect the information.

The Regional Water Boards highly recommend that processors discuss their draft RWD 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 produced. 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 their 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 and removal efficiencies prior to discharge. The description should include maximum and average flow and concentrations of Biochemical Oxygen Demand (BOD), total suspended solids (TSS), TDS, standard minerals, total nitrogen (TN), and nitrate 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 surrogate 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 water balance, including: (1) wastewater flows from all sources (e.g., process water, supplemental 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 evaporation data if an enhanced evaporation system is present; (5) estimated percolation rates for any effluent storage reservoir; and (6) irrigation scheduling and application rates. The water balance must be completed by a California Registered Civil 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. Estimated 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 scaled map of the site showing the location and dimension of major buildings, roads and parking areas, process and wastewater treatment infrastructure, drainage control structures, onsite wells, ponds, and process/rinse water land 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 peak discharge and seasonal precipitation during the winter months. The integrated land application system, including ponds, should be designed to accommodate an appropriately high annual precipitation to characterize a maximum water flow event. The Central Valley Water Board uses a 100-year return period annual precipitation distributed monthly (Region 5 policy) according to the average monthly precipitation patterns and anticipated process/rinse water volumes. Typically, no less than two feet of freeboard should 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 below freeboard 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.
- **New WDRs often require dischargers to line storage ponds** – The discharger may be required to provide a Pond Liner Work Plan that includes a Construction Quality Assurance Plan, Geotechnical Investigation Report, and Pond Operation, Maintenance, and Monitoring Plan
- **Information on Soil Types Underlying the Ponds and Application Areas** – Provide soils information, including data from onsite borings, if available. This may also include published reference data available on the US Department of Agriculture, Natural Resources Conservation Service Web Soil Survey (https://websoilsurvey.nrcs.usda.gov).
- **Groundwater Information** – Provide information on depth to first encountered groundwater, flow direction, and flow gradient based on wells of known construction with well screens placed in the upper aquifer. If such data is not available, estimates based on published sources may be used, or local groundwater quality data that may be available in the State Board's GeoTracker system (https://geotracker.waterboards.ca.gov/). Background groundwater quality is an important factor in evaluating the potential impact of any discharge. Regional Water Board staff 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. A groundwater monitoring well installation and sampling workplan may also be required.

- **Storm Water Management Information** – Provide slope and direction of surface drainage at the proposed facility and disposal area as well as annual precipitation and evaporation data, including an appropriate return period precipitation. Information on how the facility plans to address compliance with the Industrial General Permit for Stormwater (Order 2014-0057-DWQ as Amended in 2015 and 2018) should be included. Visit the Industrial Stormwater Program page on the State Board's website for the most current information (https://www.waterboards.ca.gov/water_issues/programs/stormwater/industrial.html)
- **Surface Water Information** – Describe the nearby surface water bodies and any connections from the facility to these water bodies.
- **Water Quality and Quantity for Facility Source Water** – Describe the source water and provide water quality information and quantity information, if appropriate. 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 and system design capacities 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 measures to monitor and protect groundwater quality.

Additional site-specific information, such as a description of domestic wastewater management methods, may sometimes be requested for inclusion in the RWD by the Regional Water Board staff. 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 evaluate the proposed project. Staff reviews the RWD and issues comments, which can include a request for more information, prior to accepting the RWD and preparing tentative WDRs for the facility. The WDRs typically describe the discharge and applicable laws pertaining to the discharge and site-specific requirements for the discharge, including prohibitions, specifications, and receiving water limitations and provisions. The tentative WDR package will 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 a site map, process flow diagrams, and guidelines for preparation of groundwater technical reports or monitoring well installation methods (Appendix D).

The discharger negotiates final permit conditions to be contained in the WDR with the Regional Water Board staff. If there are no adverse comments from the public, 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 potential effect on underlying groundwater. Current information concerning the procedure for preparing a monitoring well installation work plan and monitoring well installation report 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 apply. 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 permit requirements for some types of discharges (known as categorical waivers) or individual discharges. Granting of waivers is subject to the discharger meeting certain conditions, and the waivers may be terminated at any time. Typically, 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 3-3.

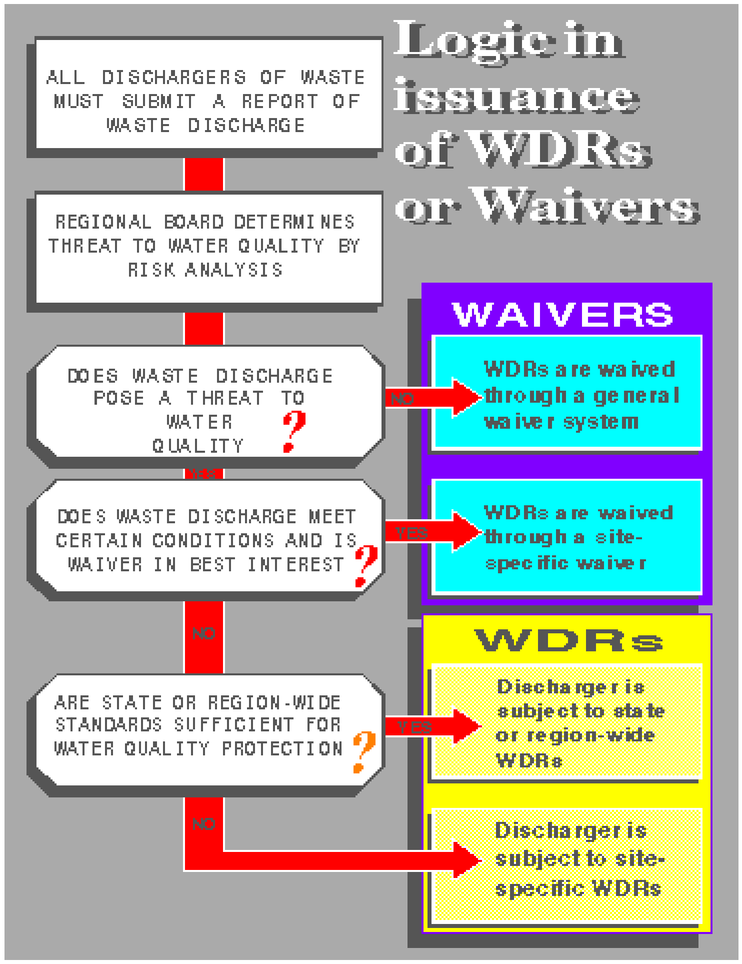

Figure 3 3. Logic in issuance of WDRs or waivers

For example, the Central Valley Regional Water Board (Region 5) has several waivers that may be applicable for dischargers in this region. Visit the Central Valley Regional Water Board's website for more information on applicable waivers (https://www.waterboards.ca.gov/centralvalley/board_decisions/adopted_orders/waivers/).

The following waivers are most relevant to food processing operations in Region 5:

- **Waivers for Discharges from Irrigated Lands (Resolution R5-2011-0032)**
- **Waivers for Confined Animal Facilities (Resolution R5-2003-0033)**
- **Waivers for Disaster-Related Wastes During a State of Emergency (Order No. R5-2018-0017)**
- **Waivers for Small Food Processors and Small Wineries (Resolution No. R5-2020-002).** Small food processors (generating less than 100,000 gallons of process wastewater per year), including wineries (crushing less than 800 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.

- **Low Threat Waiver for Specific Types of Discharge to Land (Resolution No. R5-2018-0085).** This type of waiver may be applicable to specific types of discharges to land that are deemed to pose a low level of environmental "threat". The County of Stanislaus, Food Processing By-Products Re-Use Program is currently covered under this Waiver. The Waiver is scheduled to be renewed in December 2023.
- **Statewide General Waste Discharge Requirements (WDRs) for Discharges to Land with a Low Threat to Water Quality (General WDRs).** State Water Resources Control Board Water Quality Order No. 2003-0003-DWQ. This order is commonly used for small projects with low potential threat.

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, a RWD, and a waste management plan including waste characterization also may be 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.

3.1.7 California Environmental Quality Act (CEQA)

California's Environmental Quality Act (CEQA) is a statewide program to protect environmental quality. Under CEQA, a lead agency, often a city, county or other agency, is identified to conduct an Initial Study of a proposed project that includes a preliminary assessment of potential environmental impacts of the proposed project. If no significant impacts are identified, the outcome is a Negative Declaration that the project is not expected to have a significant adverse impact on the environment and the project can proceed. If some impacts are identified but can be mitigated to a less than significant level, a Mitigated Negative Declaration may be prepared. Negative Declarations and Mitigated Negative Declaration documents are circulated for public review through the State Clearinghouse.

If potential impacts are identified, the applicant must conduct a more extensive, in-depth CEQA analysis and prepare an Environmental Impact Report (EIR). This includes soliciting public participation and establishing feasible mitigation measures with the goal of reducing the impact of the facilities on the environment. The lead agency will be required to substantiate the proposed project's specific social, economic, legal, technical or other benefits despite the unavoidable significant environmental effects.

3.1.8 Statewide Winery General Order

The General Order for Wineries was adopted by the State Water Resources Control Board on 20 January 2021 to provide coverage for approximately 1,500 wineries throughout California. The General Order covers most wineries that discharge to a land application area, ponds, or subsurface disposal systems.

Wineries who discharge between 10,000 and 15,000,000 gallons per year (gal/yr) have monitoring and reporting requirements for four size ranges. Wineries that discharge less than 10,000 gal/yr are not required to apply for this permit and those larger than 15,000,000 gal/yr need a site specific individual WDR. The monitoring requirements are less for wineries who discharge between 10,000 and 30,000 gal/yr and wineries that discharge 1,000,001-15,000,000 gal/yr have more detailed requirements.

For more information on this permit, visit the State Board's website: (https://www.waterboards.ca.gov/water_issues/programs/waste_discharge_requirements/winery_order.html)

3.1.9 Sustainable Groundwater Management Act

California's Sustainable Groundwater Management Act (SGMA) was passed in 2014 to establish a statewide framework to help protect groundwater resources over the long-term. The SGMA program is based on Assembly Bill 1739, Assembly Bill 1168, and Senate Bill 1319 that authorized development of statewide Regulations. SGMA requires local agencies to form groundwater sustainability agencies (GSAs) for groundwater basins in need of groundwater protection. The GSAs develop and implement groundwater sustainability plans (GSPs) to avoid undesirable results and mitigate overdraft of aquifers within 20 years.

The California Division of Water Resources (DWR) supports SGMA implementation by providing regulatory oversight by evaluating GSPs, and giving ongoing assistance to GSAs in developing best management practices and guidance, and providing planning, technical, and financial assistance. For more information on this program and for more information on how to join a local GSA, visit DWR's website: https://water.ca.gov/programs/groundwater-management/sgma-groundwater-management.Regional Regulations

3.1.10 Central Valley Region Programs

This section summarizes examples of regulations in the Central Valley Region that may affect food processors. If located in another region, visit the applicable Regional Water Board Website for other regional regulations.

Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS). The CV-SALTS program was initiated by the Central Valley Regional Water Board in 2006 and was made part of the Sacramento and San Joaquin River Basin Plan and the Tulare Lake Basin Plan with a Basin Plan Amendment in 2018 (Resolution R5-2018-0034 and Resolution R5-2020-0057).

The primary goals of CV-SALTS are to provide a safe drinking water supply for Central Valley residents who may be affected by elevated nitrate levels in domestic wells, achieve balanced salt and nitrate loadings across the Central Valley, and implement a solution to restore the water quality of groundwater where feasible. CV-SALTS has two components, the Nitrate Control Program and the Salt Control Program.

The Nitrate Control Program is phased and dischargers in Priority 1 groundwater subbasins received Notices to Comply (NTCs) in 2020. Dischargers in Priority 2 groundwater subbasins will receive NTCs between 2022 and 2024, and the remaining basins in the Central Valley are not prioritized. Compliance with the nitrate control program can be achieved with either Pathway A (Individual Permitting Approach) or Pathway B (Management Zone Permitting Approach). The individual permitting pathway requires that a discharger have a nitrogen limit. If the limit is exceeded, the discharger must address the problem. If a discharger joins the management zone permitting group, immediate nitrate limits are waived and the dischargers work together to meet compliance levels. Each groundwater subbasin is required to form a Management Zone that allows dischargers to take the Pathway B approach and meet compliance as a regional coalition. For more information on how to connect with management zones, visit the CV-SALTS website (https://www.cvsalinity.org/nitrate-program/).

Dischargers with Salt Control Program NTCs sent in 2021 chose one of two compliance pathways (Conservative Permitting Approach or Alternative Permitting Approach). The Conservative Permitting Approach is applicable to individual facilities with a discharge EC of 700 micromhos per centimeter or less (0.7 deci-Seimens/m), which many food processors may not meet. Compliance with the Alternative Permitting Approach requires dischargers to participate in and financially support the Prioritization and Optimization (P&O) Study that is currently being conducted by the Central Valley Salinity Coalition. For more information on the Salt Control Program and how to pay annual fees for the P&O Study, visit the CV-SALTS website (https://www.cvsalinity.org/salt-program/).

The first phase of the CV-SALTS program includes developing early action nitrate management plans for both the individual and management zone permitting approaches. The early actions include community engagement, sampling and testing individual wells, and delivering bottled water where needed to supply drinking water with low levels of nitrate. Most of the dischargers in the program have selected the Pathway B Management Zone Permitting Approach for nitrate and the Alternative Permitting Approach to support the P&O Study for salinity.

Irrigated Lands Regulatory Program (ILRP). The ILRP was initiated in 2003 by the Central Valley Regional Water Board to prevent agricultural runoff from impairing surface waters, and later in 2012 the Central Valley Regional Water Board expanded the regulations to cover discharges to both surface and ground waters. The program was created to address discharge of wastes from commercial irrigated lands that can harm aquatic life or make water unusable for drinking or agricultural uses. The overall goal of ILRP is to protect surface water and groundwater beneficial uses. The ILRP program issues permits and conducts compliance and enforcement activities to ensure growers comply with the Regional Water Board's regulations. Growers have the option to join coalitions to share some of the compliance requirements, and are required to implement plans to prevent sediment, fertilizer, pesticides, manure, or other farming materials from entering surface or groundwater through irrigation or stormwater runoff or leaching.

Regulatory coverage under this program is required if you own or operate land that is irrigated to produce crops or pasture for commercial purposes. For more information on the ILRP program and compliance, visit the Central Valley Regional Water Board's website (https://www.waterboards.ca.gov/centralvalley/water_issues/irrigated_lands/).

3.2 Enforcement

As part of their responsibilities to protect, maintain and enhance waters of the state, the Water Code authorizes 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 taking action under the Water Code. The following actions can be taken:

- The Regional Water Board can require a discharger with a WDR to conduct special studies or evaluations if there is reasonable evidence that the discharge may be causing adverse environmental impacts. The Regional Water Board can require the discharger to address specific issues using an order to provide information or conduct studies based on California Water Code Section 13267. The order can be issued in a "13267" letter to the dischargers with specific requirements and a deadline. This is considered to be the least formal of enforcement measures.

- Regional Water Board staff periodically make inspections of facilities with WDRs. When an inspector identifies problems or issues with facility operations during a site visit, the inspector alerts the facility representative of the issues. If the issue appears to be a violation of the facility's WDR, The Regional Water Board may issue a Notice of Violation (NOV) describing the concerns and requests that the facility respond to the NOV on or before a certain date.
- An Assessment of Civil Liability can also be issued for a discharger's actions. This method is typically pursued if the discharger is not cooperative with previous enforcement techniques.
- Failure to comply with terms in a WDR permit or creation of an unreasonable or threatened-unreasonable impact on water quality or beneficial uses can also result in more prescriptive Orders including a Cleanup and Abatement Order, Cease and Desist Order, or referral to the Attorney General.

  The State Board's Water Quality Enforcement Policy, adopted by Resolution 2002-0040, describes these alternative actions and under what circumstances they should be taken. The 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 many counties, a Conditional Use Permit issued by the County Planning Department is required for new facility construction or expansions. As mentioned in Section 3.1.7, cities and counties may also act as the lead agency for CEQA compliance.

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 historically considered food processing or winery wastes discharged to septic systems to be equivalent to domestic waste, therefore under their purview. The State Onsite Wastewater Treatment System (OWTS) Policy has superseded local county requirements and further defined what is domestic wastewater vs. high strength wastewater. For more information on the OWTS Policy, visit the State Water Board's Website (https://www.waterboards.ca.gov/water_issues/programs/owts/).

3.4 References

California Water Code. 1970. Porter-Cologne Water Quality Control Act. California Water Code Division 1, Chapter 2, Article 3, sections 13000 et seq.

State Water Resources Control Board. 1968. Statement of Policy with Respect to Maintaining High Quality Waters in California. Resolution No. 68-16.

USEPA. 1972. Clean Water Act. 33 U.S.C., 1251 et seq.; 40 C.F.R. Part 122 et seq. and Part 400 et seq.

Chapter 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. Further detail on chemical constituent loading from application of process/rinse water onto land is provided in Chapter 7.

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. Refer to Chapter 7 for further details on N interactions in process/rinse water and soil and methods for estimating N loading.

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 (H2PO4- or HPO42-), 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 biochemical 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. Refer to Chapter 7 for irrigation considerations based on suspended and settleable solids concentration.

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:** 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:** 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:** 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:** 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:** 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:** 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:** 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:** 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., 1985). 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. For Ca_x values see Table 4-1 below.

Table 4-1. Ca_x Values (meq/L) for Use in Calculating adjR_{na} of Process/Rinse Water

Ratio of HCO_3/Ca	Salinity of Applied Water (EC) (dS/m)						
	0.1	0.3	0.5	1.0	1.5	3.0	6.0
.05	13.2	13.92	14.40	15.26	15.91	17.28	19.06
.15	6.34	6.69	6.92	7.34	7.65	8.31	9.17
.25	4.51	4.76	4.92	5.22	5.44	5.91	6.52
.50	2.84	3.00	3.10	3.29	3.43	3.72	4.11
1.00	1.79	1.89	1.96	2.09	2.16	2.35	2.59
2.00	1.13	1.19	1.23	1.31	1.36	1.48	1.63
3.50	0.78	0.82	0.85	0.90	0.94	1.02	1.12
7.00	0.49	0.52	0.53	0.57	0.59	0.64	0.71
20.00	0.24	0.26	0.26	0.28	0.29	0.32	0.35

Source: Westcot and Ayers (1984)

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. Salt loading considerations are discussed in Chapter 7.

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. Due to interactions between water quality parameters based on environmental conditions, parameters should be considered together, not independently, when assessing potential impacts from application of process/rinse 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 4-2. Irrigation Water Quality Guidelines

Type of problem	Units	Degree of Restriction[a]		
		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)

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, as opposed to sprinkler, 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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Chapter 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 (CaCO3) 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	https://www.ncei.noaa.gov/
California Irrigation Management Information System (CIMIS)	https://cimis.water.ca.gov/
Western Regional Climate Center	https://wrcc.dri.edu/

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 Natural Resources Conservation Service (NRCS), 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.

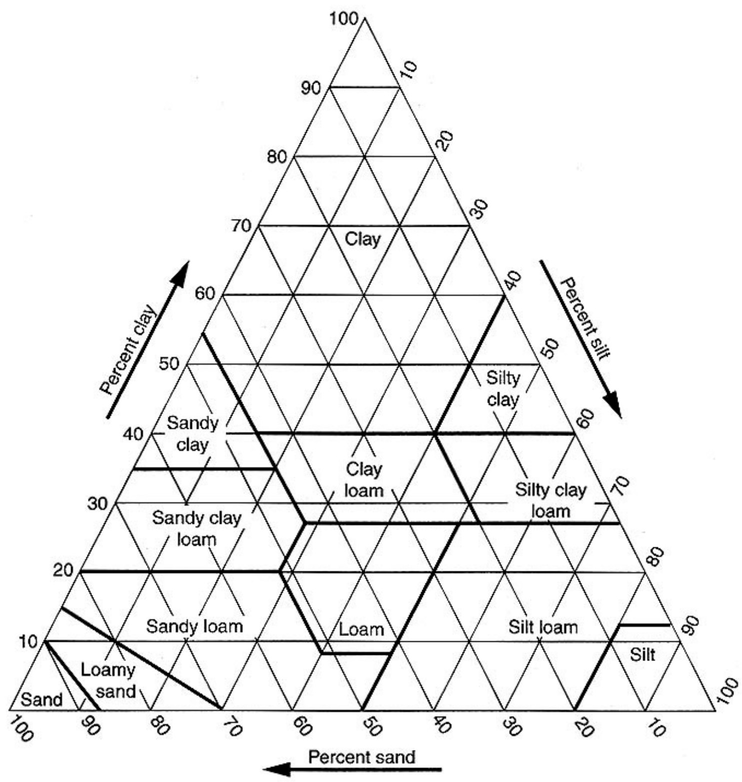

Figure 5-1. Textural triangle

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.

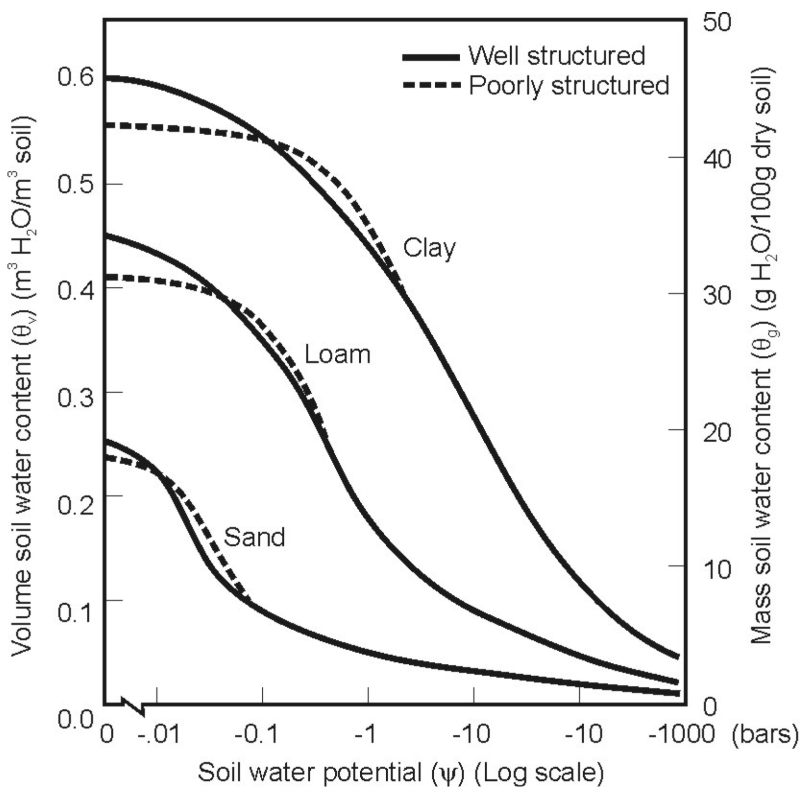

Figure 5-2. General relationship between soil water characteristics and soil texture

Table 5-3. Available Water Holding Capacity for Different Soil Types		
	Available Water Holding Capacity	
Soil Type	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), and this depth is appropriate for vegetables or root crops. A soil depth of three to four feet is adequate for forage crops.

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:

$$I = \frac{Q}{A * t} \quad (5\text{-}1)$$

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

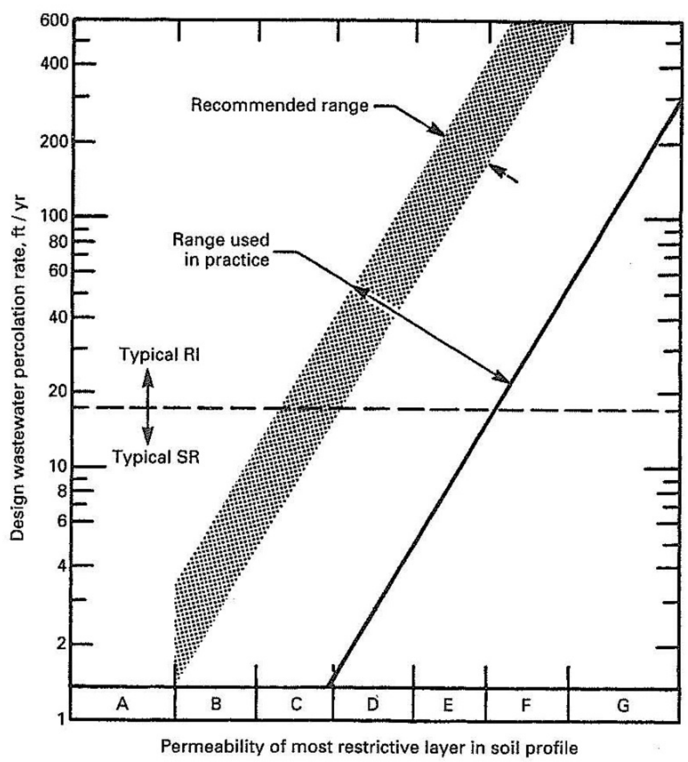

Figure 5-3. Design percolation rate Vs. NRCS soil permeability classifications for slow rate and rapid infiltration land treatment (Crites, et al., 2000); A= very slow, G= very rapid.

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^{+}), potassium (K^{+}), chloride (Cl^{-}), bicarbonate (HCO_3^{-}), carbonate (CO_3^{2-}) 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 r educed 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 can be accomplished by initially taking evenly spaced samples across the area of the site (e.g., using 100 foot by 100 foot grids) with multiple sample depths at each location, and then subsequently taking annual samples randomly at multiple depths. Maps of site salinity, and other parameters (e.g., nutrients), can be generated from the sampling results. These maps can be used to inform variable rate process/rinse water applications to even out constituent distribution across the site. This method of discreet soil sampling is useful for precision agriculture; however, it may not be practical and may be excessively expensive for many land application operations.

Salinity stress may also be detected via multispectral imaging of crops. Aerial imaging can offer site-wide monitoring of crop stress with individual plant resolution. In areas where salt stress is suspected, multispectral imaging can reveal changes in near infrared absorbance that indicate stress induced changes in photosynthesis. Additionally, soils with sufficient salinity to cause surface crusting can exhibit changes in surface reflectance that can also be detected through aerial multispectral imaging.

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. The EM survey method is useful for measuring soil salinity but is not appropriate for evaluating other soil properties.

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 (See Chapter 10).

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 determines 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 observations 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 a half 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.

Data from nearby wells can be obtained from a variety of sources including the State Water Resources Control Board's GeoTracker database, California Department of Water Resources' (DWR) Water Data Library (WDL), and DWR's Well Completion Reports. Selected web addresses for publicly available California well data are provided in the following table.

Organization	Web Address
State Water Resources Control Board – GeoTracker	https://geotracker.waterboards.ca.gov/
DWR – WDL	https://wdl.water.ca.gov/waterdatalibrary/
DWR – Well Completion Reports	https://water.ca.gov/Programs/Groundwater-Management/Wells/Well-Completion-Reports

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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Chapter 6

Water Use and Crop Selection

This chapter describes the characteristics of crops that impact their use in land treatment: water use, nutrient uptake, tolerance for trace constituents, and salinity and fixed dissolved solids (FDS). 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 to produce 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, help maintain long-term infiltration rates, and provide a suitable habitat for microbial populations that support nitrogen transformations and organic matter decomposition (BOD consumption). In slow application 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 method for determining regional compatibility of crops for land treatment is to investigate the surrounding plant systems.

Once regional issues are considered, crop selection should be based on specific system objectives including nutrient uptake, root zone depth, cultural practices, season of growth, compatibility with hydraulic loading (quantity and timing), and salt tolerance.

For food processors that discharge processing/rinse water year-round, land application areas should also be vegetated year-round so that fields can be irrigated during wet periods. Winter land application areas should have a crop cover that will use some water and the irrigated area should be large enough during winter months so that only small irrigation amounts are applied. During the active growing season, a smaller irrigated area is required and almost all land application areas will require supplemental irrigation. Double crops are often used for land application areas: a winter crop is planted in the fall and harvested as hay in spring so that a summer crop can be planted. Often, a summer crop can have multiple cuttings. Although plant uptake is not the only form of nutrient management that takes place in the soil-plant system, plants are often selected for their propensity for uptake of a certain nutrient and/or large quantities of water. When the crop is harvested and removed from the site, the constituents taken up by the crop are removed and the potential for process/rinse water constituents to impact underlying groundwater is decreased.

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 air, and run-off. Calculation of baseline ET, commonly called reference ET (ETo), is one part of determining crop evapotranspiration (ETc). Actual ETc can be based on reference ET adjusted for specific crops and is sufficiently accurate for water balances and irrigation scheduling. Recently, methods including remote sensing and use of in-field measurements have been used to determine actual ETc with improved accuracy,

6.2.1 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 and vegetation does not cover the ground surface, a large portion of ET is evaporation from the soil surface. When plants achieve 70 to 80 percent canopy cover, soil evaporation may be reduced 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. Figure 6-1 shows that soil evaporation decreases rapidly after precipitation or irrigation and reaches approximately 20 percent of maximum after 72 to 96 hours. Evaporation from the soil is increased by maintaining moist surface conditions. Evaporation rates vary from sub-surface drip irrigation, which has very little evaporation, to frequent small sprinkler applications, which can evaporate a high percentage of the applied water.

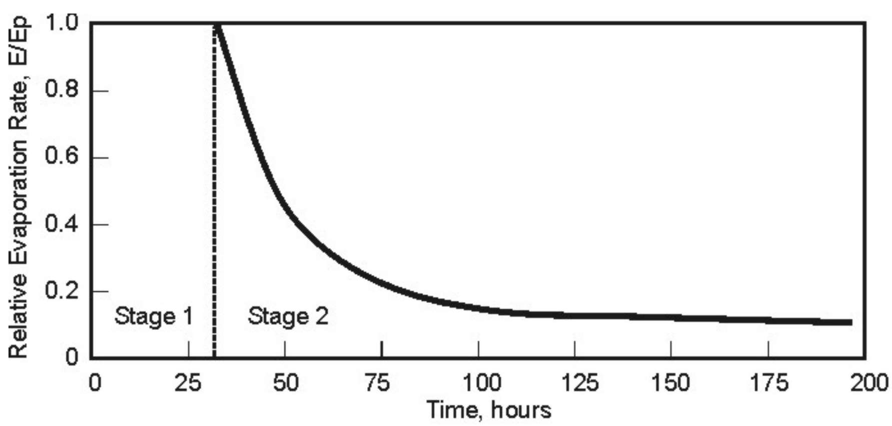


Figure 6-1. Evaporation from bare soil which was initially wet

Source: Hanks and Ashcroft, 1980

6.2.2 Transpiration and Crop Evapotranspiration

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 remaining water and dissolved nutrients and salt pass through the plant. Nutrients are absorbed by the plant and the water leaves as vapor through the openings in the leaves known as stomata.

The drier and hotter the air, the higher the potential ET rate will be. Plant transpiration may be decreased at high temperatures that may stress plants or in dry soils that hold water more tightly. 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 soil water, and general plant health. Most methods used to calculate ET assume that transpiration is not impacted by plant health or water stress.

Crop evapotranspiration (ETc) is commonly calculated based on two factors: a measured reference evapotranspiration (ETo) and a crop coefficient (Kc) representing the specific crop and growth stage. Further discussion of ETo and Kc is included in Sections 6.2.3 and 6.2.4.

Table 6-1 contains a range of expected annual ETc of a variety of crops. These ranges account for crop properties, length of growing season, and variability in climate.

Table 6-1. Range of Growing Season Crop Evapotranspiration[a]

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

a. *Based on the work of Burt, (1995).*

Monthly estimates of example crop ETc in the San Joaquin Valley, are shown in Table 6-2. More comprehensive ETc data for other regions of California can be found on the Irrigation Training and Research Center's website (www.itrc.org). The first row shows the grass ETo as a reference and the remaining rows show ETc rates for various crops that are commonly grown in this region. Double cropping is often used for process/rinse water land application because many food processors discharge water year-round. Combining a grain for hay winter crop with summer corn is a common double crop. In areas such as the San Joaquin Valley of California with wet winters and dry summers, monthly ET rarely varies more than 10 percent from the historical averages.

Table 6-2. Typical Evapotranspiration in the Southern San Joaquin Valley[a]

	Evapotranspiration (inches)												
Crops	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Grass Reference ETo	1.0	2.3	4.4	6.3	8.2	8.2	8.4	7.3	5.7	4.0	1.6	1.1	**58.4**
Cherry, Plum and Prune			0.9	3.8	7.3	7.9	7.7	6.5	5.2	2.4			**41.6**
Peach, Nectarine and Apricots			0.7	2.9	6.9	7.9	7.8	6.7	4.8	2.9			**40.5**
Almonds		2.4	2.6	5.9	8.2	8.2	7.9	7.0	5.1	2.9	1.2		**51.2**
Immature Almonds		1.1	0.8	3.9	5.9	6.2	6.1	5.4	3.8	1.9	0.8		**35.9**
Walnuts				3.0	7.7	9.3	9.4	8.1	5.8	2.8	1.1		**47.2**
Pistachio				1.7	2.7	6.8	8.9	7.8	5.7	3.1	0.9		**37.6**
Misc. Deciduous			0.9	3.4	7.2	7.5	7.3	6.6	4.9	2.5			**40.2**
Grain and Grain Hay	1.1	2.4	4.8	7.0	4.0						0.9	1.2	**21.5**
Cotton				1.4	1.9	5.4	8.9	8.1	5.8	1.8			**33.2**
Safflower and Sunflower	1.1	1.2	1.8	6.2	9.6	8.2	1.2	0.0	0.0	0.3	0.9	1.2	**31.7**
Corn and Grain Sorghum					2.9	7.6	8.8	5.5					**24.8**
Alfalfa Hay and Clover	1.1	2.5	4.3	6.2	7.6	7.9	7.5	6.6	5.1	2.1	1.4	1.3	**53.5**
Pasture and Misc. Grasses	1.1	1.5	2.2	5.4	8.1	8.3	8.3	7.3	5.7	3.5	1.3	1.2	**54.0**
Tomatoes and Peppers				1.6	4.6	8.8	7.2						**22.2**
Potatoes, Sugar beets, Turnip	1.1	1.3	2.5	6.8	9.2	9.3	7.8						**38.0**
Melons, Squash, and Cucumbers						2.4	5.7	6.2	1.8				**16.0**
Onions and Garlic	1.1	2.2	3.9	5.8	5.4	0.8						1.2	**20.4**
Citrus (no ground cover)	1.1	2.4	3.6	5.1	6.3	6.7	6.4	5.6	4.4	3.5	1.5	1.2	**47.7**
Immature Citrus	1.1	1.7	1.6	3.7	3.9	4.6	4.2	3.7	2.9	2.5	1.2	1.2	**32.2**
Misc Subtropical	1.1	1.0	0.9	3.4	7.2	7.5	7.3	6.6	4.9	2.5	0.8	1.1	**44.2**
Grape Vines (80% canopy)				3.7	6.3	7.4	7.3	5.5	4.1	2.3			**36.6**
Immature Grapes Vines				1.4	3.5	5.0	5.0	3.8	2.2	0.3			**21.3**

a. *From the Irrigation Training and Research Center (www.itrc.org/etdata/index.html), ETo Zone 15, typical year, ET for irrigation scheduling and design.*

6.2.3 Reference Evapotranspiration (ETo)

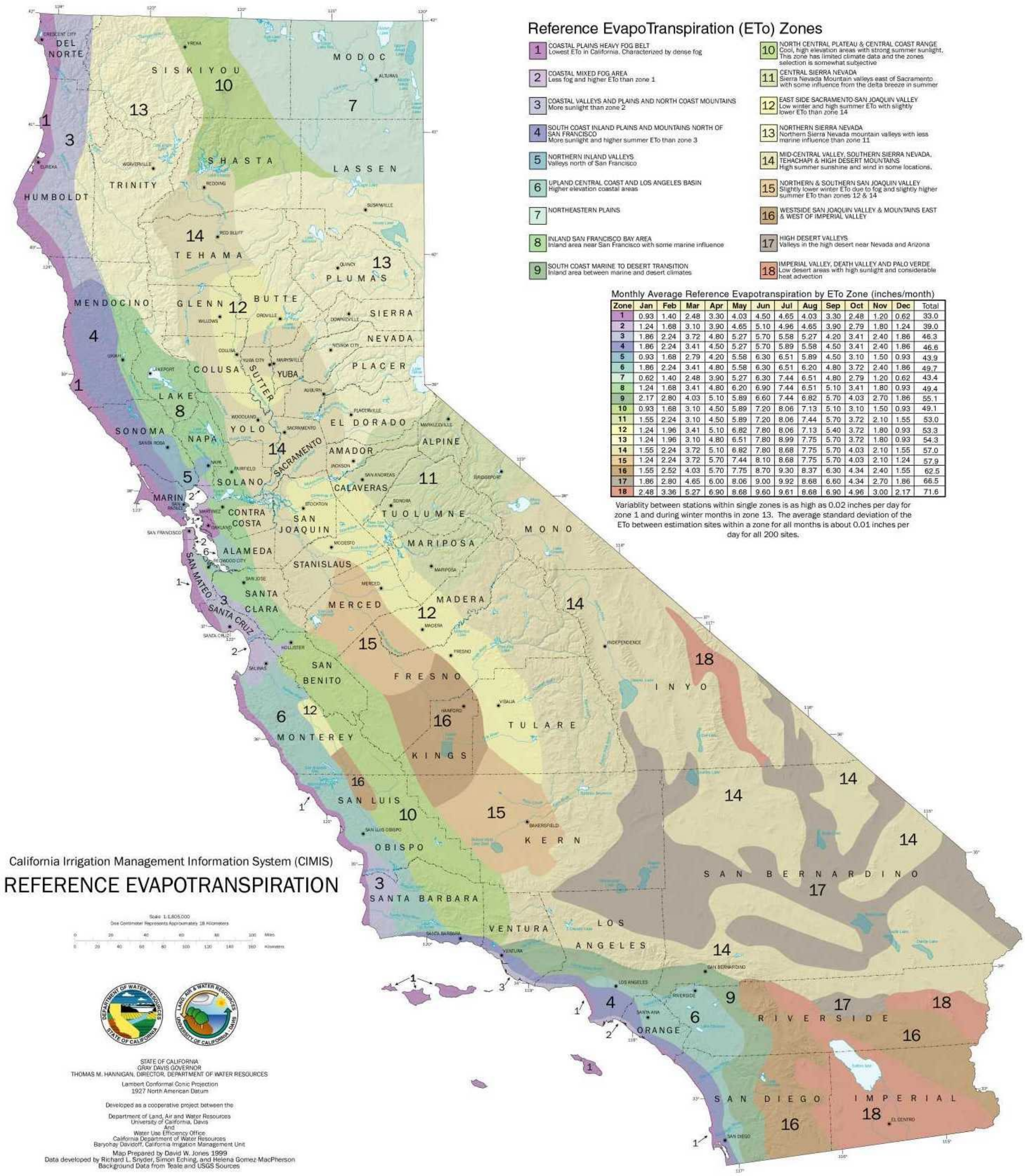
ETo is a term used to describe the ET rate from a known surface, such as closely cut grass or alfalfa (i.e., a reference crop). Alfalfa ETo (also referred to as ETr) normally exceeds grass ETo by 0 to 30 percent; the example shown in Table 6-1 shows that Alfalfa ETo is approximately 20% greater than grass ETo. ETo is commonly expressed in either inches or millimeters. The ETo for an average year is referred to as 'normal' year ETo. ETo is often reported on a daily or monthly basis.

Measurement and Calculation Methods. In the past, evaporation pans have been used for site specific measurements of ETo (Doorenbos and Pruitt, 1977). Evaporation pan measurements are almost always higher than actual ETo because evaporation pans filled with water have higher evaporation rates than plants. Measured evaporation pan water loss must be multiplied by a factor ranging from 0.55 to 0.85 depending on wind speed and relative humidity (Doorenbos and Pruitt, 1977). Because of inherent measurement inaccuracies, evaporation pans are no longer in common use.

Current methods for calculating ETo are based on use of meteorological data collected at weather stations or using remote sensing methods. In California, the FAO Penman-Monteith method has been used in the past to calculate ETo using meteorological data (Allen et al., 1998) but other versions of the basic meteorological calculations are also in current use including the American Society of Civil Engineers (ASCE) Standardized ETo methods and a version used by the California Irrigation Management Information System (CIMIS), which operates over 130 active weather stations throughout the state. CIMIS uses a Modified Penman-Monteith equation consistent with ASCE Standardized ETo to calculate monthly ETo and daily ETo using up to date data from their weather stations. The CIMIS website also has a map of California with 18 climate zones, shown in Figure 6-2. The figure also shows a table of 'normal' monthly ETo values for each climate zone that can be used for projects that address areas instead of specific locations. CIMIS also provides daily ETo maps covering all of California (SpatialCIMIS). This is a major advancement in obtaining local ETo data, care must be taken when looking at areas further away from active CIMIS stations because the extrapolation/interpolation of ETo can have significant errors.

Remote sensing of ET using satellite imagery can also provide climate information including evapotranspiration. In general, a surface energy balance using surface temperature measurements from satellites is the best method since it can provide actual evapotranspiration throughout a field and over multiple fields. General details on remote sensing of ET can be found in Jensen and Allen (2016).

An application of remote sensing of ET conducted at the Irrigation Training and Research Center (ITRC), California Polytechnic State University, San Luis Obispo demonstrates the measurements and application of remote sensing for water balances and water management (Howes et al., 2012).



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

6.2.4 Crop ET and Crop Coefficients (Kc)

Kc values are determined by the ratio of the measured ET for a crop (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 an estimate of ETc. In California, practitioners often use the calculations and Kc recommendations from CIMIS. The University of California Cooperative Extension Service 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".

– The leaflets are available at http://www.cimis.water.ca.gov and the Kc values are designed for use with CIMIS ETo information.

Kc values change based on the growth stage of the plant and are commonly divided into four growth stages (see Table 6-3): 1) initial growth stage (10 percent ground cover), 2) Crop-development (up to 80 percent groundcover), 3) Midseason stage (effective full groundcover), and 4) Late-season stage (full maturity until harvest).

Table 6-3. Length of Four Crop Growth Stages for Typical Annual Crops[a]

	Growth Stage (Days)			
Crop	1	2	3	4
Alfalfa 1st cut	10	20	20	10
Alfalfa, 2nd and 3rd cut	5	10	10	5
Barley/Oats/Wheat - Summer	20	50	60	30
Barley/Oats/Wheat - Winter	20	60	70	30
Corn	30	40	50	50
Cotton	45	90	45	45
Deciduous orchard	30	50	130	30
Grass Pasture - Summer	10	20		
Sudan grass, 1st cut	25	25	15	10
Sudan grass, 2nd and 3rd cut	3	15	12	7
Sugar beets	25	65	100	65

a. *Allen et al., 1998*

If local Kc values are not available, estimates from Table 6-4 can be used. Coefficients for annual crops (row crops) will vary widely through the season from a small coefficient during the seedling stage of the crop to a larger coefficient when the crop is at full cover and the soil is completely shaded.

Table 6-4. Crop Coefficients (Kc) for Initial, Midseason and late Season Conditions[a]			
Crop	Initial	Midseason	End
Alfalfa, individual cuts	0.4	1.2	1.15
Almonds, no ground cover	0.4	0.9	0.65
Barley, Oats		1.15	0.25
Bermuda grass, individual cuts	0.55	1.0	0.85
Clover, individual cuts	0.4	1.15	1.1
Citrus, 50% canopy	0.65	0.6	0.65
Citrus, 50% canopy, ground cover	0.75	0.7	0.75
Corn		1.2	0.6-0.35
Cotton		1.15-1.2	0.7-0.5
Open water, < 2m		1.05	1.05
Open water, >5m		0.65	1.25
Orchard, no ground cover	0.55	0.9	0.65
Orchard, ground cover	0.8	1.15	0.85
Pasture grass, grazed	0.4	0.85-1.05	0.85
Sorghum		1.0-1.1	0.55
Soybeans		1.15	0.5
Sudan grass, individual cuts	0.5	1.15	1.1
Sugar beets	0.35	1.2	0.7
Turf grass, warm season	0.8	0.85	0.85
Turf grass, cool season	0.9	0.95	0.95
Wheat, Spring		1.15	0.25-0.4
Wheat, Winter	0.7	1.15	0.25-0.4

a. *Allen et al., 1998*

When process/rinse water land application occurs year-round using double crops, Kc values may be modified to account for different season lengths than those for single crops and for crops that behave differently during summer and winter climates.

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 between 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 soil water status, soil N reserves, and resulting nutrient stress. Crop residue, straw, and other matter 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.

Table 6-5 shows a compendium of nitrogen removal data for California based on harvested yields (Geisseler, 2016; Burt et al., 2019; Geisseler, 2021). Hay crops including alfalfa and grasses remove between 50.8 and 62.3 pounds of nitrogen per ton harvested.

Table 6-5. Nitrogen Uptake by Harvested Crops in California[a]

Commodity	Harvested Yield (lb N/ton)	% Moisture (%)	Number of Observations
Alfalfa – Hay	62.3	12	49
Alfalfa – Silage	24.0	65	6
Fescue, Tall – Hay	50.8	12	260
Oat – Hay	21.7	12	49
Orchard grass – Hay	54.5	12	60
Ryegrass, Perennial – Hay	54.9	12	60
Sorghum – Silage	7.34	65	260
Triticale – Grain	40.4	12	51
Triticale – Silage	9.03	70	19
Wheat, common – Grain	43.0	12	113
Wheat – Silage	10.5	70	39
Wheat, durum – Grain	42.1	12	41
Lettuce, Iceberg	2.63	-	45
Onions	3.94	-	13
Sweet potatoes	4.74	-	11
Tomatoes, processing	2.73	-	24
Almonds, kernels	136	-	31
Grapes – Raisins	10.1	15	16
Grapes - Table	2.26	-	16
Grapes – Wine	3.60	-	8
Lemons	2.58	-	21
Nectarines	3.64	-	31
Oranges	2.96	-	26
Pistachios, dry yield	56.1	-	11
Prunes, dried	11.2	-	18
Walnut, with shells	31.9	-	18

a. *Data from Geisseler, 2016 as presented by Burt et al., 2019.*

The highest uptake of N, phosphorus, and potassium can generally be achieved by perennial grasses and legumes. It should be recognized that although legumes normally fix N from the air, they will preferentially take up N from the soil-water solution, when 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 6-6 for crops commonly selected for process/rinse water land application.

Essentially all N absorbed from the soil by plant roots is in inorganic forms, either nitrate (NO_3) or ammonium (NH_4). Young plants generally absorb ammonium more readily than nitrate; but nitrate uptake increases as the plant ages. Soil conditions that promote plant growth (warm and well aerated) also promote the microbial conversion of ammonium to nitrate and a portion of organic forms of N to inorganic forms. 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.

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 nutrient removal should be based on yield goals and nutrient compositions that local experience indicates can be achieved with good management on similar soils.

Table 6-6. Nutrient Uptake Rates for Selected Crops[a]

	Lb/acre·year[b]		
Crop	Nitrogen, N	Phosphorus, P	Potassium, K
Forage 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
Orchard grass	220-310	18-45	200-280
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
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, grain	140	12	18-50

Source: USEPA, 2006 and other references.

a. 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 6-6. 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).

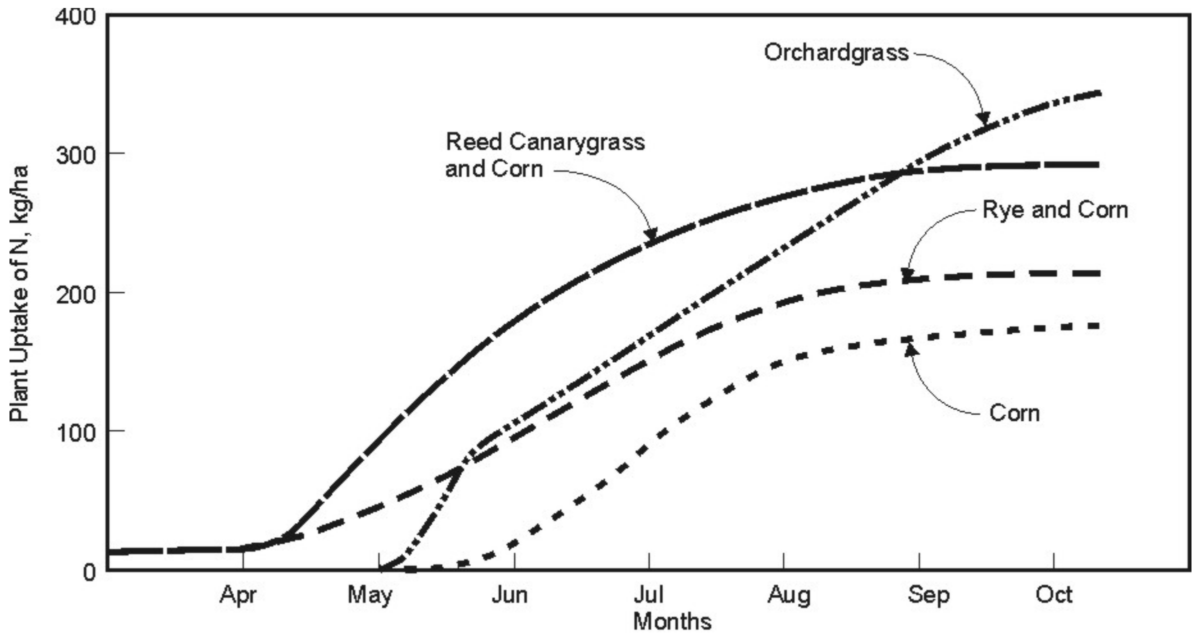
Table 6-7. Typical Effective Rooting Depth of Plants

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

Source: Burt, 1995

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 generic uptake rates shown can vary with climate, overall nutrient status, and cultural practices employed by the field manager.

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. The long growing seasons in California allow planting double crops to increase annual consumptive water use and crop nitrogen uptake. Double crop combinations that are commonly used include summer crops of soybeans, silage corn, sorghum, or Sudan grass with good revenue potential, and winter crops of barley, oats, wheat, vetch, or forage grass.



Note: 1 kg/ha = 0.89 Lb/acre

Figure 6-3. Nitrogen uptake for annual and perennial crops

Some forage crops can have even higher N uptakes than those in Table 6-5. 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.

6.4 Salt and Fixed Dissolved Solids Uptake

Crops take up other dissolved minerals including nutrients, cations, anions, boron, and metals. Table 6-8 shows crop uptake values for selected constituents. The mass removed ranges from less than 150 tons per acre to over 1,100 tons per acre.

The total mass of dissolved constituents removed can also be estimated by measuring the ash content of the crop. The ash content provides an estimate of the mineral solids or FDS in the tissue sample even though some constituents are volatilized during the lab testing and are not accounted for. Table 6-9 shows results of FDS removal testing of various crops that were grown with process/rinse water.

Table 6-8. Constituent Uptake Estimates for Crops

Crop	Yield Per Acre	N	P205	K20	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

a. *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/*

b. *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.*

Table 6-9. Yield and Salt Removal of Various Crops

	Average Yield dry tons/acre	Ash %	FDS Salts Removed Lb/Acre
Alfalfa[a]	6.6	16%	2,093
Barley[a]	3.9	10%	759
Corn[b]	11.7	7.5%	1,750
Winter wheat[b]	5.2	13%	1,321
Tall Fescue[a]	8.4	12%	2,083

Source: Tim Ruby, Del Monte Foods Company, 2007

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 constituents that make up Fixed Dissolved Solids (FDS) depends on the crop and the crop yield. To estimate the salts removed by the harvested crop, test the tissue samples for ash (mineral) content and multiply the results times the dry weight yield. The average yield and percentage of ash shown in Table 6-9 are multiplied to calculate FDS removed.

Additional crop uptake values for process/rinse water land application are shown in Appendix H for other crops and locations, The procedure for determining the ash content of plant tissue is also provided in Appendix H.

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Chapter 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 do 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 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, designing pretreatment facilities and an irrigation system, and planning the irrigation system operation. 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 planning 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 are substantially below agronomic rates[a]. 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, appropriate operation, and monitoring. May require specific design and operation 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.

a. 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 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, substantial denitrification and immobilization of N usually 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. 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 of process water mostly occurs over the course of the processing season. Mineralization rate of land applied process solids is similar to crop residues, with the organic nitrogen becoming plant available over a period 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 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 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.

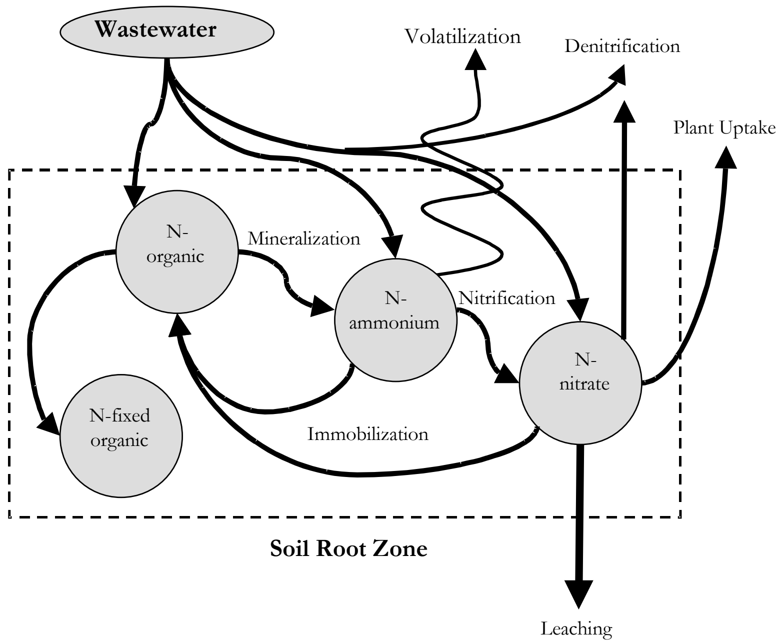

Figure 7-1. Soil nitrogen fluxes

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). Shimek (2019) found up to 93% loss of mineral nitrogen for long term (7 day) flooding and resting cycles on clay loam soil for process/rinse water from a California site. He also found losses were minimal for the soil maintained at a constant 40% of water holding capacity and 38% for another site with clay loam soil maintained at a constant 60% of water holding capacity (Shimek, 2015).

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 1,200 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 the 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. Conservative assumptions should especially be applied where hydraulic loading rates are high enough to flush nitrate through the root zone without sufficient crop uptake opportunity, such as for applications during crop dormancy periods.

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.*

As a point of comparison, the Central Coast Regional Water Board (2021) recently established organic fertilizer discount factors for a range of C:N ratios based on first year nitrogen availability. Table MRP-3 in the Order shows a nitrogen availability of 35% for an 8:1 C:N ratio, not including denitrification losses due to flood irrigation.

Soil monitoring can provide a means for determining if nitrogen loading is excessive. UC Davis researchers (Lazicki and Geisseler, 2016) give a nominal early season threshold value for Nitrate-N as 20 mg/kg to provide adequate nitrogen for early crop development. Lazicki and Geisseler also reference other studies listing thresholds for irrigated corn ranging from 13 to 50 mg/kg for areas with low winter precipitation. Many soils labs show less than 10 mg/kg as deficient and over 40 mg/kg as excessive.

Long term soil monitoring at process/rinsewater flood and periodic move sprinkler irrigation sites has shown that soil nitrate-N concentrations at one foot depth tend to be mostly deficient to moderate (< 30 mg/kg NO_3-N) and rarely exceeding moderate levels. Samples from two foot depth are often nitrogen deficient (< 10 mg/kg). Conversely, repeated applications of waste solids over many years without sufficient cropping has sometimes shown a buildup of soil nitrate-N. The use of soil sampling and analysis to monitor nitrogen loading effects at sites is discussed further in Chapter 10.

Reduced yield will result if the net available 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.

$$L_n = U/(1-f) \quad (7\text{-}1)$$

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.

Another tool that can be used to check the risk of excess nitrogen leaching includes crop tissue monitoring, especially for hay crops. This is discussed further in Chapter 10.

Groundwater aging evaluation can help determine whether groundwater nitrate or other impacts are due to recent events or from activities further in the past. This is also discussed in Chapter 10.

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)[a]	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.

a. After accounting for nitrogen losses and unavailability of nitrogen using Table 7-2 and Equation 7-1.

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, arsenic, 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.

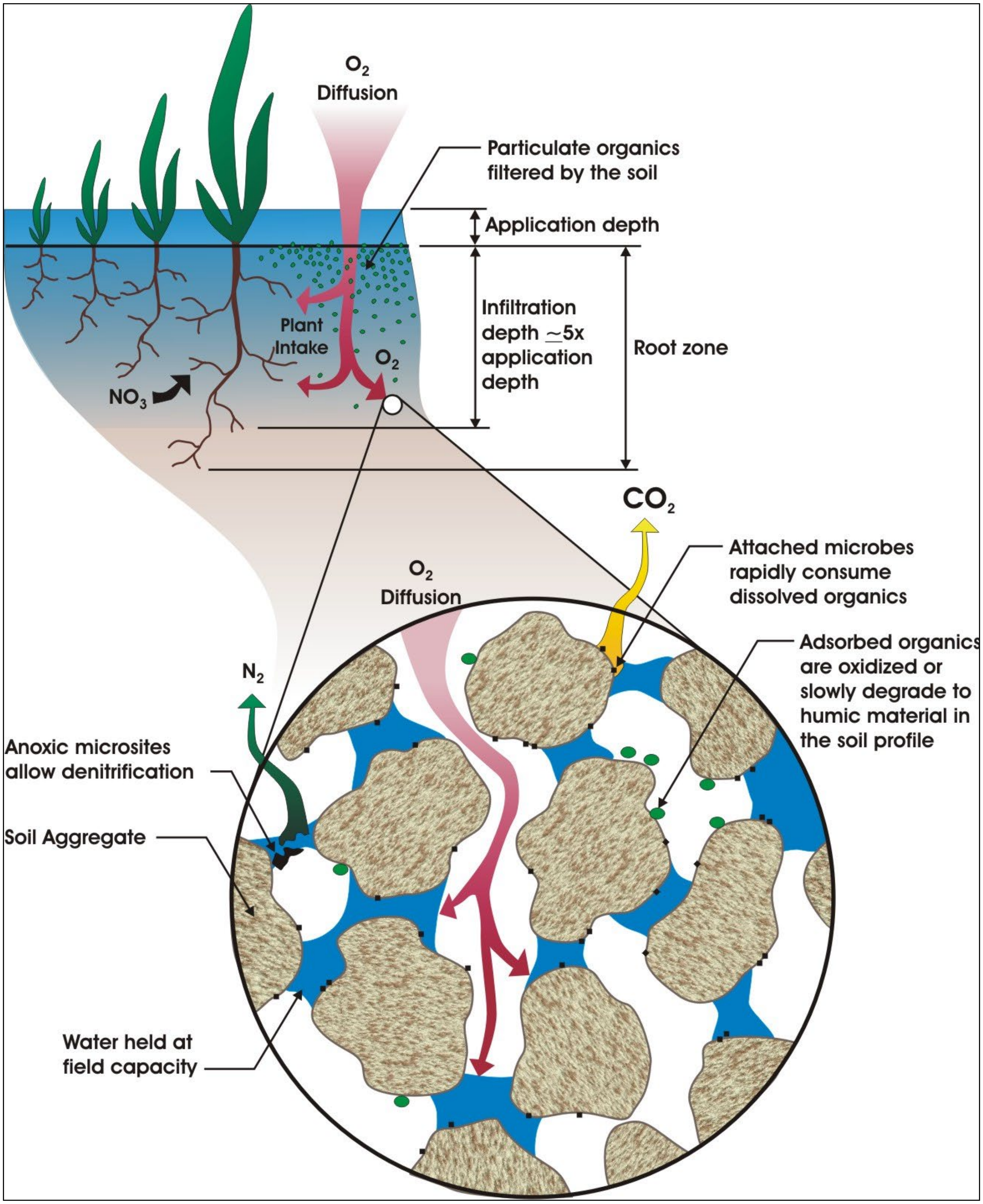

Figure 7-2. Removal mechanisms in land treatment systems

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 ion 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.

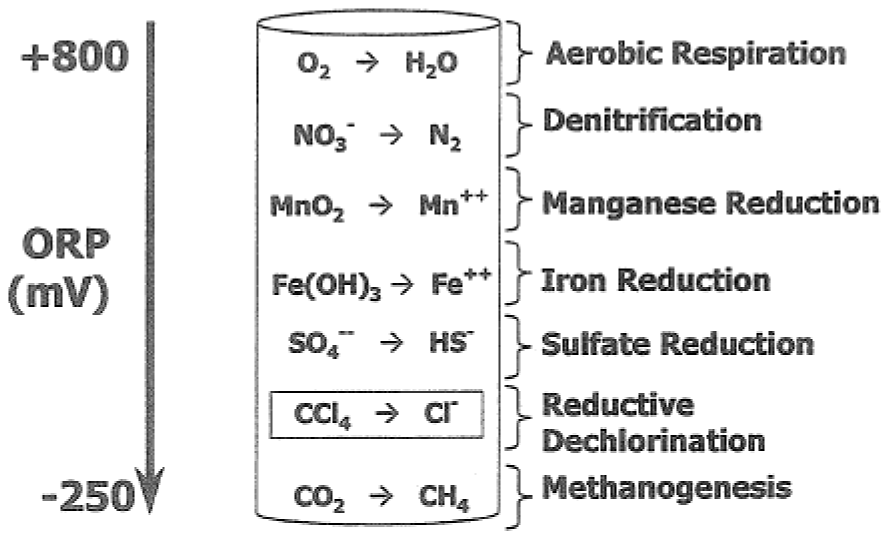

Figure 7-3. Idealized sequence of electron accepting processes

Source: 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. In a 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). Shallow groundwater monitoring for sites with moderately high BOD loading rates has generally shown an increase in average manganese concentrations from upgradient to downgradient wells but has been inconclusive for iron and arsenic. Interpretation can be difficult because downgradient wells are often closer to waterways and lowland marsh areas where more reducing conditions occur naturally.

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. Carbon dioxide is a byproduct of aerobic and anaerobic breakdown of organics. It can react with solid calcium carbonate to form disassociated calcium and bicarbonate. 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 (Overcash and Pal 1979):

$$N_{O2} = 2(C_{O2}\text{-}Cp)\cdot [Dp\cdot t/\pi]^{1/2} \qquad (7\text{-}2)$$

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 (300 g/m^3)

Cp = vapor phase O_2 concentration required in soil to prevent adverse yields or root growth (140 g/m^3)

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.
- Does not consider the re-aeration of the soil column during the non-processing season with low or no loadings

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. The bolded row shows the limit of effective reaeration for the study.

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

Source: Coody et al, 1986

a. *Atmospheric O_2 and CO_2 concentrations are 8.56 and 0.014 mol/m3, respectively.*

b. *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:

$t = \pi / Dp \cdot [N_{O2}/2(C_{O2}\text{-}Cp)]^2$ (7-3)

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.

$t_i = 3600 \cdot d/I$(7-4)

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. Mechanical move sprinklers, such as center pivots or linear move sprinklers, can have particularly high oxygenation rates. 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.

Soil column tests for irrigation with process/rinse water for the City of Lodi showed that cycle average BOD loadings between 50 lb/ac-day and 200 lb/ac-day produced similar results in percolate for constituents of concern. No evidence of downward metals migration was evident in the data for those loading rates. The Lodi results support the approach presented above.

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

Typical irrigation rates with food processing washwater are similar to clean water irrigation rates and would be similar to what the EPA categorizes as “slow rate” land application. 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.

$$I = (ET - Re - Ws) \cdot (1+LR) / eff \qquad (7\text{-}5)$$

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

Source: Western Fertilizer Handbook

a. Relative to NaNO3 at 100

b. Using salt index of NaCl at 154

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, et. al, 2014). 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 (LR) is the fraction of applied water required to maintain a desired salinity level in the soil at the spot in the field receiving the least amount of water. It is a net value meaning it does not include the water needed to overcome irrigation non-uniformity.

The leaching requirement is determined based on the crop sensitivity to soil salinity and the irrigation water salinity as shown in Equation 7-7, known as the Rhoades LR (Ayars et al, 2012).

$$LR = \frac{EC_w}{5EC_e^{*} - EC_w} \qquad (7\text{-}7)$$

The salinity is measured as electrical conductivity of the extract (ECe) and electrical conductivity of the applied water (ECw). The $EC_e{}^*$ is known as the threshold ECe and is the level of salinity that a crop can tolerate before its yield is reduced (Table 7-7 and 7-8).

Table 7-7. Salinity Threshold Tolerance for Fiber, Specialty and Grain Crops that may be Grown with Processed Water

Fiber, specialty, and grain				
Common Name	Tolerance based on:	Threshold Ece (dS/m)	Slope (% Yield Decline per dS/m above threshold)	Relative Sensitivity
Barley	Grain yield	8	5	T
Canola or rapeseed	Seed yield	9.7	14	T
Canola or rapeseed	Seed yield	11	13	T
Corn	Grain yield	1.7	12	MS
Cotton	Seed yield	7.7	5.2	T
Cramble	Seed yield	2	6.5	MS
Flax	Seed yield	1.7	12	MS
Guar	Seed yield	8.8	17	T
Kenaf	Stem DW	8.1	11.6	T
Lesquerella	Seed yield	6.1	19	MT
Peanut	Seed yield	3.2	29	MS
Rice, paddy	Grain yield	3	12	S
Rye (cereal)	Grain yield	11.4	10.8	T
Safflower	Seed yield	8	10	T
Sorghum	Grain yield	6.8	16	MT
Soybean	Seed yield	5	20	MT
Sugarbeet	Storage root	7	5.9	T
Sugarcane	Shoot DW	1.7	5.9	MS
Sunflower	Seed yield	4.8	5	T
Triticale	Grain yield	6.1	2.5	T
Wheat	Grain yield	6	7.1	MT
Wheat	Grain yield	8.6	3	T
Wheat, Durum	Grain yield	5.9	3.8	T

Adapted from Grieve et al, 2012.

Table 7-8. Salinity Threshold Tolerance for Some Forage Crops that may be Grown with Processed Water				
Forages (silage, hay, green chop)				
Common Name	Tolerance based on:	Threshold Ece (dS/m)	Slope (% Yield Decline per dS/m above threshold)	Relative Sensitivity
Alfalfa	Shoot DW	2	7.3	MS
Barley (forage)	Shoot DW	6	7.1	MT
Bermudagrass	Shoot DW	6.9	6.4	T
Broadbean	Shoot DW	1.6	9.6	MS
Clover, alsike	Shoot DW	*1.5*	*12*	MS
Clover, Berseem	Shoot DW	*1.5*	*5.7*	MS
Clover, ladino	Shoot DW	1.5	12	MS
Clover, red	Shoot DW	1.5	12	MS
Clover, straw	Shoot DW	1.5	12	MS
Corn (forage)	Shoot DW	1.8	7.4	S
Cowpea (forag)	Shoot DW	2.5	11	MS
Fescue, tall	Shoot DW	3.9	5.3	MT
Foxtail, meadow	Shoot DW	1.5	9.6	MS
Hardinggrass	Shoot DW	*4.6*	7.6	MT
Orchardgrass	Shoot DW	1.5	6.2	MS
Rye (forage)	Shoot DW	7.6	4.9	T
Ryegrass, perennial	Shoot DW	5.6	7.6	MT
Sesbania	Shoot DW	2.3	7	MS
Sphaerophysa	Shoot DW	2.2	7	MS
Sudangrass	Shoot DW	2.85	4.3	MT
Trefoil, big	Shoot DW	2.3	19	MS
Trefoil, narrowleaf	Shoot DW	5	10	MT
Vetch, common	Shoot DW	3	11	MS
Wheat (forage)	Shoot DW	4.5	2.6	MT
Wheat, Durum (forage)	Shoot DW	2.1	2.5	MT
Wheatgrass, standard crested	Shoot DW	3.5	4	MT
Wheatgrass, fairway crested	Shoot DW	7.5	6.9	T
Wheatgrass, tall	Shoot DW	7.5	4.2	T
Wildrye, beardless	Shoot DW	2.7	6	MT

Adapted from Grieve et al, 2012.

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 was created using the Rhoades LR equation; therefore, the LR can be derived directly from the graph using the ECw (same as Ca in on the horizontal axis) and ECe threshold on the vertical axis.

Once the LR is found, the volume of required irrigation water to meet that leaching requirement can be determined using Equation 7-5. It is most common to conduct leaching irrigation during periods of low evapotranspiration demands. For summer crops, this could be during winter pre-irrigation when the temperatures and, depending on the crop type, the field may be free of vegetation. For winter crops, leaching may occur during early season irrigations or pre-irrigation in the early fall. It is not recommended to add additional water to leaching during each irrigation because of uncertainty in achieving appropriate leaching. A more appropriate method is to use Equation 7-5 annually (ET and effective rainfall over the season) to compute the needed seasonal irrigation with and without the LR. Subtracting these results provides the gross LR needed for that season or year and can be applied at the appropriate time. Soil samples should be taken annually to assess the effectiveness of leaching. These samples should be taken either at the tail ends of the field for surface irrigation or randomly throughout the field for sprinkler and drip/micro irrigation. Comparisons of TDS and the percentage of each cation should be compared from year to year to identify any potential buildup.

An alternative to the annual leaching using the traditional LR method is to conduct reclamation leaching events every 5 or 10 years depending on the water quality and crop sensitivity. This type of salinity management is described in Keren and Miyamoto (2012) and Burt and Isbell (2005). Basic premise is to remove approximately 90% of the salinity from a specified root zone, an equivalent depth of water must be leached through the soil. This means that if a three-foot root zone is desired, approximately three acre-feet of water per acre needs to be leached through the soil. These three acre-feet are in addition to the water needed to bring the root zone to field capacity before leaching can occur. This type of leaching is common in arid areas where leaching will occur during a wet year when excess water may be available.

The leaching fraction 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 7-8. The equation is only valid when weathering and precipitation of salts are insignificant.

$$\mathrm{LF} = \frac{D_d}{D_a} = \frac{C_a}{C_d} \tag{7-8}$$

LF = leaching fraction, unitless
D_d = drainage depth, m
D_a = depth applied, m
C_a = mineral salinity of applied water, dS/m
C_d = salinity in drainage water, dS/m

Equation 7-8 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 (in dS/m) due to mineral salts can be estimated by dividing the mineral salinity (typically estimated from fixed dissolved solids or FDS in mg/L) of process/rinse water by 0.64 and again by 1,000 (Luthin, 1978).

If Equation 7-8 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 7-9.

$$C_d = \frac{C_a}{LR} \qquad (7\text{-}9)$$

All terms are described above.

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 7-9.

Table 7-9. 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 7-9 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.

The effect of salinity on crop growth is shown in Figure 7-4. The leaching requirement as a function of applied salinity is shown on Figure 7-5.

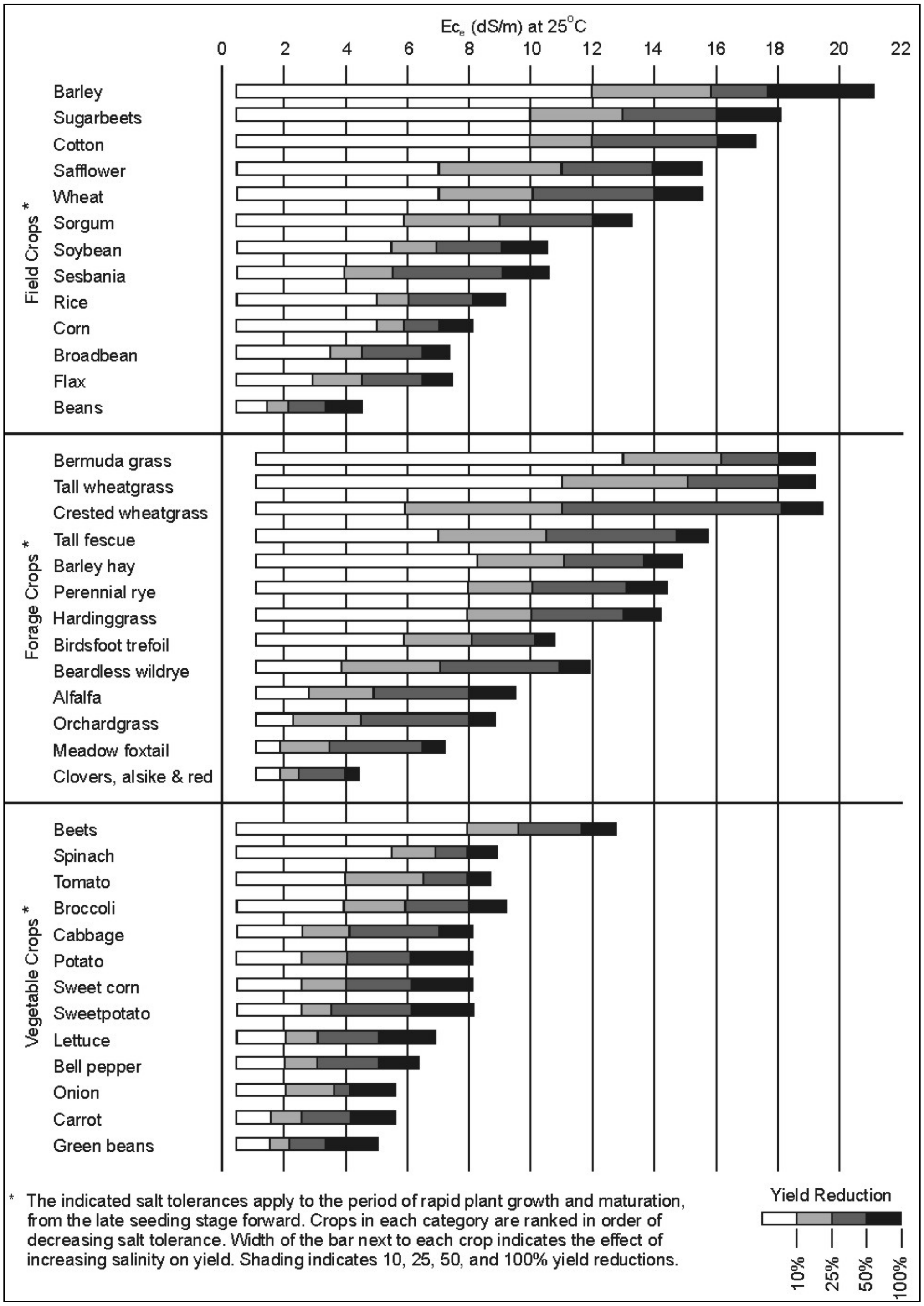

Figure 7-4. Effect of salinity on growth of field crops

Source: USDA, 1992

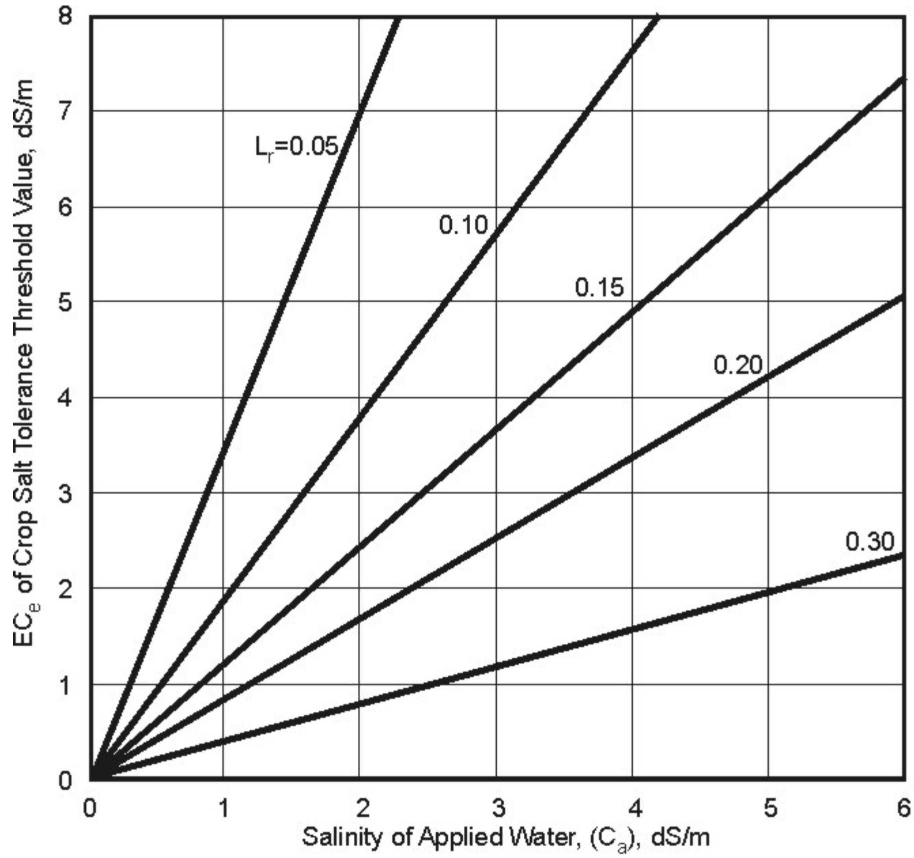

Figure 7-5. Leaching requirement as a function of applied salinity and ECe of crop salinity threshold

Source: 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 the point that they may clog nozzles and emitters. A general rule of filtration recommendations is presented in Table 7-10. 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 7-10. Filtration Recommendations by Application Method	
Irrigation Type	**Required Filtration**
Drip	1/10 emitter size
Microspray and Sprinkler	1/7 nozzle size

Source: Burt and Styles, 1994

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. However, 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 7-11.

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 7-11. Suitable pH of Mineral Soils for Various Crops

Herbaceous plants	Trees & shrubs	Soil pH 4–5: Strongly acid and very strongly acid soils	Soil pH 5–6: Range of moderately acid soils	Soil pH 6–7+: 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 should be taken from typical regional values obtained from the USDA Resource Conservation Service, local Agricultural Extension office or other local sources. Leaching requirements can be determined using methods described in Section 7.6. 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 7-10.

$$A = TL / LL \tag{7-10}$$

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 loam 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.

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Chapter 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. The volume and chemical composition of effluent may vary hourly, diurnally and seasonally. At most facilities, concentrations of organics (BOD), salts and nitrogen (N) are the primary concerns (refer to Chapter 4). 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 (PAA) 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. Spent caustic from peeling one type of product can be recovered and reused for peeling another product that requires a lower strength caustic solution.

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, resulting 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
- Equalization

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), nitrogen, and pH control 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.

8.4.1.1 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 high 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.

8.4.1.2 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.

8.4.1.3 Gravity Settling

Settling, or sedimentation, allows particles that are denser 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.

8.4.1.4 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.

8.4.1.5 Suspended Air Flotation

The suspended air flotation (SAF®) is a different approach to flotation than DAF. The SAF® process uses aphron technology of free-floating soap bubbles to float the solids (Tchobanoglous, et al., 2022). Unlike DAF, the micro bubbles for SAF® are formed at atmospheric pressure, so no pressurization is required. The advantages of SAF® are a lower footprint (20 percent of conventional DAF) and lower power requirement.

8.4.1.6 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.

If drip/micro or center pivot irrigation are used, primary filtration is an absolute necessity. Currently screen filters with rotating suction scanners are very common for processed water center pivots. These devices can be electric or hydraulic driven. They require a good prefiltration system that will remove all particles greater than 2 millimeters in size. Media tanks are also a very good option as a primary filter. They can easily be automated and work well under a wide range of conditions. Prefiltration is not as important with sand media tanks as it is with screens with rotating suction wands. Sand media tanks are by far the most widely used filtration device with drip/micro irrigation in California.

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, 2014).

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.

8.4.3.1 Recirculating Gravel Filter

The recirculating gravel filter consists of a sprinkler system of intermittent application to a bed of pea gravel underlain by drain rock. The hydraulic loading rates for recirculating gravel filters range from 3 to 5 gallons per day per square foot (gpd/ft^2). The BOD loading rates for recirculating gravel filters range from 87 to 348 lb/acre-day, which is similar to low-rate trickling filters. BOD removal depends on the influent concentration and can exceed 90 percent (Crites and Tchobanoglous, 1998).

8.4.3.2 Vertical Flow Constructed Wetlands

Vertical flow constructed wetlands consist of wetland plants in sandy soil with underdrains for the treated water. Distribution systems are micro-sprinklers or drip emitters. Removals of BOD, TSS and ammonia are similar to those for recirculating gravel filters (Crites, et.al, 2014).

8.4.3.3 BioFiltro Biodynamic Aerobic System

The BioFiltro BIDA® System is a wastewater treatment technology that was developed in Chile in 1990. The company is now based out of Davis, CA. The patented Biodynamic Aerobic (BIDA®) System consists of a bed of wood shavings underlain by drain rock and an effluent recovery system. Bacteria and earthworms are added to promote biological treatment and decomposition of applied organics and solids. Wastewater is screened and adjusted for pH before being intermittently sprinkled over the surface of the bed. The drain rock layer has passive vents to help facilitate an aerobic environment. Over time, the worms convert nutrients into worm castings or vermicompost, a natural fertilizer and soil amendment. The process is somewhat similar to a recirculating gravel filter (Crites and Tchobanoglous, 1998). Periodic removal of worms and vermicompost is required as well as resupplying the wood shavings as needed.

The technology has the benefits of using minimal energy and producing minimal amounts of sludge. The hydraulic loading rate design criteria for the design of food processing and winery wastewater has been set at an average of 3.75 gpd/ft^2 by BioFiltro based on monthly average flow. At this loading rate, projects reportedly achieve an average 90 percent removal of applied biochemical oxygen demand and total suspended solids (Miito, et.al, 2021).

8.4.3.4 Biologically Activated Aerobic Treatment

Biologically Activated Aerobic Treatment (BAAT) is a form of BOD reduction that is incorporated into an equalization concept. Essentially the BAAT process is an aerated tank with nutrient addition that serves as equalization and reduction of BOD concentrations (Flippin and Crites, 2004). The typical hydraulic detention time is 1 day and there is no settling or solids removal. The advantages over simple equalization are reduced need for odor control and conversion of soluble BOD into carbon dioxide and bacterial cells. Reductions of soluble BOD of 70 percent have been seen for food processing facilities.

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. Technologies for treating high strength can be found in Tchobanoglous et al, 2014.

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 New Technology

New technology for wastewater treatment and reuse is constantly being developed. The new technologies described in this chapter have been adopted in full-scale operations in the food and beverage industry for pretreatment prior to land application.

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Chapter 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. Additionally, full crop removal through haying or silage is more effective for nitrogen removal.

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 to have sufficient land. 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 (see Chapter 8) 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 pretreatment 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 odors 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. 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, non-workdays or hours, off-peak electricity rate operation, 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.

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).

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 with a uniform slop via small ditches (aka. furrows) 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 the 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 with high potential for runoff. • Poor uniformity is often an issue.
Center pivot	The 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. • Low labor requirements and relatively easy to remote control.
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. • Can have excellent distribution uniformity • Expensive technique
Surface drip	Low flow emitters placed on the ground surface apply water to crops	• Newer wastewater applications use “micro-sprinklers” to minimize clogging problems.
Subsurface drip	Emitters are buried 6 – 12 inches deep as a semi-permanent installation.	• Some difficulties with rodent damage and microbial growth in emitters. • Not recommended for permanent crops such as trees and vines because of root intrusion and pinching

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.

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 tailwater return systems. Uncontrolled tailwater is unacceptable. Tailwater cannot 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). Burt (1995) provides design recommendations for appropriate flow rate per width depending on the soil type and slope.

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 4 to 6 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 in sandier soils. 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. A common rule of thumb for tailwater is that tailwater should occur for half of the irrigation set time. That means that if it takes 4 hours to reach the end of the field, when tailwater starts, the total set times should be 8 hours so tailwater occurs for 4 hours. This balances opportunity time and improves distribution uniformity (Burt, 1995).

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 on undulating topography, 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 such as wheel-line, “Big gun” systems, and mechanical move irrigation systems like center pivots.

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. 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. Poor uniformity and potential for spray drift are problems with big gun systems and they are rarely used in California for these reasons.

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 flow results in application rates of 0.35 to 0.45 inches per day under normal operating conditions. However, this flow rate should be determined based on peak ET and operating hour constraints as previously discussed. 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 which are rarely used anymore. 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 but are often not cost effective unless land values are very high and require significantly more maintenance than the center pivot alone. Pressure regulators on each sprinkler drop are recommended to improve the distribution uniformity. A detailed discussion of center pivot designs for wastewater applications can be found in Gaudi et al. (2007).

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. Good filtration with a fine mesh (or mesh equivalent) is recommended to reduce the clogging of nozzles.

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 polyethylene (PE) irrigation hose or tape laid on the ground surface along crop rows. This pipe either has emitters manually placed into the hose (online) or emitters inside the hose (inline) placed by the manufacturer. Because the systems are on the ground surface, they must either be removed or destroyed during crop harvest unless they are in an orchard or vineyard. 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. Microbial growth can be controlled through regular injection of chlorine or acids. Most drip systems require filtration of 120-150 mesh (or mesh equivalent) to prevent plugging. Sand media tanks are the most widely used and are highly recommended.

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. Burt and Styles (2016) contains comprehensive design and practical considerations for drip and microspray systems.

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 > 2% are not ideal; >8% may require sprinkler or drip system	Systems can tolerate moderate slopes and uneven terrain if designed properly
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	No	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 does not directly affect drip or micro sprinkler irrigation system design or suitability. 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. The most common irrigation scheduling reference used is Allen et al. (1998), often called FAO 56. Howes et al. (2007) discusses how FAO 56 methods are used in wastewater applications for water and nitrogen management.

Once hydraulic needs are known, the decision whether to use process/rinse water or supplemental irrigation water can be based on the supply of process/rinse 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/rinse 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 practice does not optimize process/rinse 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, the need for land leveling and tailwater return systems 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. The down sides of traveling gun systems are poor distribution uniformity and potential for offsite spray drift.

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.

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Chapter 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;
- Crop yield, biomass, and constituents;
- Irrigation type (surface, drip, sprinkler);
- Groundwater flow and water quality; 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 to support operational adjustments and modifications are discussed in the final section 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/crop management and irrigation uniformity and distribution. Monitoring observations will document the behavior of the land application program and identify improved operating procedures or adjustments to improve system performance.

Common crop management factors based on operational monitoring include changing irrigation practices; scheduling harvest, replanting, changing crops, fertilizing, and weeding. Scheduling preventative maintenance and repair or expanding or improving the management system can also be based on evaluation of monitoring data. Frequent review of operational monitoring serves an important “early warning” function; minor problems that are identified quickly can be corrected before groundwater, soil, or cropping impacts occur.

Compliance monitoring is an equally important monitoring category intended to provide documentation for regulatory oversight and compliance with the Monitoring and Reporting Program (MRP) requirements associated with the facility’s Waste Discharge Requirements Order (WDRs). The MRP typically identifies points of compliance for monitoring process/rinse water flow and water quality, source water quality, groundwater level and water quality, crop growth and nutrient uptake, solids land application, supplemental irrigation additions, and daily process/rinse water applications by field. Process/rinse water is monitored to quantify hydraulic, nutrient and salt loading rates. Groundwater monitoring is conducted to assess whether water quality impacts have occurred that could be caused by the applied water. Factors to be considered in establishing compliance monitoring points are discussed in the following sections of this chapter.

The 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, quarterly, 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 show the differences between compliance and operational monitoring. For a land application site with more than one field, field-by-field flows and timing are recorded to determine loading rates for water, organic loading (BOD_5), nutrients, and salts. For operational monitoring, irrigation amounts (including both process/rinse water and supplemental irrigation water) are measured daily and are used to determine where to apply facility flows for the following days. This decision also relies on information for time of last irrigation, soil moisture status, current and projected weather conditions, cropping patterns, and scheduling needs for other fields in the land application program.

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.

Table 10-1. Typical[a] 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 • Correlation of flow and water quality with in-plant processes
Field-by-Field Loadings	• Daily to monthly process/rinse water application, inches • Annual solids loading, pounds per acre • Calculation of organic, nitrogen, and salt loadings	• Daily to monthly supplemental irrigation water application, inches • Daily to monthly climate data (precipitation, evapotranspiration)
Residuals (Solids)	• Weekly/monthly mass applied; annual total • Quarterly nutrients and salinity applied	• Weekly solids water content • Characterize solids constituents prior to land application
Soil Testing	• Annual or semi-annual chemistry, nutrients, salinity	• Annual available P and available K for crop nutrient supply analysis • Periodic soil moisture readings
Crops	• Harvest and planting dates and biomass yield • Nutrients/salts removed for each field	• Annual tissue ash weight, total Nitrogen
Groundwater	• Quarterly water level and constituents of concern for each well • Annual general minerals	• Spikes or large changes in groundwater constituents • Long term trends in compliance monitoring results may be used in determining operational changes.
Routine Inspection Needs	• Odors or spills • Solids land application uniformity	• Pumping system operating pressures, field operating pressures, proper operation of irrigation system, leaks along pipeline, ponding, crop health, runoff, etc.

a. *Compliance monitoring is usually required for risk category 2 or 3 process/rinse water sites. Monitoring at risk category 1 sites will normally be less intensive and less frequent than the values shown in the table.*

10.1.1 Facility Sampling Plan

Successful land application sites are almost always monitored in accordance with a site-specific Sampling and Analysis Plan (SAP). A SAP may be required by a facility's WDRs and MRP. The SAP should be developed to document and provide detailed guidance regarding monitoring requirements, analytical/measurement methods, sampling frequency, analysis, and reporting frequency. The plan should provide both measurement protocols for regulatory compliance and those used for operations monitoring.

Table 10-2 summarizes the suggested contents of the SAP. The plan should provide necessary information only; too much detail may make the document unwieldy and limit its usefulness as a reference.

Key information to incorporate in the SAP include: use of grab sampling when appropriate (often for operations monitoring), selection of representative sampling locations that are readily accessible, use of and directions for automated composite sampling, and protocols for collecting and storing written inspection notes and results.

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 specific instructions.

The SAP should also include standard operating procedures (SOPs) for instrument calibration, sample shipping and chain-of-custody procedures, review of data upon receipt, etc. More detailed supporting material, such as SOPs 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 laboratory 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 • Maps of monitoring locations • 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 • Required laboratory reporting limits to meet MCLs or other accuracy limits • Data analysis procedures • Quality control/quality assurance (QA/QC) program
Requirements by sample medium	• Sections for: Facility source water, process/rinse water, supplemental irrigation water, and solids generation • For each land application area: soil, crops, and groundwater • Each section should address: equipment and supplies, sampling technique, in-field monitoring measurements, sampling location(s), sampling frequency, sample preservation, required laboratory tests, QA/QC needs, additional observations, reporting frequency
Possible Appendices	• Health and Safety Plan • Example data collection forms, chain-of-custody form • Detailed description of groundwater sampling methods (e.g. EPA 1995) • Copy of the facility's Waste Discharge Requirements and Monitoring and Reporting Program

10.2 Water Monitoring

WDR Orders issued to a facility for land application routinely require measurement of flow and water quality parameters. More detailed observations may also be needed to document timing and distribution of flows. This section addresses monitoring for WDR compliance and/or evaluation of the land application system operations.

10.2.1 Flow and Volume Measurement Methods

Flow monitoring is usually required for facility source water, process/rinse water, and supplemental irrigation water. Monitoring data are also used to document the effectiveness of land application in treating or removing constituents in applied water. Common monitoring requirements are described in the following section for moderate to large, risk category 3 facilities (risk categories are described in Section 7.2 and Table 7-1). For smaller or lower risk facilities (risk categories 1 and 2), less monitoring may be required.

Table 10-3 summarizes monitoring and measurements used for water flow and volume monitoring for risk category 3; requirements are lower for risk categories 1 and 2. Regulatory requirements often specify daily measurements of process/rinse water to assess compliance with flow limits that can include average monthly flow and daily maximum flow. Daily flow monitoring for both process/rinse water and supplemental irrigation water are used to calculate daily hydraulic loading for each field used for land application. Land application area managers often compare daily loading rates with incoming precipitation and crop evapotranspiration in a site water balance to determine a) whether adequate soil water is available to crops, and b) whether the soil profile is sufficiently full and does not need water for a few days.

Table 10-3. Water Flow and Volume Monitoring

Parameter	Measurement[a]
Process/rinse water	Daily, weekly, or monthly total flow[b]
Supplemental irrigation water	Total applied volume
Field by field application amounts	Process/rinse water daily volume applied to each land application area field Daily flow of supplemental irrigation to each land application area field Visual inspection for irrigation uniformity, runoff, equipment malfunctioning, standing water, erosion
Lagoon or storage pond	Water level in relation to maximum and minimum operating levels
Pumps and pipelines	Routine visual inspection for leaks Routine pressure checks to identify leaks, other equipment failures, need for maintenance
Climate	Precipitation[c] Evapotranspiration[c]

a. *This table indicates the sampling frequency; the reporting frequency is lower, usually weekly, monthly, or quarterly.*

b. *Recommended frequencies are monthly for risk category 1, weekly for risk category 2, and daily for risk category 3.*

c. *Climate data is 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, and calibration should be regularly scheduled at least once per year. Table 10-4 outlines methods used to measure process/rinse water flows and summarizes the advantages and disadvantages of these methods.

Direct flow measurement devices provide reliable data when properly installed and maintained (including periodic inspection, preventative maintenance, and calibration). 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 be a totalizing flowmeter that allows measurement of the instantaneous flow rate of process/rinse water and records the total volume.

Flow measurement requires sufficient straight length of pipe or channel to develop uninterrupted, smooth laminar flow to provide consistent and reliable data. Typically, a straight length of approximately ten pipe diameters should be available upstream of the flowmeter and the piping should remain straight for approximately four pipe diameters downstream (Dingman, 1994). Styles et al. (2020) were able to place full bore magnetic meters within two to three pipe diameters without impacting accuracy.

Table 10-4. Flow Measurement Methods		
Method	**Alternatives**	**Advantages/Disadvantages**
Intrusive flow meters (meter components within the pipe)	• 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 (EC) can cause failure of sensing components resulting in higher maintenance
Non-intrusive flow meters (no components in pipe)	• Magnetic • Ultrasonic/Doppler	• These sensors have no parts in the flow • Higher capital cost: often, these are used at main pump station and alternative methods are used for individual fields
Open channel flow measurements	• Weir-type • Parshall or Ramp flume	• Requires uniform control length channel to establish proper flow conditions for measurement. Measurements can be recorded using a pressure transducer and datalogger or telemetry • Simple, reliable operation;
Incoming water supply correlation	• Discharge volume is estimated as a percentage of total incoming source water supply	• Supply water is clean, relatively simple to measure using meters • A correlation of incoming flow and in-plant loss with 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 to calculate flow • 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

Flow measurement in pipes 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.

A disadvantage of intrusive flow measurement devices is the effect of process/rinse water on the sensor itself. Since process/rinse water 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 flow measurement devices are often less expensive to install than other metering methods although operating and maintenance expenses may be higher and reliability lower.

Non-intrusive flow measurement devices are becoming more widely used despite the fact that they are often more expensive to purchase and install. Common non-intrusive sensing technologies include magnetic flowmeters and ultrasonic or Doppler type sensors

Open channel flow measurements are used for both total flow measurements in facilities and to measure the flow distributed to individual fields under surface irrigation. These flow measurement devices typically direct the flow through a critical flow measurement device such as a weir or flow measurement flume. These devices allow the user to measure the water depth upstream and relate that to an accurate flow. Acoustic doppler velocity meters and non-contact laser and ultrasonic devices have also been developed specifically for open channel flow measurement. More information on these flow measurement devices can be found in the USBR Flow Measurement Manual (USBR, 2001), Howes et al. (2010), and Feist et al. (2021).

In the absence of direct flow measurements, Table 10-4 also lists methods that are used to estimate process/rinse water discharge flows. These techniques are commonly used by small food processors with varying levels of skill and expertise who start with these methods and improve practices in the future:

- Flow can be estimated as a percentage of the facility's incoming source water supply. This method requires accurate flow measurement into the facility and measurements and calibration to establish uses of water in the facility that is not discharged to land application, losses of water during food processing, and other facility uses. The water discharged to the land application area is then calculated by difference.
- For applications where process/rinse water is not measured but is pumped, flow estimates can be made based on an initial calibration with a flow meter to an hour-meter on the pump. Pump discharge pressure must be measured during the calibration and while the pump is running. This method requires 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 or pond 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 viable alternative.

10.2.2 Climate Monitoring

Climate information, specifically, precipitation and evapotranspiration data, are used to schedule irrigation and as input to 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 western states including California have an excellent network of National Weather Service stations for precipitation and temperature data managed by the Western Region Climate Center). The University of California Cooperative Extension Service has an excellent agricultural weather station network, the California Irrigation Management Information System (CIMIS) described in Chapter 6, Section 6.2.3. CIMIS that maintains weather data and irrigation scheduling tools for use by agriculturists and other irrigators. Chapter 6 also provides information on remote sensing methods to obtain precipitation and evapotranspiration data to estimate irrigation needs and complete a soil water balance to support groundwater antidegradation assessments. Up to date climate data is essential to making accurate estimates of irrigation needs as climate patterns change over time.

10.2.3 Water Quality Monitoring of Process/Rinse Water and Supplemental Irrigation

The requirements for process/rinse water quality data specified in a facility's WDRs generally focus on data needed to calculate field loadings as part of evaluating crop uptake of salts and nutrients and potential impacts to groundwater quality. The MRP generally specifies analytical procedures and the required frequency of monitoring and reporting. If these are not specified, the facility operating personnel may list them in the facility's SAP.

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 nitrogen, salt, and BOD_5 loading calculations are explained in Chapter 7.

Table 10-5. Typical Process/Rinse Water Quality Monitoring Parameters and Frequency

Parameter	Objective	Risk Cat.	Typical Frequency	Comment
pH	Operational and compliance	1	Monthly	• Low pH may be used as an indirect indicator of anoxic conditions • Low pH may also affect soil pH and soil chemistry
		2	Weekly	
		3	Daily or continuous	
EC	Operational and compliance	1	Monthly	• The EC is a simple indirect measurement of salinity • EC measurements can be correlated with FDS and with TDS when BOD and organic acids are negligible
		2	Weekly	
		3	Daily or continuous	
Temperature	Operational and compliance	all	Process specific	• Often not of critical importance, unless stillage wastewater is a component
BOD/COD	Compliance	1	2 / year	• BOD loading rate limitations in pounds per acre per day are set in WDRs to match estimated site assimilation capacity and to prevent nuisance odors • COD is a good proxy for BOD for operational purposes since the time for laboratory analysis is shorter
		2	2 / month	
		3	After each land application event	
TSS	Compliance	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	
TDS	Compliance	1	2 / year	• TDS quantifies inorganic and organic constituents in process/rinse water • It is often used as a surrogate to estimate the concentrations of salt ions
		2	Monthly	
		3	Weekly	
FDS	Compliance	1	2 / year	• FDS measures the inorganic portion of TDS, without the organic acids fraction which degrades rapidly in soil
		2	Monthly	
		3	Weekly	
Salt ions	Compliance	1	Initial	• Sum of ions is a good way to estimate the inorganic portion of TDS. Important ions include Ca, Mg, Na, K, Cl, SO_4, HCO_3 , CO3. This is often included in WDRs as part of monitoring 'General Minerals.' • Measurement of salt ions allows calculation of the Sodium Adsorption Ratio (SAR)
		2	Annual	
		3	2 / year	
Nitrogen	Operational and compliance	1	Annual	• TKN, NO_3-N, NH_3-N should be measured • Total Nitrogen can be calculated from these nitrogen species
		2,3	Monthly	
Phosphorus	Operational and compliance	all	Annual	• Total Phosphorus can be measured but phosphate (PO_4) is often measured for crop nutrition applications
Others	Operational	all	Annual or less frequently	• Boron or molybdenum affect plant health; can be important to monitor. • Trihalomethanes, if chlorine or bromine are principal disinfectants. • Total or Fecal coliform if there is a risk of cross-connection with a sanitary sewer

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) , Phosphate (PO_4).

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 present and of concern • Water level and freeboard
Field by field application amounts	• Constituent loading rates 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 (HCO3), Carbonate (CO3), Phosphate (PO4), Fixed Dissolved Solids (FDS), Total Dissolved Solids (TDS)

The sampling frequency information in Tables 10-5 and 10-6 is based on WDRs and MRPs in common use in the California Central Valley. If more frequent sampling is conducted for operational needs or to address short term concerns, the analytical results for the additional samples must be provided to the Regional Water Board.

10.3 Solid Residuals Monitoring

Food processing facilities often generate significant quantities of byproduct solids (called residuals) as part of their operations. Sources of residuals may include byproduct solids separated at the processor's receiving station (or winery crush pad), initial screening of process/rinse water, material removed from sedimentation basins, and solids that settle in lagoons or other process/rinse 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 for nitrogen, salts, and organic matter. Standard monitoring parameters and needs include:

- **Amount of material**. Weight of material should be recorded, along with source of the material and 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 nitrogen species (organic-N, Ammonia-N and Nitrate-N), total phosphorus, total solids, and moisture content. 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 and Vadose Zone Monitoring. This helps provide an estimate of soil capacity for additional loading of constituents.
- **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. A log of the sites used for solids land application should be maintained in facility records.

  Note that residuals are often applied on a wet weight basis. If this is done, analytical data must be converted using measured moisture content.

– **Regulatory requirements.** Increasingly, Regional Water Boards effectively limit application of solids to land application areas by establishing an annual loading rate limit that applies to the sum of process/rinse water and solids applied. When solids are applied to off-site fields, solids amounts and constituent application must also be tracked and reported.

10.4 Soil and Vadose Zone Monitoring

Soil and vadose zone monitoring is key to evaluating the management of land application to avoid impacts to underlying groundwater. 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.

The term 'vadose zone' is used to describe the unsaturated subsurface zone that lies above the groundwater table. The root zone is at the top of the vadose zone where crop roots take up water and constituents. Land application sites should be designed and managed to allow effective soil chemical and physical treatment processes within the root zone. Root zone monitoring is the primary tool to characterize soil processes. Soil monitoring should also be a part of all process/rinse water application operations to monitor system effectiveness.

Groundwater monitoring is used to assess groundwater quality for land application system compliance purposes, except for situations where well installation would be impractical from a cost or data utility perspective. This may occur when the land application site is underlain by "deep groundwater" (greater than 100 feet below ground surface, 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 more intensive soil monitoring to provide an indication of ongoing effectiveness of land treatment in the root zone to limit groundwater quality impacts.

Soil testing and analysis are an important part of land application site operational monitoring. Soil data are used for several purposes in land application systems:

– Assessment of stored nutrient supply for crops;

– Document treatment efficiency of the soil plant system;

– Evaluate soil chemistry to determine suitability for vigorous crop growth and maintenance of soil structure;

– Use soil water balance monitoring to support irrigation scheduling and manage deep percolation; and

– Assess land application site condition over time.

While this information is useful for operational monitoring, soil monitoring results can be highly variable on both spatial and temporal scales. As a result, soil data are generally not used for compliance purposes when groundwater is accessible as an alternative. Groundwater monitoring provides a more reliable and long-term 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.

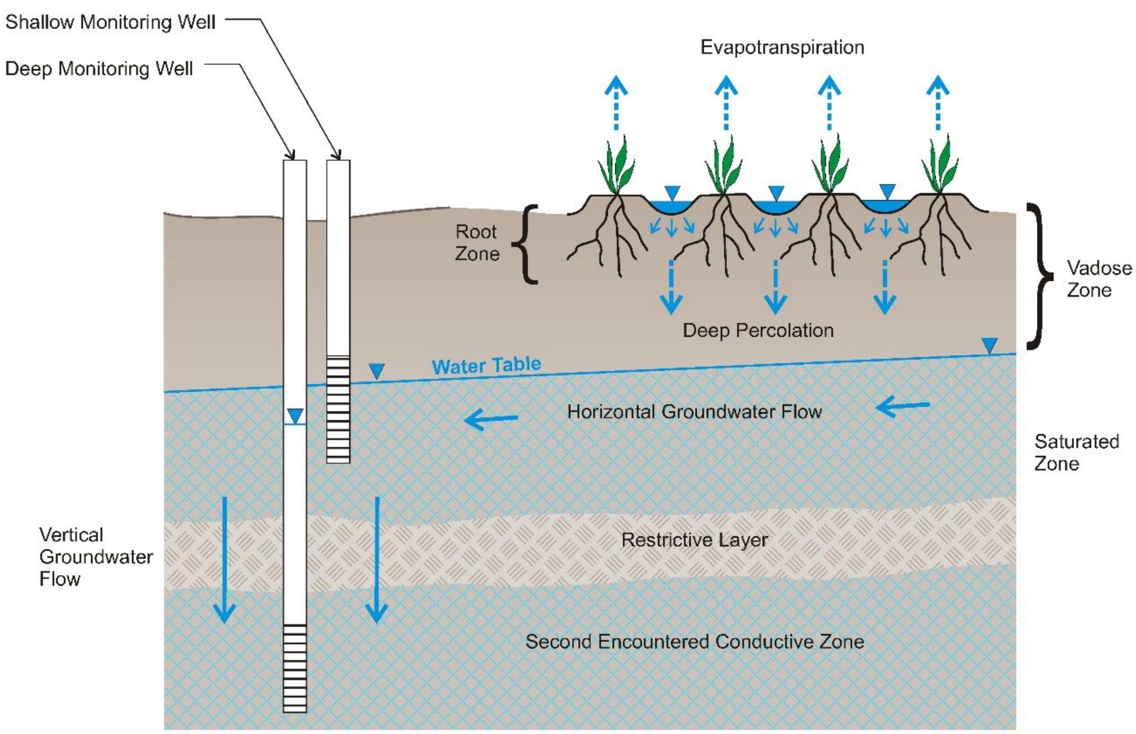


Figure 10-1. Schematic cross section of defined monitoring features

10.4.1 Soil Chemical Monitoring

Soil sampling methods for land application systems rely on soil samples collected within land application fields. Samples should be taken from each field that is an individual management unit in terms of soil type and crop grown. In the past, Regional Water Boards have required intensive soil sampling and analysis to quantify soil storage of nutrients and salts including seasonal increases and decreases. In the past few years, some Regional Water Boards have decreased WDR requirements to an annual frequency to focus on long term changes in soil storage.

Samples for soil chemical characterization should be collected at several depths within the crop root zone. In addition, each sample should be a representative spatial composite based on a minimum of ten 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 composited soil samples taken at three depths for approximately every 50 acres for category 1 and 2 sites. For risk category 3 sites, composited samples should be taken at three depths for approximately every 30 acres. Additional samples may be needed for sites with numerous soil types.

For seasonal soil characterization, samples should be collected before a spring crop is planted and after each crop is harvested during the year. Additional samples may 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.

Basic soil chemistry analyses for land application sites are described in Table 10-7:

- **General Soil Chemistry.** pH and EC 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 (see Chapter 5).

  Organic matter percentage is a slowly changing basic soil parameter that also describes surface soils. In addition, monitoring organic matter allows calculation of the carbon to nitrogen ratio. When the carbon to nitrogen Ratio (C:N) is high, nitrogen may be sequestered in the soil and less nitrogen will be available to plants.

- **Nutrients.** Nitrogen and phosphorus are commonly measured constituents. Available potassium should also be analyzed for to determine potential crop 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). If soil nutrient concentrations increase from sampling date to sampling date, this indicates that the nutrient loading rate may be too high for the crop to assimilate.

- **Soil Salinity.** In addition to EC measured on a saturated paste extract, specific cations are often measured in the soil (sodium, calcium, magnesium, and 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).

Soil testing laboratories often provide analytical panels of parameters that will include the parameters in Table 10-7 along with micronutrients and other parameters. Depending on site specific soil conditions, the additional parameters may be useful in determining suitability for certain crops and/or whether special soil amendments should be considered to enhance crop vigor.

Table 10-7. Soil Chemical and Physical Monitoring Guidelines				
Parameter	Risk Category	Frequency	Depth Ranges (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, TKN	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	
Soluble Iron and Manganese	1	Not required		Iron and Manganese have secondary MCLs These constituents are often used to document that anoxic conditions have occurred, likely due to organic loading (see Figure 7-3).
	2,3	Monthly	2-3, 4-6	

Definitions: Electrical conductivity of saturated paste extract (EC_e),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). Calculate Sodium Absorption Ratio (SAR) and ESP (Exchangeable Sodium Percentage).

10.4.1.1 Additional Soil Analysis

An important goal of a land application system should be the conversion of readily available and degradable organic matter to stable organic matter in the soil. This conversion will increase the humic portion of the soil organic matter where microbial populations make carbon and nitrogen available to plants. 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 measures of soil quality are microbial biomass carbon composition and microbial biomass nitrogen composition. These tests and others may become more common for land application sites as their value is proven through research.

10.4.1.2 Evaluation of Soil Sampling Data

Trend Analysis. Flow charts for soil monitoring interpretation and trend analysis are shown in Appendix E. Under good management, nitrate levels should be fairly stable over time although there may be some variation between years. Site operators should focus on the long-term trends for nitrogen species and other constituents in the soil profile. The 4 to 6 foot depth in the soil is a key zone to monitor to anticipate potential impacts to groundwater quality. Nitrate levels should be decreasing with depth, but fluctuations at a given depth are likely to occur when excess nitrate in one year is stored and then recovered by crops in the next year.

Generally Acceptable Ranges of nitrogen, pH, and salinity. 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 (post-harvest)[a]	10 – 20 mg/Kg
pH	5.5[b] – 8.5
EC (saturated paste extract)	0 - 2 μmhos/cm

a. *Nitrogen in the top 2 feet of soil.*

b. *Acceptable soil pH can be lower for some crops, particularly in high rainfall areas with naturally low soil pH. See Table 7-9.*

10.4.2 Soil Moisture Monitoring and Soil Water Balance

For land application systems, total facility flow and the distribution of process/rinse water among the irrigation fields is key 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 delivery system to the fields and application method (pumped conveyance, surface irrigation, sprinklers, drip systems, etc.) influences the choice of in-field distribution monitoring method.

Direct Measurement. For systems where process/rinse water is pumped to the field(s), the direct measurement flowmeters described in Table 10-4 provide total flow but information on which fields are irrigated must also be collected. Use of hour-meters and estimation of flow from pump discharge and system pressure data are also feasible for estimating in-field distribution of water. On-going pressure measurements are required in conjunction with this method because process/rinse water suspended solids may affect system pressures and water delivery by restricting flow in pipelines, sprinkler nozzles, or gated pipe openings. Monitoring pressures in the field can indicate when to conduct ongoing, routine maintenance or 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 account for the loss or return of “tailwater” flow if return of the tailwater from the end of the irrigated area is practiced.

The purpose of soil moisture monitoring is to assist irrigation scheduling and to identify periods of leaching below the root zone 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). Newer developments of remote sensing of actual ET (discussed in Chapter 6) can provide an alternative to soil moisture measurements for this calibration.

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 Sampling.** Soil samples are collected using a soil auger or soil probe. The samples are weighed, dried at 105 C, and weighed again to determine moisture content by difference between wet and dry weights. The method is labor intensive, disturbs the soil profile for each measurement, and requires time to dry the samples. The method requires a sampler to visit each field to collect samples and assess soil conditions. Experienced irrigators often estimate water supply and need for irrigation using the “feel” method to assess soil moisture conditions by holding soil in their hands and gauging the amount of water available. The “feel” method is one of the only non-laboratory methods that can be used to directly estimate soil moisture depletion. The USDA NRCS has published instructions on how to assess soil moisture using the “feel” method (USDA, 1998).
- **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 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 and other electronic methods 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.

Soil moisture monitoring can be a valuable tool for managing irrigation. Commercial services are available that will provide sensors and installation, frequent or continuous monitoring, and weekly estimates of upcoming irrigation needs.

10.4.3 Soil Water Balance

Soil water balance calculations require a strict accounting of inflows and outflows and the boundary conditions for this balance. The vertical boundaries are the top of the crop canopy and the bottom of the root zone. The horizontal boundaries are the field boundaries for a field or the overall farm boundary if evaluating multiple fields together. If the soil water balance is being used to determine irrigation requirements, the soil water balance should be conducted on a daily or weekly basis.

Process/rinse water sites that are regulated require a soil water balance that incorporates calculation of percolation below the root zone. Percolation is used to assess water moving below the root zone to groundwater and the potential for groundwater quality impacts. The following form of soil water balance addresses both irrigation and percolation.

Future soil water =

Current soil water + Precipitation – Evapotranspiration + Net Irrigation – Percolation

This equation shows that future soil water is the sum of current soil water, precipitation and irrigation minus evapotranspiration and percolation. The equation is then rearranged to solve for future soil water plus percolation:

(Future soil water + estimated Percolation) =

Current soil water + estimated Precipitation – estimated Evapotranspiration + estimated Net Irrigation

Follow these steps to calculate the sum of future soil water and percolation:

1. The available soil water storage capacity (AWC) of the field is required to calculate percolation. This information can be found in the USDA-NRCS Web Soil Survey (https://websoilsurvey.nrcs.usda.gov).
2. This equation takes current soil water, adds forecasted precipitation, and subtracts forecasted evapotranspiration for 3 to 7 days depending on the likely irrigation schedule. These estimates can be made using information from CIMIS or other providers of climate data.
3. Next, an estimated irrigation amount is selected and the equation is solved for (future soil water + estimated percolation).
4. If (future soil water + estimated percolation) is greater than AWC, then actual percolation is calculated as (future soil water + estimated percolation – AWC). If (future soil water + estimated percolation) is less than AWC, then actual percolation is zero.
5. If actual percolation is greater than 0, then a lower irrigation amount can be selected if percolation isn't needed for root zone water quality. If actual percolation is 0, the irrigation could be increased.

The soil water balance method outlined above demonstrates how a soil water balance can be used to estimate irrigation needs based on information about climate conditions and soil properties. This same method can be used to assess the amount of percolation below the root zone that may occur. This information can be used to determine potential impacts of cropping and irrigation practices on underlying groundwater.

10.4.4 Other Vadose Zone Soil Monitoring Methods

A number of soil monitoring methods are in use or in development, primarily for agricultural research or vadose zone studies. Some of these methods will also be of value for process/rinse water land application monitoring. The following paragraphs briefly describe monitoring methods in current use.

Lysimeters. Lysimeters are devices that sample soil water and, based on the measurement methods applied, can be used to:

- **Measure Evaporation**. Weighing lysimeters use a scale to measure weight change in a block of soil in a container that does not allow lateral or downward flow. These are used almost exclusively for research purposes; additional technical information is available in ASTM standards (ASTM, 1992).
- **Collect Water Samples for Water Quality Analysis.** Several methods can be used to collect water samples from soil pores. The most common methods are use of suction lysimeters that apply suction to a porous ceramic cup installed at a specific depth in the soil to collect a water sample. The water is collected and analyzed for nutrients and/or salinity constituents to assess movement in or below the crop root zone. These methods require some

disturbance of the soil profile during installation and depend on a separate soil water balance coupled with a chemical constituent balance to allow interpretation of the sample results.

A second class of lysimeters used for sampling are drainage lysimeters that are installed beneath a soil zone of interest and rely on gravity to collect a water sample. These devices have similar weaknesses to suction lysimeters: disturbance during installation and reliance on a separate soil water and constituent balance. In addition, the cost of drainage lysimeters including equipment, installation, and field monitoring costs restrict use of these devices to research projects, not operations management.

Lysimeters will likely continue to be used for research purposes but the level of effort and cost to employ lysimeters for monitoring of land application areas minimizes their use.

Electromagnetic (EM) geophysical surveys. Geophysical equipment can be used to obtain electrical conductance values for the shallow soil zone. These surveys would not be part of regular site monitoring, but they do provide a useful evaluation of salinity using transects across a site. Section 5.3.7 provides a description of this method.

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 sulfur hexafluoride (SF_6), and/or chlorofluorocarbon (CFC) concentrations because these constituents were introduced into the atmosphere within the last 70 years. Groundwater age information is useful for understanding the background hydrologic conditions and natural background quality. Stable isotopes ^{18}O and ^{2}H can also provide useful information on ultimate groundwater sources. Groundwater age, source, and monitoring data can be used to estimate the lag time between land application area loadings and potential impacts to groundwater quality in monitoring wells.

Other Vadose Zone Measurements. Measurements of soil aeration, soil gases, and soil water parameters measurement using selective electrodes are more customarily used for research-oriented purposes than land application area monitoring. Soil aeration status can be measured to assess potential concerns related to BOD loading at land application sites. Analytical methods are summarized in available soils texts (American Society of Agronomy, 1986).

Soil water parameters such as pH, oxidation-reduction potential (ORP), and specific constituents can be measured directly by selective electrodes placed in the soil. 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. Gas concentrations can indicate 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 but buried line-source samplers may be useful for operations monitoring in the future.

10.5 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. The value of crops harvested from the site may provide an additional incentive to carefully manage land application fields. Attention to crop needs including irrigation water and nutrients will result in better management for agricultural production, process water treatment, and environmental protection objectives.

Recommendations for routine monitoring of crops are provided in Table 10-9. 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 10-9. Example Crop Monitoring Parameters

Parameter	Description
Crop management and growth chronology	Crop management activities should be logged including planting, harvests, primary tillage operations, fertilizer applications, and observations of crop health.
Biomass removal	Track biomass 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.
Constituent removal	Analyze harvested crop tissue for TKN, NO_3-N and other nutrients[a]. Tissue samples should be composites of at least 10 equal-size samples of harvested portions of the crop. Samples should be packaged to prevent moisture loss. Salts can be evaluated if appropriate for a specific site (by measuring salt ions or ash weight).

a. *Typical nitrogen concentrations in harvested plant parts have also been provided by Giesseler (2021). A partial list was shown in Table 6-5 of Chapter 6.*

Nutrient uptake is a primary function of the crop for land application purposes, especially for nitrogen. 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). Annual harvest samples also do not include nitrogen in roots and stubble, which would mineralize slowly over time. Available net nitrogen loading and crop uptake should be nearly equivalent, at least when averages over several years are 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. Tissue samples be taken for these two constituents prior to use of Sudan grass as feed.

10.6 Groundwater Monitoring

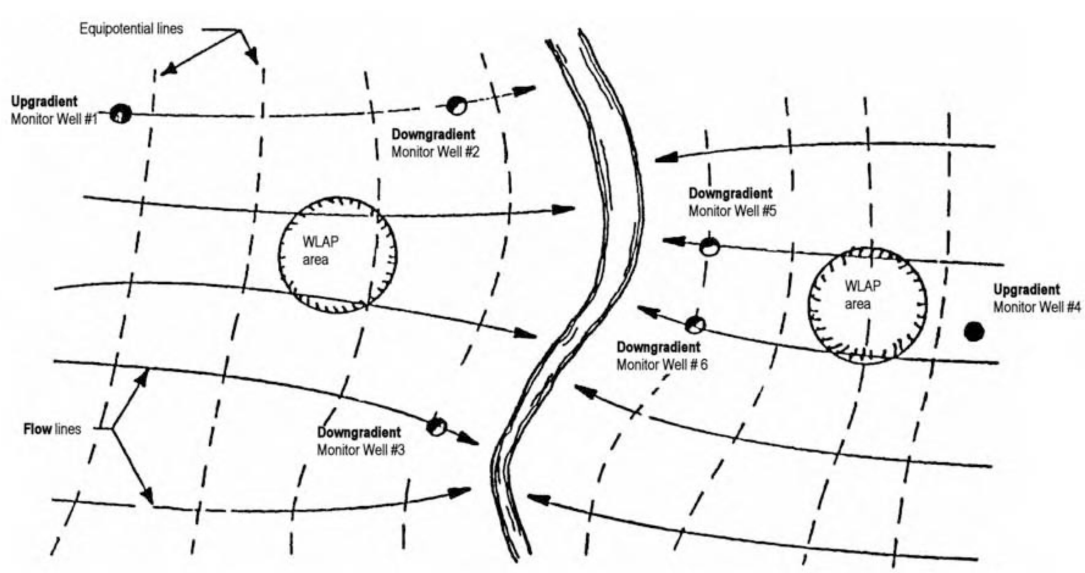
The need for and scope of groundwater monitoring depends on facility type and size, process/rinse water characteristics, land application area management, nutrient and salt loading rates, and aquifer and site characteristics. There are circumstances where groundwater quality monitoring may not be necessary, as in the case where process/rinse water constituent loading rates are below levels of regulatory concern (i.e., de minimus rates). A small facility at risk categories 1 or 2 does not need as extensive a monitoring program as a risk category 3 facility.

If required, groundwater monitoring will be in the MRP for the facility. 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 with 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. In some cases, existing wells may be used to characterize upgradient groundwater quality.
- 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.

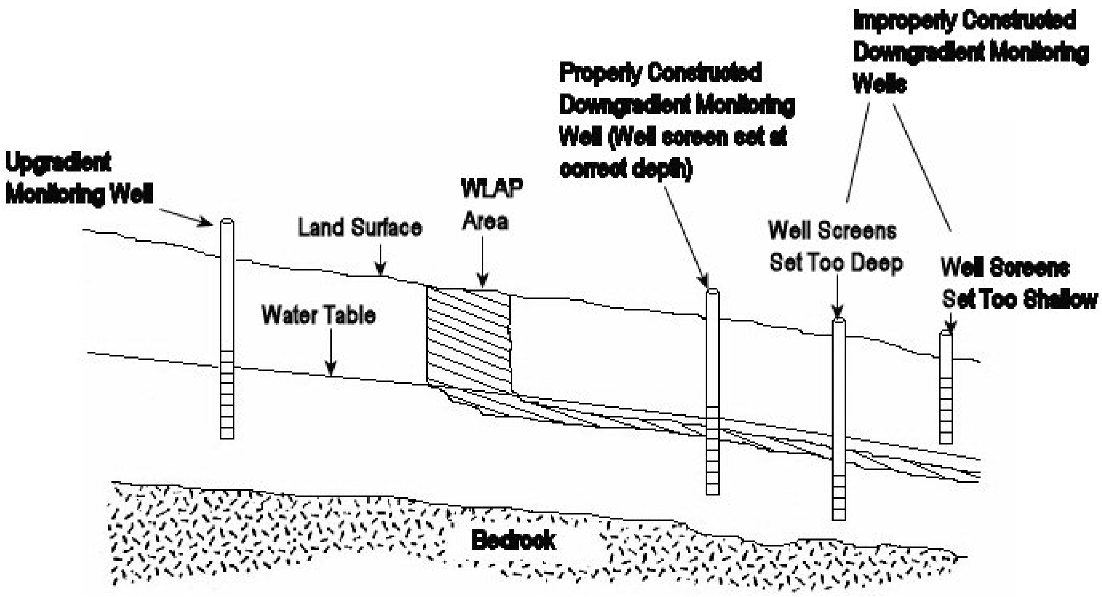
There are no definitive regulatory guidelines for determining the number and configuration of monitoring wells needed for a facility's land application area but a minimum of three wells are required to characterize groundwater flow direction and gradient. The number, locations and construction details for monitoring wells will depend on the size of the application area, loading rates and hydrogeologic conditions underlying the application site. At least one upgradient and two downgradient wells are typically necessary, with a point of compliance near the downgradient boundary of the 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.



Source: Idaho Department of Environmental Quality (2005)

Figure 10-2. Improper (left) and proper (right) locations for groundwater monitoring wells

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 and 2 downgradient wells	Augment w/reconnaissance survey (push-sampling) at larger sites to assess potential variability
3	At least 1 upgradient well and 2 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 indicate 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. 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 analyses[a]	Field measurement of water level, pH, EC, Temperature with portable equipment. Laboratory analysis per MRP and sampling plan. Other constituents may be 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.*

10.6.1 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.

10.6.1.1 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 that 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 cross-gradient 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 tolerance limit of background groundwater quality values. Section 7.6.3 provides a discussion of background groundwater quality as related to salinity.

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.

10.6.1.2 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.

10.7 Periodic Evaluation of the Land Application Program

The land application program should be evaluated, revised, and updated periodically as conditions change. As part of a program update or revision records of inspections, routine maintenance of facilities, and accumulated datasets should be reviewed.

Table 10-12 provides an example inspection form to use for periodic evaluations of infrastructure and land application areas based on maintenance needs. The form provides a list of system components and inspection factors. A third blank column provides a location to take notes on observations. Comments of the inspector should include recommended actions.

The inspection forms should incorporate meter readings, pressure checks, times that various activities take place, etc. 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 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. Facility files could also include process-related records, such as the volume of chemicals used for cleaning, energy consumption and other pertinent data.

Table 10-12. Sample Routine Maintenance Inspection Checklist for Land Application Sites		
Feature	Inspection	Observation and 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	

Combined Data Evaluation. Data from each monitoring location 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, documenting 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 estimates of deep percolation, fate of constituents in the vadose zone, transport of constituents to groundwater, changes in groundwater quality, and the rate of movement of groundwater. This information 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 specify the required evaluations and reports but the data evaluation will likely address operational matters not covered by the WDR.

Operational Adjustments and Modifications. Review of inspection reports and thorough data evaluation may identify management practices that should be re-evaluated. 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 10-13.

Table 10-13. 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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Chapter 11

Research Needs

As indicated in Chapter 1, the manual was revised through a collaborative effort between CLFP, peer reviewers, and consultants. As individual chapters were revised, new information derived from monitoring programs at permitted facilities as well as new research findings from other sources were combined to update each chapter. This approach resulted in valuable improvements to the manual.

At the same time, new topics and new information were identified but could not be adequately addressed within the timeframe allotted for revision of the manual.

The following table shows a preliminary draft list of research areas and topics that could be addressed in the future:

Table 11-1. Suggested Topics for Applied Research for Process/Rinse Water Land Application. Category

	Topic
Organic matter and Microbial populations	• Determine soil aeration for common soil textures at land application sites under various BOD loading rates. • Evaluate use of soil-gas testing to confirm soil aeration and maintenance of aerobic microbial activity under various BOD loading rates in soils at land application sites • Determine nitrogen immobilization and mineralization rates of organic nitrogen for common process/rinse water land application methods. • Assess the correlation of BOD loading with dissolved iron and manganese and arsenic in receiving groundwater. • Determine the minimum organic loading necessary to maintain and enhance soil health and fertility.
Nutrients	• Evaluate the effect of soil aeration on nutrient availability and nutrient losses • Correlate nitrogen transformations with soil organic matter and microbial populations
Salinity/TDS	• Compare the salinity uptake by various cover crops, considering climate and applied water quality. • Identify best practicable treatment and control methods to minimize salinity impacts on groundwater. • Identify alternative methods for peeling fruit to minimize use of caustic. • Identify alternative cleaning products to minimize introduction of sodium. • Identify alternatives to water softener and boiler blowdown chemicals. • Determine the management approach to long-term immobilization of salts by chemical precipitation in the soil. • Determine how process/rinse water application affects soil cation exchange potential.
Groundwater Protection	• Evaluate the actual nature and extent of groundwater quality impacts at land application sites based on existing groundwater quality monitoring data. • Develop methods to evaluate potential impacts of land application on groundwater based on soil monitoring and remote sensing.
Soil and Vadose Zone Monitoring	• Assess the correlation between the thickness and texture of vadose zone and treatment processes And changes in process/rinse water quality during infiltration. • 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. • Develop methods to provide individual field irrigation scheduling recommendations based on soil monitoring and remote sensing.
Soil/ Site Selection	• Investigate whether long-term wastewater application has an effect on soil buffering capacity. • Confirm that soil (and soil solution) is not adversely affected by wastewater with a pH in the range of 3 to 10.
Crop Irrigation	• Develop methods for improving crop uptake of nutrients and salts using double and triple crops. • Develop year round crop coefficients for double and triple crops.

This 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. 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.

Chapter 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 purchase 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.

12.1.3.1 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 lb/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.

12.1.3.2 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.

12.1.3.3 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 requirement (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.

$$LR = \frac{(EC_w)}{(5EC_e^* - EC_w)}$$

Orchardgrass threshold ECe = 1.5 dS/m

TDS = 350 ppm (assumed average of process water and GW)

ECw = 0.5 dS/m (approximated as 350 ppm/(700 ppm per dS/m))

$$LR = \frac{(0.5)}{(5 \cdot 1.5 - 0.5)} = 0.07$$

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

$I = (ET - R_e - W_s) \cdot (1+LR) / eff$ (7-5)

Maximum Irrigation Rate = (9.0 – 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 = 8.0 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

= 6.1 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.

12.1.3.4 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)	BOD5 (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.

12.2.3.1 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:

$L_n = U/(1-f)$ (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.

12.2.3.2 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

$N_{O2} = 2(C_{O2}\text{-}Cp)\cdot [Dp\cdot t/\pi]^{1/2}$ (7-2)

Total Oxygen Flux = 2 • (300 - 140) • (0.6 • 0.16 • 1.62 • 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).

12.2.3.3 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.

12.2.3.4 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.

12.2.3.5 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.

Agronomic. Loading rates or practices in accordance with crop needs, including allowances for losses and inefficiencies similar to local farming practices.

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 at contour intervals to hold the water.

Conventional wastewater treatment. Reduction of pollutant concentrations in wastewater by physical, chemical, or biological means.

Chemical oxygen demand. as determined by Standard Methods 5220.

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 sloping, relatively impermeable soil that has been planted to vegetation. Biological 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 or BOD_5- Five-day biochemical oxygen demand (Standard Methods 5210 B)

BOD_u – ultimate biochemical oxygen demand

BPT - best practicable treatment technology

cm - centimeter

COD - chemical oxygen demand (Standard Methods 5220)

CVSALTS - Central Valley Salinity Alternatives for Long-Term Sustainability

cu. m - cubic meter

deg C - degree Centigrade

deg F - degree Fahrenheit

DWR - Department of Water Resources

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

FDS - fixed dissolved solids (after ignition at 550 degrees C as per Standard Methods 2540 E)

fps - feet per second

ft - foot

gal. - gallon

gpm - gallons per minute

ha - hectare

hr - hour

in. - inch

ILRP - Irrigated Lands Regulatory Program

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

OWTS - Onsite Wastewater Treatment Systems

NRCS - Natural Resources Conservation Service

ppm - parts per million

psi - pounds per square inch

SAR - sodium adsorption ratio

SCS - Soil Conservation Service

sec - second

SGMA - Sustainable Groundwater Management Act

sq ft - square foot

SS - suspended solids (also referred to as TSS for total suspended solids, Standard Methods 2540 D)

STPCC - sewage treatment plant construction cost (index)

TOC - total organic carbon

TDS - total dissolved solids (Standard Methods 2540 C)

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:

1. Those landfill facilities that must use a joint Solid Waste Facility Permit Application Form, California Integrated Waste Management Board Form E-1-77; and

2. 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

State of California
Regional Water Quality Control Board

APPLICATION/REPORT OF WASTE DISCHARGE GENERAL INFORMATION FORM FOR WASTE DISCHARGE REQUIREMENTS OR NPDES PERMIT

INSTRUCTIONS

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, phone number, and email 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, phone number, and email. 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, telephone number, and email 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".

Address where annual fee invoices should be sent, 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".

II. TYPE OF DISCHARGE

Mark the appropriate box to describe whether the waste will be discharged to: Land or 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

- 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.
- 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.
- 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.)

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.

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 ______________ Email ______________

B. FACILITY OWNER:

Name ______________________________

Address ______________________________

City/State/Zip Code ______________________________

Contact Person ______________________________

Telephone Number ______________ Email ______________

Federal Tax ID ______________________________

Owner Type (*Mark one*):

☐ Individual ☐ Corporation ☐ Governmental Agency ☐ Partnership

☐ Other: ______________________________

C. FACILITY OPERATOR (The agency or business, not the person):

Name ______________________________

Address ______________________________

City/State/Zip Code ______________________________

Contact Person ______________________________

Telephone Number ______________ Email ______________

Operator Type (*Mark one*):

☐ Individual ☐ Corporation ☐ Governmental Agency ☐ Partnership

☐ Other: ______________________________

D. OWNER OF THE LAND

Name ______________________________

Address ______________________________

City/State/Zip Code ______________________________

Contact Person ______________________________

Telephone Number ______________ Email ______________

Owner Type (*Mark one*):

☐ Individual ☐ Corporation ☐ Governmental Agency ☐ Partnership

☐ Other: ______________________________

E. ADDRESS WHERE LEGAL NOTICE MAY BE SERVED

Address ______________________________

City/State/Zip Code ______________________________

Contact Person ______________________________

Telephone Number ______________ Email ______________

F. BILLING ADDRESS

Address ______________________________

City/State/Zip Code ______________________________

Contact Person ______________________________

Telephone Number ______________ Email ______________

II. TYPE OF DISCHARGE

Check Type of Discharge(s) Described in this Application:

☐ **Waste Discharge to Land** ☐ **Waste Discharge to Surface Water**

Check all that apply:

☐ Animal or Aquacultural Wastewater
☐ Animal Waste Solids
☐ Biosolids/Residual
☐ Cooling Water
☐ Domestic/ Municipal Wastewater Treatment and Disposal
☐ Dredge Material Disposal
☐ Hazardous Waste (*see instructions*)
☐ Industrial Process Wastewater
☐ Land Treatment Unit
☐ Landfill (*see instructions*)
☐ Mining
☐ Storm Water
☐ Surface Impoundment
☐ Waste Pile
☐ Wastewater Reclamation
☐ Other, *please describe* ______________

III. LOCATION OF THE FACILITY

Describe the physical location of the facility:

1. Assessor's Parcel Number(s)

    Facility: ____________________

    Discharge Point: ____________________

2. Latitude

    Facility: ____________________

    Discharge Point: ____________________

3. Longitude

    Facility: ____________________

    Discharge Point: ____________________

IV. REASON FOR FILING

Check all that apply:

- ☐ 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:

____

____

Has a "Notice of Determination" been filed under CEQA?

☐ Yes ☐ No

If Yes, enclose a copy of the CEQA document, Environmental Impact Report (EIR), 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: ____________________

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.

TECHNICAL INFORMATION
FOR A REPORT OF WASTE DISCHARGE
For
Discharges to Land in the WDR (Non 15[1]) Program (Individual WDRs Only)

This document provides guidance for applying for individual waste discharge requirements only. If you believe that your discharge would be appropriately regulated under general waste discharge requirements or general waiver, please see the links below and contact Central Valley Water Board staff for guidance.

General WDRs: http://www.waterboards.ca.gov/centralvalley/board_decisions/adopted_orders/#General
Waivers: http://www.waterboards.ca.gov/centralvalley/board_decisions/adopted_orders/#Waivers

Table of Contents

[1] The Non 15 Program regulates discharges to land that are exempt from Title 27 of the California Code of Regulations. See the following link for a brief explanation of Title 27 and exemptions that may be used: http://www.waterboards.ca.gov/water_issues/programs/land_disposal/waste_discharge_requirements.shtml

I. What is a Report of Waste Discharge?

A Report of Waste Discharge (ROWD) is an application for waste discharge requirements. A ROWD consists of the following:

A completed and signed Form 200, which can be downloaded from the internet at http://www.waterboards.ca.gov/publications_forms/forms/docs/form200.pdf.

1. A technical report prepared by a California registered Civil Engineer that presents the Information listed in the table below.
2. For a new or previously unpermitted discharges, a check for the first annual fee made payableto the *State Water Resources Control Board*. Consult with staff to determine the required fee.There is no fee if you are applying for revised or updated WDRs because you are already subject to an annual permit fee. The current fee schedule can be viewed at the following link: http://www.waterboards.ca.gov/resources/fees/index.shtml#wdr

II. Compliance with the California Environmental Quality Act (CEQA)

Although not required as part of the ROWD, for new, previously unpermitted, or expanding/changing discharges, you must also submit a copy of any draft and final environmental review documents prepared to comply with the California Environmental Quality Act (CEQA).

If the local planning agency (city or county, as applicable) or another public agency has determined thatthe project (or expansion, changes, etc.) does not require any discretionary action by that agency, the Central Valley Water Board may be the lead agency for the purposes of CEQA, and you will be required to submit an Initial Study and pay all fees and other costs associated with the CEQA process unless the Board determines that the action falls within the scope of a categorical or statutory exemption. Fees associated with the filing of an Initial Study may include a California Department of Fish and Wildlife fee, County Clerk recording fees, and costs for publishing the CEQA Notice of Intent in a local newspaper. Consult with your local planning agency and Central Valley Water Board staff if you have any questions about CEQA. Additional information about CEQA is also available at the following link: https://opr.ca.gov/ceqa/.

III. What is Required for the ROWD Technical Report?

Please note the following tips to expedite the ROWD review and waste discharge requirements development:

- Providing the information in the same order as the list below will help to expedite the ROWD review. Staff will use this as a checklist.
- If any of the information is missing or incomplete, the ROWD will be deemed incomplete and the process (and your project) will be delayed until all of the required information is submitted. You will be notified in writing of the ROWD status after it has been reviewed. If the ROWD is incomplete, we will specify the additional information that is required to complete the ROWD.
- All numerical data presented in tables and calculations performed using spreadsheets should be provided in digital form (MS Excel compatible spreadsheet).
- If some of the information listed below can be found in a previous technical report prepared by a registered professional, the ROWD can incorporate the report as an appendix, but the ROWD text must specify where in the report the required information can be found. However, if appended reports contain information that conflicts with the body of the ROWD, it may cause further delays.

A. General Information
1. Is this a new/proposed or existing facility?
2. If this is an existing facility, is the discharge currently regulated under Waste Discharge Requirements (WDRs) issued by the Central Valley Water Board?
a. If so, provide the WDRs order number.
b. If not, provide the name of the local agency that issued the current permit.
3. Provide a copy of any other permits that reference or relate to the wastewater disposal system. This includes Use Permits and Surface Mining and Reclamation Act (SMARA) reclamation plans, etc.
4. Provide the following for the facility that generates the waste and the site where the waste is discharged:
a. Street address (provide street name and distance from nearest cross street if there is no street number).
b. The approximate latitude and longitude of the facility that generates the wastewater, wastewater treatment facilities, and wastewater land disposal areas.
c. Township, Range, and Section.
d. Assessor's parcel numbers.

B. Wastewater Facility and Discharge *Complete this section for both new/proposed facilities and existing facilities*.
1. A description of the sources and types of wastewater flowing into the system from:
a. Residential (population served and number of connections or equivalent dwelling units).
b. Commercial (number of connections by type).
c. Industrial (number of connections by type).
2. Design influent flow rates (average daily, dry weather daily, peak hour, peak day, and peak month), and the design treatment capacity of the system with respect to each of these. For new/proposed facilities, provide the methods used to estimate these design parameters and copies of all calculations.
3. For existing facilities, a summary table of monthly influent flow totals and monthly precipitation totals for the last five years. Explain any data gaps, outliers, and/or unusual circumstances that might affect measured flow rates. If sewer inflow and infiltration (I/I) contributes significantly to influent flow, provide an I/I analysis to project I/I as a function of total annual precipitation and/or groundwater level as appropriate.
4. A detailed description of the facilities that generate wastewater, and all wastewater conveyance, treatment, and disposal systems. Use site plans and conceptual drawings as appropriate to illustrate locations and typical construction. Include all treatment processes. The following maps, plans, and illustrations are needed:
a. A facility location map showing local topography, the facility location and/or boundaries, streets, and surface waters (including storm water drainage ditches, irrigation canals, and irrigation/tailwater ditches).
b. A process flow schematic for the entire treatment and disposal system. Include existing and proposed flow monitoring devices and sampling locations proposed to determine compliance with the WDRs.

c.	A scaled treatment plant site plan.
d.	A scaled map showing the limits of all proposed wastewater treatment, storage and disposal areas.
5.	Characterization of the source water (the community or process water supply), influent wastewater quality (prior to treatment or discharge), and treated effluent quality. See Table 1 for a minimum list of constituents to be analyzed.
6.	For POTWs and domestic wastewater facilities, a description of the sewer system, sewer materials and age, and lift station details (type, location, capacity, backup systems, and alarms features). Discuss potential inflow and infiltration (I/I) rates in light of local groundwater conditions and sewer system materials/design. For industrial facilities, a description of the industrial wastewater collection and conveyance system.
7.	A description of proposed alarm systems, emergency wastewater storage facilities, and other means of preventing treatment system bypass or failure during reasonably foreseeable overload conditions (e.g., peak flows, power failure, sewer blockage). Consider both potential problems at the treatment system and within the conveyance system.
8.	Preventive and contingency measures for controlling spills and accidental discharges.
9.	Flood and frost protection measures (structural and operational) employed at the facility.
10.	For debris, grit and screenings, sludge, and biosolids the following:
a.	A description of solids generation rates, on-site treatment and handling systems, and short-term storage procedures.
b.	A description of solids disposal practices.
c.	For facilities that do not have continuous sludge wasting systems (i.e., where sludge accumulates in treatment and/or storage ponds), the frequency of assessing accumulated sludge volume, the date of the last sludge volume assessment, the date of the last sludge cleanout, and expected frequency of future sludge cleanout activities
11.	For each wastewater treatment, storage, or disposal pond and containment structure, provide the following information:
a.	Identification (name) and function of the pond.
b.	Surface area, depth, and volumetric capacity at two feet of freeboard.
c.	Height (relative to surrounding grade), crest width, interior slope, and exterior slope of each berm or levee.
d.	Materials used to construct each berm or levee.
e.	Description of engineered liner, if any. Include a copy of the Construction Quality Assurance (CQA) Report if one was prepared.
f.	Estimated steady state percolation rate for each unlined pond.
g.	Depth to shallow groundwater below the base and pond inverts.
h.	Overfilling/overflow prevention features.
i.	Operation and maintenance procedures.
12.	For subsurface disposal systems, provide the design basis and documentation demonstrating that the system has been designed in accordance with applicable regulations, codes, ordinances, and guidelines. If the design deviates from these requirements, provide justification in terms of system longevity, maintainability, and groundwater protection.

13. If treated domestic effluent will be recycled for beneficial reuse or if wastewater will reused or land-applied[2], provide a complete description of the following:
a. Ownership and contact information for each landowner[3].
b. Effluent disinfection system.
c. Effluent conveyance systems.
d. Water recycling/Land application areas (LAA) areas.
e. Cropping plans.
f. Planned operations (planting and harvest, irrigation method, irrigation frequency, irrigation amounts).
g. Expected nutrient loadings (pounds per acre per year total nitrogen).
h. Expected salt loadings (pounds per acre per year total dissolved solids).
i. Tailwater management methods.
j. Storm water runoff management methods.
k. Setback distances from the edge of each recycling/land application area from the property boundary, public streets, occupied structures owned by others, and surface waters/surface water conveyances.
l. Plans that illustrate items c, d, i, j, and k above
14. If wastewater effluent will be recycled pursuant to Title 22 of the California Code of Regulations (e.g., if domestic wastewater is recycled to grow crops, irrigate landscaping, provide pasture for livestock, or for landscape or recreational impoundments, including reclamation sites owned by a POTWs, unless water is recycled solely for irrigation of landscaping at the POTW site) a Title 22 Engineering Report must be submitted to both the Central Valley Water board and the Division of Drinking Water[4].
15. Projected monthly water balances demonstrating adequate containment capacity for both the average rainfall year and the 100-year return period total annual precipitation, including consideration of at least the following:
a. For POTWs and private domestic wastewater facilities, initial baseline influent and I/I flows as well as baseline influent and I/I flows at full build out with an aging sewer system.
b. A minimum of two feet of freeboard in each pond at all times (unless a registered civil engineer determines that a lower freeboard level will not cause overtopping or berm failure).
c. Historical local evapotranspiration, pan evaporation, and lake evaporation data (monthly average values).
d. Local precipitation data with the 100-year return period annual total distributed monthly in accordance with mean monthly precipitation patterns.
e. Proposed recycling area/land application area/disposal system hydraulic loading rates distributed monthly in accordance with expected seasonal variations based on crop evapotranspiration rates.
f. Projected long-term percolation rates (including consideration of percolation from unlined ponds and the effects of solids plugging on all ponds).

2 Uses of recycled water that are limited to landscape irrigation (including golf courses) can be regulated under General WDRs issued by the State Water Board. See this webpage for more information: https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/requirements.html

3 Landowners are typically named in WDRs as co-dischargers, and the WDRs may include separate requirements with which co-dischargers must comply.

4 To the extent this information is already presented in the Title 22 Engineering Report, the ROWD may incorporate that report by reference. The Title 22 Engineering Report must also be submitted to the Division of Drinking Water for review and approval.

16. Proposed flow limits and basis for the limits. Consider dry weather flows vs. peak flows and seasonal variations. Include the technical basis for the proposed flow limit (e.g., design treatment capacity; hydraulic capacity of a main lift station, headworks, or other system element; and demonstrated effluent storage/disposal capacity).
17. A narrative description of treatment system operation and maintenance procedures to be employed, including those associated with effluent storage and disposal.
18. For POTWs, the level of operator certification and staffing; the names and grade levels of all certified operators, and the hours that the facility is manned.
19. For privately owned domestic wastewater treatment facilities, the names and grade levels of all certified operators, and the hours that the facility is manned. If the facility does not have a certified operator, provide justification for not retaining one.

C. Planned Changes in the Facility and Discharge (for existing facilities only)

1. Describe in detail any and all planned changes in the facility or discharge, addressing each of items listed in Section B above.

D. Local and Site-Specific Conditions (Illustrate with maps as appropriate)

1. Neighboring land uses.
2. Typical crops grown (if agricultural area).
3. Irrigation water source(s) and volume and quality data (if agricultural area).
4. Terrain and site drainage features.
5. Nearest surface water drainage course.
6. FEMA floodplain designation(s).
7. Average Annual precipitation (inches)
8. 100-year 365-day precipitation (inches)
9. Reference evapotranspiration (monthly and annual total)
10. Pan evaporation (monthly and annual total)
11. A description of the types and depths of soil underlying ponds and/or effluent disposal areas (include a copy of the geotechnical report and/or NRCS soil report). Include at least the following:
    a. Depth of unsaturated soil when groundwater is closest to the surface.
    b. Soil types based on site-specific information, sampling locations (accurately measured and recorded), description and results of percolation tests or other tests used to estimate soil long-term infiltration rates. Include depth, thickness, and soil horizons. Soils must be described at a minimum of five feet below the bottom of any disposal unit.
    c. Bedrock type and condition encountered in disposal area, if any.
    d. A scaled map depicting soil/rock types and test locations.
12. Provide the following information about hydrogeology and groundwater:
    a. Stratigraphy, groundwater elevation and gradient, transmissivity, and influence of all recharge and pumping sources (site conceptual model).
    b. Elevation and gradient of first groundwater at the facility
    c. Depth to highest anticipated groundwater based upon onsite measurements taken during wet season.

d. Shallow groundwater quality for typical waste constituents, up/down gradient. (See Table 1)
e. Information on monitoring well locations, construction details, and locations of any geological features (e.g. aquitards, subterranean channels, faults) and aquifer characteristics.
f. Summary of historical groundwater monitoring results (last 5 years for existing facilities, 2 years for new/planned facilities).
E. Antidegradation Analysis
The State Water Resources Control Board Resolution No. 68-16 (the Antidegradation Policy) requires that the Central Valley Water Board maintain the high quality of waters of the state until it is demonstrated that any change in quality will be consistent with maximum benefit to the people of the state, will not unreasonably affect beneficial uses, and will not result in exceedances of one or more water quality objectives. If a discharge will degrade groundwater quality but will not cause an exceedance of one or more water quality objectives, the discharger must demonstrate that all practicable treatment or control measures have been implemented or will be implemented such that the Board can consider these measures to represent the "best practicable treatment or control" (BPTC) of the constituents of concern. Demonstrating that BPTC has been, or will be, implemented at the site can provide justification for the Board to allow the current level of degradation to continue or increase (as applicable), or for the Board to allow any degradation in the case of a new discharge. The Antidegradation Policy is incorporated into our Basin Plans, which also include implementation plans that we follow. See the following link for the Basin Plans and other important policy documents: http://www.waterboards.ca.gov/centralvalley/plans_policies/
The Antidegradation Analysis must include the following:
1. For existing facilities, whether the discharge has caused degradation. If so, for which constituents, to what degree, and whether the discharge has caused exceedance of a water quality objective.
2. The potential for the discharge to degrade groundwater quality (for new discharges) or further degrade groundwater quality (for existing discharges, whether or not the discharge is expanding).
The assessment must be made based on site-specific data and shall include the following items for each constituent listed in the effluent category on Table 1:
a. Characterization of all waste constituents to be discharged that have the potential to degrade groundwater quality;
b. Characterization of shallow groundwater quality (i.e., the uppermost layer of the uppermost aquifer) for typical waste constituents[5] upgradient and downgradient of the site and comparison to established water quality objectives [6] (include tabulated historical groundwater monitoring data and groundwater elevation contour maps for the last eight monitoring events);
c. A description of the geology and hydrogeologic conditions of the site including groundwater elevation and gradient, transmissivity, influence of all known recharge and pumping sources, and subsurface conditions at the facility, including any proposed new disposal site or storage ponds;

[5] Include analyses for the following: total coliform organisms, total dissolved solids, fixed dissolved solids,electrical conductivity, nitrate nitrogen, total nitrogen, and major anions and cations

[6] Compare to Basin Plan water quality objectives, including drinking water standards, agricultural water quality goals, etc.

d. Groundwater degradation , if any, that has resulted from existing operations, other nearby discharges, or natural occurrences;

e. The areal extent that the discharge has impacted or will impact the quality of the shallow groundwater, if any;

f. The concentration found and/or expected increase in concentration in shallow groundwater foreach constituent.

g. If degradation has occurred or is expected to occur describe the following:

i. Any facility design features and operational practices that reduce the potential for groundwater degradation (treatment or control). Such features might include salinity source control, other pollutant source control, advanced treatment, disinfection, concrete treatment structures, and pond lining systems, etc.

ii. Additional treatment or control measures that could be implemented and a preliminary capital and annual operations and maintenance cost estimate for each.

iii. How current treatment and control measures are justified as BPTC (i.e., what justifies not implementing additional measures);

iv. How no water quality objectives will be exceeded; and

v. Why allowing existing and/or anticipated degradation is in the best interest of the people of the state.

F. Industrial Storm Water Permit

The State Water Resources Control Board adopted Order 2014-0057-DWQ (NPDES General Permit CAS000001) specifying waste discharge requirements for discharges of storm water associated with industrial activities, and requiring submittal of a Notice of Intent by all affected industrial dischargers. Many industrial facilities and some domestic wastewater treatment facilities are required to obtain coverage under this permit. Provide evidence that the facility is exempt or hasapplied for coverage under the Industrial Storm Water Permit.

See the following link for more information:

http://www.waterboards.ca.gov/centralvalley/water_issues/storm_water/industrial_general_permits/

G. General WDRs for Sanitary Sewer Systems.

The State Water Resources Control Board adopted Statewide General Waste Discharge Requirements for Sanitary Sewer Systems (Order 2006-0003-DWQ). The permit requires all public agencies that own or operate sanitary sewer systems greater than one mile in length to obtain coverage. Provide evidence that the facility is exempt or has applied for coverage under the General WDRs for Sanitary Sewer Systems.

See the following link for more information:

http://www.waterboards.ca.gov/water_issues/programs/sso/index.shtml

H. Department of Water Resources Well Standards

The California Department of Water Resources sets standards for the construction and destruction of groundwater wells (hereafter DWR Well Standards), as described in *California Well Standards Bulletin 74-90* (June 1991) and *Water Well Standards: State of California Bulletin 94-81* (December 1981). These standards, and any more stringent standards adopted by the State or county pursuant to Water Code section 13801, apply to all monitoring wells. Discuss whether existing monitoring wells at the facility were constructed in accordance with the Department of Water Resources Well Standards.

See the following link for more information: https://water.ca.gov/well-standards

I. Salt and Nitrate Control Programs

The Central Valley Regional Water Board adopted Basin Plan amendments incorporating new programs for addressing ongoing salt and nitrate accumulation on 31 May 2018 (Resolution No. R5-2018-0034). The resolution resulted from a Central Valley Regional Water Board initiated collaborative stakeholder initiative known as the Central Valley Salinity Alternatives for Long-term Sustainability (CV-SALTS).

Nitrate Control Program

After the effective date of the Nitrate Control Program, new dischargers located in groundwater basin/sub-basin (regardless of priority) or those with a material change to their operation that increases the level of nitrate discharged to groundwater must comply with the Nitrate Control Program and provide data and information as applicable. This provision does not apply to dischargers located in areas that are not part of a designated basin/sub-basin unless the Executive Officer of the Central Valley Water Board determines, based on the specific facts of the discharge, that it should be subject to the Nitrate Control Program and the Board's Executive Officer notifies the discharger accordingly.

This Nitrate Control Program NTC requires that discharges choose between two compliance pathways:

- **Pathway A:** New individual permitting options. The Board will set more stringent nitrate requirements in your permit to ensure that nitrate impacts will not cause a problem for drinking water users.
- **Pathway B:** Form or Join a Local Management Zone with other Permittees. A Management Zone is an association of permittees that work together to reduce nitrate loading and to provide replacement water

Salt Control Program

A new permittee, or existing permittee seeking a permit modification due to a substantial and/or material change which increases salt concentration or load from a facility, shall indicate how the permittee intends to comply with the Salt Control Program at the time of application and provide the required information to support the decision.

- *Conservative Salinity Permitting Approach* – A permittee that selects this approach must submit an assessment of how the discharge will comply with the conservative permitting requirements set forth in the Conservative Salinity Permitting Approach. The permittee shall submit this assessment to the Central Valley Water Board with the notification to the Board of its permit compliance pathway decision. If the Board does not concur with the findings of the assessment, the Board may request additional technical and/or monitoring information with a deadline for submittal. When conducting the assessment, the permittee may use historical water quality information if the information adequately represents the character of the current discharger and/or receiving water and is approved by the Board's Executive Officer.
- *Alternative Salinity Permitting Approach* – A permittee that selects this approach shall participate in the Phase I P&O Study by providing at least the minimum required level of

financial support throughout Phase I as determined by the lead entity overseeing the P&O Study. The permittee shall provide documentation of its compliance with the required level of support with the notification to the Central Valley Water Board of its permitting decision. If the permittee has an approved salinity-related Time Schedule Order, Compliance Schedule or variance that expires prior to the completion of the Phase I P&O Study, the Board, at its discretion, may extend the Time Schedule Order or Compliance Schedule or renew or grant a variance, as appropriate and allowed by other applicable policies.

See the following links for more information about the Salt and Nitrate Control Programs:

https://www.waterboards.ca.gov/centralvalley/water_issues/salinity/

https://www.cvsalinity.org/public-info

Table 1 – ROWD Constituent Characterization List

The Report of Waste Discharge must characterize the groundwater (G), source water (S), treatment system influent (I), and effluent discharge (E) for, at minimum, the constituents indicated in the list below. The characterization must be based on a statistically significant number of representative samples as determined by an appropriately registered and/or licensed professional. All media must also be characterized for all additional waste constituents that may be in the discharge based on the facility processes employed but not listed below.

Constituent [1]	Units	Minimum Recommended Characterization Data			
		POTW/ Domestic	Food Processor	Sand and Gravel	Other Industry
Biochemical Oxygen Demand	mg/L	I, E	I, E		E
Chemical Oxygen Demand	mg/L	G, E	I, E		E
Settleable Matter	ml/L	E	E		E
Total Suspended Solids	mg/L	I, E	I, E		E
Total Dissolved Solids	mg/L	G, S, I, E	G, S, E	G	G, S, E
Fixed Dissolved Solids	mg/L		E		G, S, E
Electrical Conductivity	µmhos/cm	G, S, I, E	G, S, I, E	G, S, I, E	G, S, I, E
Total Kjeldahl Nitrogen as N	mg/L	G, S, E	G, S, E		G, S, E
Ammonia Nitrogen as N	mg/L	G, S, E	G, S, E		G, S, E
Nitrate Nitrogen as N	mg/L	G, S, E	G, S, E		G, S, E
pH	pH Units	G, S, I, E	G, S, E	G, S, I, E	G, S, I, E
General Minerals[2]					
Alkalinity	mg/L	G, S, E	G, S, E	G, S, E	G, S, E
Hardness	mg/L	G, S, E	G, S, E	G, S, E	G, S, E
Bicarbonate	mg/L	G, S, E	G, S, E	G, S, E	G, S, E
Carbonate	mg/L	G, S, E	G, S, E	G, S, E	G, S, E
Calcium	mg/L	G, S, E	G, S, E	G, S, E	G, S, E
Magnesium	mg/L	G, S, E	G, S, E	G, S, E	G, S, E
Chloride	mg/L	G, S, E	G, S, E	G, S, E	G, S, E
Potassium	mg/L	G, S, E	G, S, E	G, S, E	G, S, E
Sodium	mg/L	G, S, E	G, S, E	G, S, E	G, S, E
Sulfate	mg/L	G, S, E	G, S, E	G, S, E	G, S, E
Metals[3]					
Aluminum	ug/L	E			E
Antimony	ug/L			S, E	
Arsenic	ug/L	G, S, E	G, S, E	G, S, E	G, S, E
Barium	ug/L			S, E	
Beryllium	ug/L			S, E	
Boron	ug/L	G	G	G, S, E	G

Constituent [1]	Units	Minimum Recommended Characterization Data			
		POTW/ Domestic	Food Processor	Sand and Gravel	Other Industry
Cadmium	ug/L			S, E	
Chromium (IV)	ug/L			S, E	
Chromium (III)	ug/L			S, E	
Total Chromium	ug/L	G	G	G, S, E	G
Cobalt	ug/L			S, E	
Copper	ug/L	E	E	S, E	E
Fluoride	ug/L			S, E	
Iron	ug/L	G, S, E	G, S, E	G, S, E	G, S, E
Lead	ug/L	E		S, E	E
Mercury	ug/L	E		S, E	E
Manganese	ug/L	G, S, E	G, S, E	G, S, E	G, S, E
Molybdenum	ug/L			S, E	
Nickel	ug/L			S, E	
Selenium	ug/L			S, E	
Silver	ug/L			S, E	
Thallium	ug/L			S, E	
Vanadium	ug/L			S, E	
Zinc	ug/L	E		S, E	E
Disinfection By-Products[4]	ug/L	G, E	E		E
Formaldehyde[5]	ug/L	G, E	E		E
Phenols[5]	ug/L	G, E			E
Priority Pollutants[6]	Various	G, E			E

1 With the exception of wastewater samples, for constituents with Secondary MCLs listed in Title, 22 Table 64449-A (e.g., aluminum, copper, iron, manganese, silver, zinc, color and turbidity), samples shall be filtered with a 1.5-micron filter prior to preservation, digestion, and analysis. For all other constituents, samples shall be filtered with a 0.45-micron filter prior to preservation, digestion, and analysis. If filtering in the field is not feasible, samples shall be collected in unpreserved containers and submitted to the laboratory within 24 hours with a request (on the chain of custody form) to immediately filterthen preserve the sample.

2 General minerals analyses shall be accompanied by a cation/anion balance demonstrating complete analysis.

3 Where constituents are analyzed as part of other suites of constituents, the results may be substituted to avoid redundant analyses (i.e., arsenic results collected to fulfill the metals suite requirements may also beused to fill the Priority Pollutant suite requirements provided appropriate detection limits are used.).

4 If wastewater is disinfected using chlorination or chlorination is used in internal disinfection processes.

5 If the facility accepts holding tank waste from RVs, boats, or portable toilets.

6 The Discharger must determine which priority pollutants, if any, are likely to be present in the discharge at concentrations that might degrade groundwater quality, and must provide characterization data for those constituents.

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:

Total depth drilled
- 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.

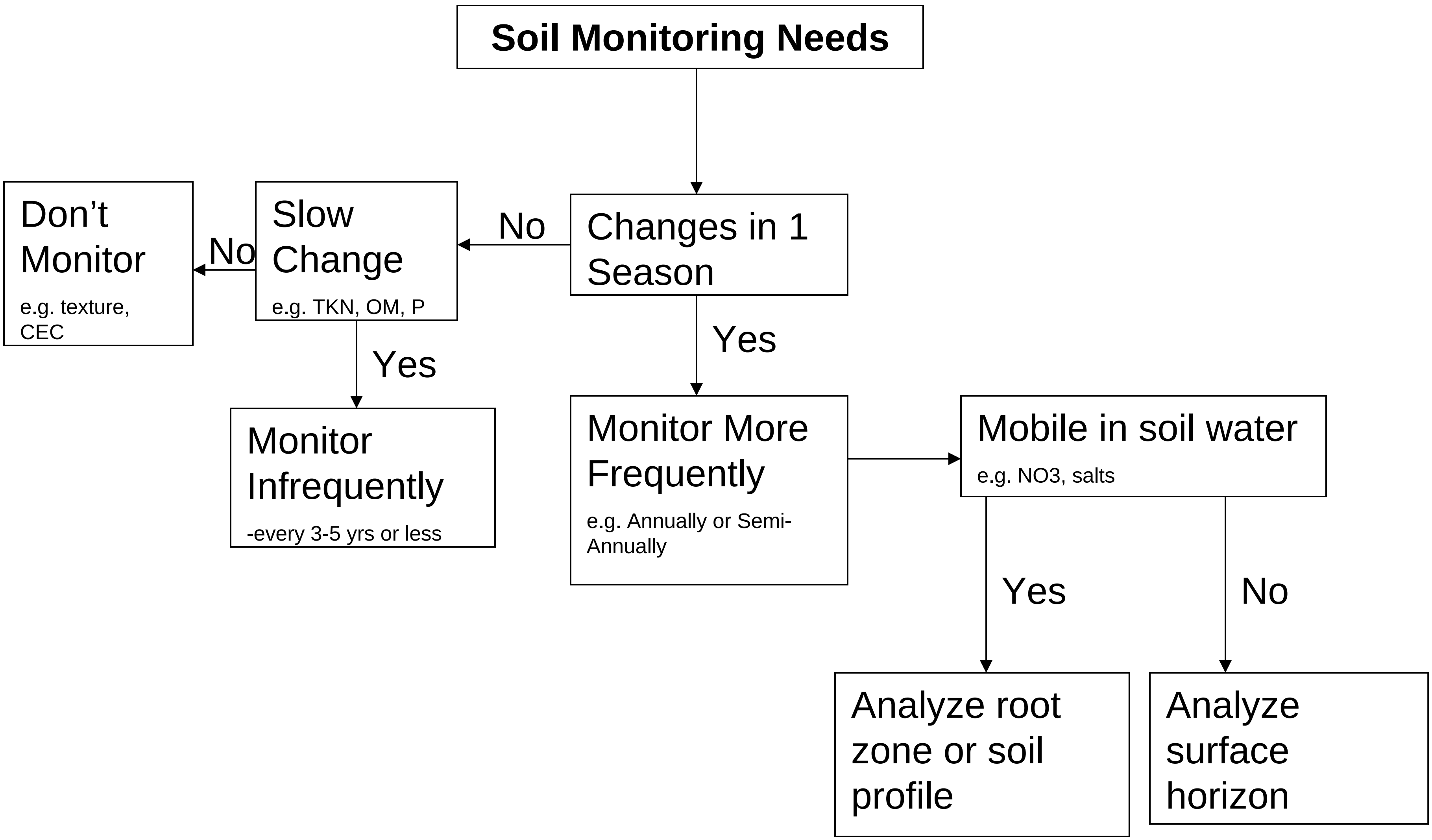
C. Well Survey:

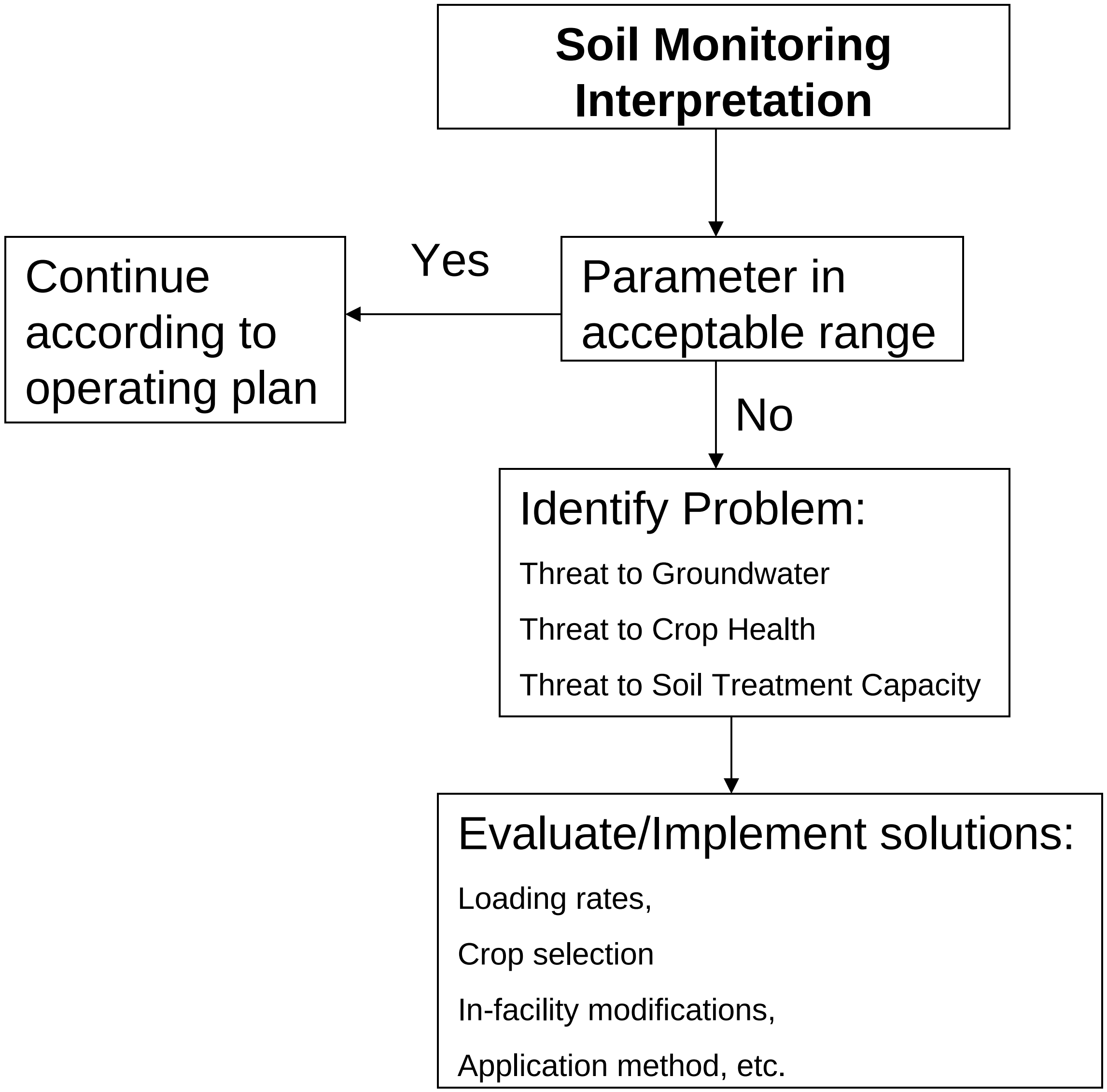
Identify the coordinate system or reference points
Survey the well casing with the cap removed (horizontal and vertical coordinates)
Registered Engineer or Licensed Surveyor's report and field notes in appendix
Describe the measuring points (i.e. ground surface, top of casing, etc.)
Tabular survey data

Appendix E: Decision Trees for Soils Evaluations

Manual of Good Practices Subcommittee #4

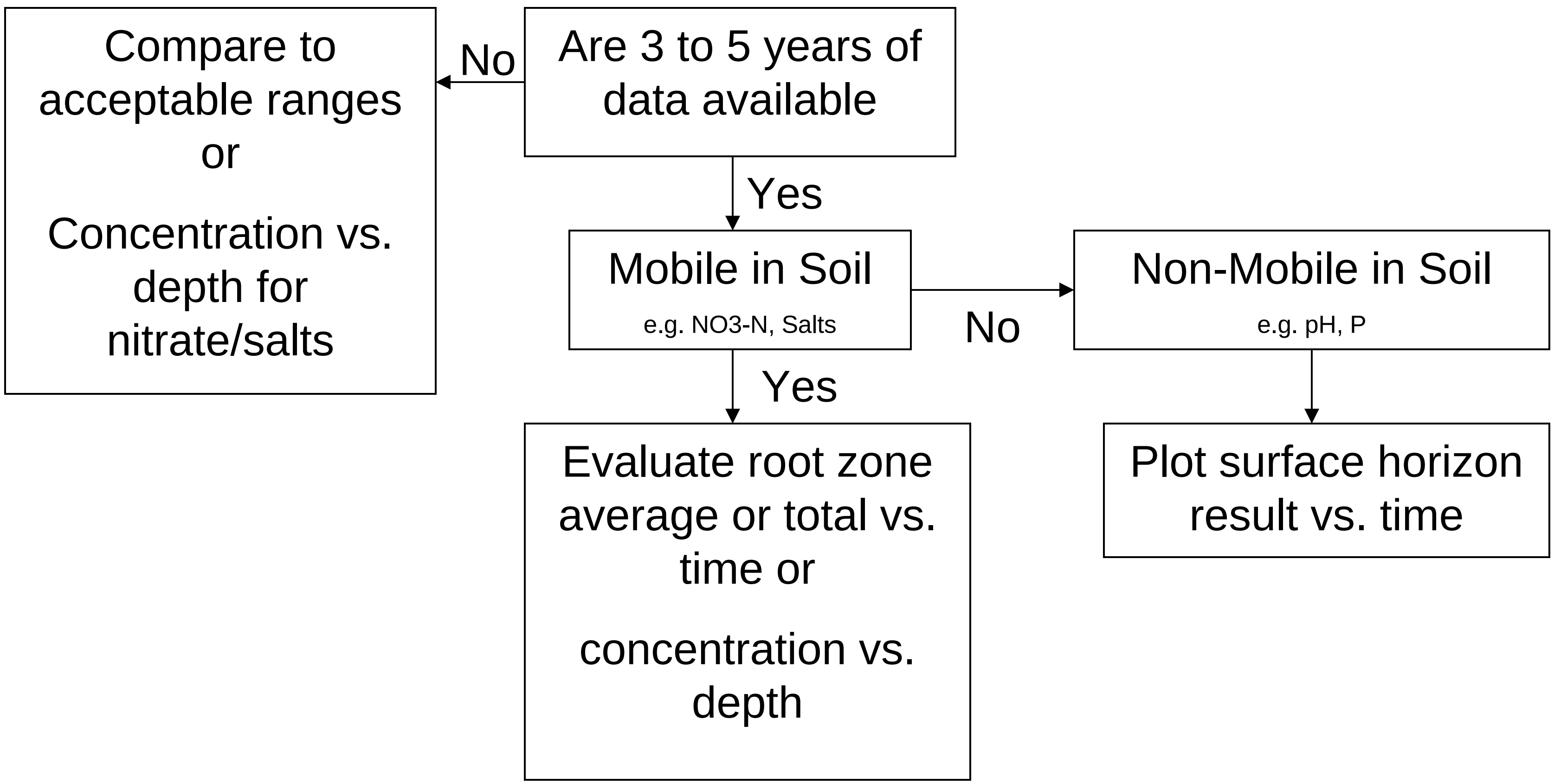
Soil Monitoring Considerations


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
Analyze root zone or soil profile
No
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.

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	K_s ($cm \cdot h^{-1}$)	A_k (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:

$P_o = K(\psi) = 80$ inches/yr, or 2.32 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, $\beta = 2.576$, 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 $\theta_s = 0.36$, $A_w = 0.0787$ and $\alpha = 0.614$ 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 $\theta = 0.16$ 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

<u>Total Dissolved Solids (TDS)</u>

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.

Recommendation: Use the sum of ions and FDS.

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.

Recommendation: Use BOD and (if needed) COD.

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.

Recommendation: Use TDS and EC.

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 and Fixed Dissolved Solids Removal by Crops

SALINITY AND FIXED DISSOLVED SOLIDS REMOVAL BY CROPS

Crop Uptake of Salinity and Fixed Dissolved Solids

Crop uptake of salts and fixed dissolved solids (FDS) 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,%	FDS uptake, lb/ton	FDS 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 FDS
Del Monte Caldwell, Idaho Site, 1993-1997

Crop	Year	Yield, lb/acre	Ash, %	FDS uptake, lb/ton	FDS 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. Compensation 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 residues 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*—Perform 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:*

$$\text{Ash} = (\text{AshW} \div \text{dw}) \times 100 \qquad \textit{Equation 15.1.1}$$

$$\text{OM} = [1 - (\text{AshW} \div \text{dw})] \times 100 \qquad \textit{Equation 15.1.2}$$

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 use.

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:

$$Ash = [AshW - T_A] \div [dw + T_R] \times 100 \quad \textit{Equation 19.1}$$

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:

$$OM = [100 - Ash] \quad \textit{Equation 19.2}$$

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