APPENDIX II

DEPARTMENT OF PESTICIDE REGULATION GRANT

MANAGEMENT PRACTICE WORKBOOKS

WORKBOOKS

Alfalfa Department of Pesticide Regulation Grant Management Practice Workbook

Tomato Department of Pesticide Regulation Grant Management Practice Workbook

Walnut Department of Pesticide Regulation Grant Management Practice Workbook

Winegrape Department of Pesticide Regulation Grant Management Practice Workbook

Controlling Offsite Movement of Agricultural Chemical Residues -- Alfalfa

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Prepared as a Component of:
California Department of Pesticide Regulation-- Pesticide Management Alliance Grant in Cooperation with the San Joaquin County and Delta Water Quality Coalition. 2010

Table of Contents

Controlling Offsite Movement of Agricultural Chemical Residues---Alfalfa

INTRODUCTION

WHAT'S IN THIS PUBLICATION?

The goal of this publication is to provide alfalfa growers with information on farming practices to help reduce the occurrence of organophosphate and synthetic pyrethroid pesticides in surface waters, which include streams, lakes, ponds, rivers, and drainage ditches. An assessment of the potential risk of offsite movement of an insecticide after a field application is performed using a flowchart for specific management practices and field conditions in alfalfa. This risk self-assessment focuses on issues that affect either the number of pesticide applications containing these active ingredients, or the offsite movement of pesticides as drift, attached to sediment, or in water that carries pesticide active ingredients.

If a significant risk is determined, a grower is able to consult the information in this manual about an array of science-based management practices to mitigate the risk that pesticides will leave the site of application and enter surface waters.

WHY IS THIS PUBLICATION NEEDED?

The Central Valley occupies about 40 percent of the land area in California and provides much of the State's agricultural production. Maintaining this productivity has required the use of about 132 million pounds of pesticides annually. Water quality in the Central Valley's rivers and streams has been impacted in part due to pesticide movement from agricultural lands into these waters. The list of impaired water bodies recently proposed for listing under the Clean Water Act Section 303(d) includes nearly a hundred water body segments in which impairment is due to agriculture. Agriculture is identified more often than any other source in the State as the likely cause of impairment.

Agricultural pesticides reach surface water bodies directly as spray drift or indirectly through irrigation or stormwater runoff from treated fields, vineyards, and orchards. Runoff waters may transport pesticides as dissolved or soil particle-adhering residues. Among the pollutants often attributable to agriculture is the organophosphate insecticide chlorpyrifos. California agriculture uses 1,425,000 pounds of chlorpyrifos annually, more than any other insecticide. Approximately half of the hundred 303(d) listed water body segments impaired due to agriculture in the Central Valley are impaired in whole or in part by chlorpyrifos. Total Maximum Daily Load is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards. The presence of chlorpyrifos in surface water and its toxicity to aquatic life has been responsible for multiple Total Maximum Daily Load (TMDL) projects in California, including one for the San Joaquin River, another for the Sacramento-San Joaquin Delta, and many other TMDLs elsewhere in the State where the process is less developed. In one study, chlorpyrifos was

responsible for mortality to the test organism, *Ceriodaphnia dubia*, in seven of ten toxic samples (de Vlaming et al. 2004).

Synthetic pyrethroids are another group of pesticides emerging as a concern. Pyrethroids are a cause for 303(d) listing of about 10 percent of agriculture-impaired water bodies in California. In a study of toxicity of sediments collected from agricultural waterways, 54 out of 200 sediment samples caused acute toxicity to the test organism, *Hyalella azteca*, and pyrethroids were responsible for the toxicity in 61 percent of those cases (Weston et al. 2009). Chlorpyrifos was the second most common contributor to toxicity, responsible for toxicity in 20 percent of the samples. Recent data indicate that pyrethroids are present at toxic levels in the water column of irrigation tailwater samples. In a study just completed, the pyrethroid lambda-cyhalothrin was responsible for toxicity to *H. azteca* in three out of six toxic samples collected at California agricultural pump stations where tailwater was being returned to nearby rivers. Chlorpyrifos was responsible for toxicity in the remaining three samples (Weston and Lydy 2010). As analyses of environmental samples for pyrethroids become more frequent, it is likely that the water quality effects of pyrethroids will be even more broadly recognized in future years.

The continued use of these effective agricultural pesticides is dependent on measures to prevent offsite movement of residues into surface waters. A listing of the active ingredients and trade names for pesticides used in alfalfa production can be found in Table 1. These insecticides are primarily used for control of Egyptian alfalfa weevil, alfalfa caterpillar, and *Lygus spp.* (in seed crops). The table is restricted to those materials with reported use in California during 2008 with use over 500 pounds annually. Organophosphates represent 81% of this list with chlorpyrifos, an organophosphate, being the highest use product based on pounds applied per year.

Table 1. Alfalfa insecticides used in California, 2008
(CDPR, California Department of Pesticide Regulation).

Active Ingredient/Common Name	Trade Name(s)	Lbs/Year	Chemical Class
chlorpyrifos	Lorsban, Lock -On	187,460	organophosphate
malathion	Malathion	105,111	organophosphate
dimethoate	Dimethoate	53,167	organophosphate
indoxacarb	Steward	28,951	oxadiazine
Naled[1]	Dibrome	17,905	organophosphate
methomyl	Lannate	17,645	carbamate
methamidophos[1]	Monitor	14,436	organophosphate
lambda-cyhalothrin	Warrior	10,957	pyrethroid
methidathion[1]	Supracide	9,699	organophosphate
methoxyfenozide	Intrepid	7,879	diacylhydrazine
bacillus thuringiensis	Dipel, Javelin, XenTari	6,954	biological
formetanate hydrochloride	Carzol	6,489	carbamate
Zeta-cypermethrin	Mustang	4,009	pyrethroid
permethrin	Pounce, Ambush	3,262	pyrethroid
beta-cyfluthrin	Baythroid	2,527	pyrethroid
bifenthrin	Capture	1,397	pyrethroid
carbaryl	Sevin	507	carbamate

[1]Section 24C for alfalfa seed production

CURRENT REGULATORY APPROACH TO SURFACE WATER PROTECTION

All growers farm under the requirement not to pollute surface and groundwater. Water leaving agricultural lands, as irrigation or stormwater runoff, can contain pesticide residues, sediment, or nutrients. These discharges are regulated by California's Central Valley Regional Water Quality Control Board (Water Board) under a program called the Irrigated Lands Regulatory Program. Essentially, the Board is enforcing the California Water Code of 1969 (CWC) and the Federal Clean Water Act of 1972. To this end the Board has:

- Established surface water quality standards in each watershed basin plan
- Enforced waste discharge requirements

THE AG WAIVER

In 1982 the Board adopted a resolution "*Waiving Waste Discharge Requirements for Specific Types of Discharge.*" The resolution contained 23 categories of waste discharges, including *irrigation return flows and stormwater runoff* from agricultural lands. The resolution also listed the conditions required to comply with the waiver, hence the term '**Conditional Ag Waiver**.' However, due to a shortage of resources at the time, the Water Board did not impose measures to verify compliance with these conditions.

The waiver, set to sunset in 2003, was amended by adopting two conditional waivers for discharges from irrigated lands. **One** was for *coalition groups* of individual dischargers that comply with the California Water Code and Water Board. **The other** was for growers to comply as individual entities. To be covered by the waivers, the coalition or individual must have filed with the Water Board by November 1, 2003 a Notice of Intent and General Report that contained specific information about their farm and then must have adhered to a plan and timeline that includes, among other things, a farm management plan and surface water monitoring plan.

WATER QUALITY COALITIONS

Water quality coalitions are generally formed by growers on a sub-watershed basis, although some are based on a specific commodity. The San Joaquin County and Delta Water Quality Coalition, for example, encompasses all of San Joaquin County and portions of Contra Costa and Calaveras Counties. The coalition includes about 500,000 acres of irrigated lands and 4500 individual members. The coalition monitors and analyzes the water quality of sub-watersheds in surface waters and facilitates the implementation of management plans. Coalitions provide outreach and support to growers in response to water quality exceedances at sub-watershed monitoring sites, in order to enhance the water quality of those water bodies affected.

Water Quality Monitoring

The coalition currently monitors water quality at numerous sites in both large and small sub-watersheds within the coalition watershed. Water samples are collected monthly, and sediment samples are collected twice per year. During 2008, water quality standards were exceeded many times. At some locations, as many as 40 percent of the samples exceeded water quality standards for pesticide residues (Management Plan, San Joaquin County Delta Water Quality Coalition, Karkoski 2008). When more than one exceedance of water quality limits occurs for any contaminant, a management plan must be developed by the coalition to address it. In addition, any single exceedance of either chlorpyrifos or diazinon triggers the requirement for a management plan.

Management Plans

The overall goal of water quality management plans, whether developed by individuals or coalition groups, is to reduce agricultural impacts on water quality in the plan area. Management plans evaluate the frequency and magnitude of exceedances and prioritizes locations for outreach.

To achieve the goal of improving water quality, a management plan must include:

- Source identification of constituents causing water quality impairments
- Outreach to growers about irrigation and dormant season management practices to protect water quality
- Evaluation of water quality improvements achieved by monitoring and implementation of management practices

Under the management plan landowners/growers must:

- Help the coalition succeed by participating in efforts to solve water quality impairments identified through water monitoring
- Staying informed – read mailings and updates, respond as necessary
- Attending grower water-quality information meetings
- Implementing management practices that mitigate the identified water quality concerns

HOW TO USE THIS MANUAL

This manual is designed to be used in a two-step process. The first step is to make a "risk assessment" of field conditions or operations to identify those farming practices that may increase the risk of offsite pesticide movement. To aid in doing this, a series of "flowcharts" are presented. Once avenues of possible pesticide movement from a particular field are identified in the first flowchart, succeeding flowcharts help "zero in" on specific conditions and operations that can be used to reduce offsite movement. When followed systematically from beginning to end, the flowcharts will guide one through a stepwise evaluation of a farming operation to identify potential problem areas.

The second step is to understand and implement management practices to address the problem areas that were identified. These management practices, presented beginning on page 20 of this publication, are divided into three broad categories:

Use Integrated Pest Management (IPM) Approaches, Handle, Apply, and Store Pesticides Correctly

Integrated Pest Management (IPM) is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used **only** after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Coupling use of IPM techniques with proper pesticide selection, handling, application, and storage can go a long way towards preventing offsite movement and protecting water quality.

These practices should be the foundation of any water quality protection program. Implementing at least some of them can also reduce risks to human health, beneficial and non-target organisms, and the environment.

Use Soil and Water Management Practices

Use soil and water management practices that reduce runoff potential. Runoff occurs when using surface irrigation or when rainfall occurs faster than it can enter the soil. Runoff water can carry pesticides in the water itself or adsorbed to eroding soil particles. Proper irrigation method selection, design, and operation, coupled with water treatments or cover crops that maximize water infiltration, help ensure that the water needs will be met and runoff kept at a minimum.

Capture, Recycle or Treat Runoff Waters

When IPM and soil and water management do not adequately address a water quality problem, techniques for physically intercepting, recycling, or chemically treating runoff water can be used to reduce offsite transport of water pesticides in water.

Quick Overview of the Risk Evaluation Process

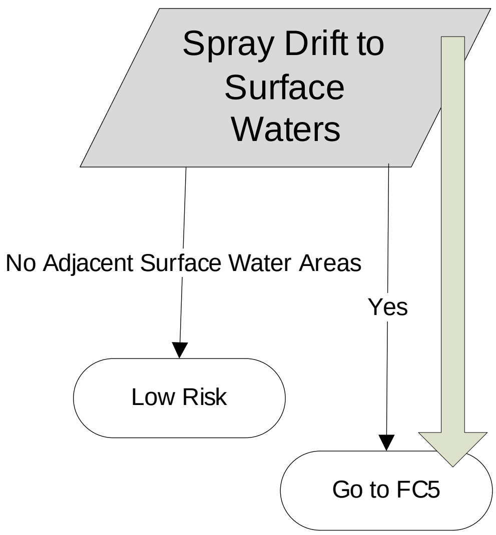
For a quick overview of the process, let's consider an example alfalfa field to illustrate how the flowcharts and management information in this manual could be used to identify and correct an offsite insecticide movement problem. We'll return to a more detailed discussion of this scenario in the case study presented in Appendix I located at the end of this manual. The opaque arrows in these flowcharts indicate the logical progression in considering the most cost effective management practices.

Crop: Alfalfa, 40 acres
Site:

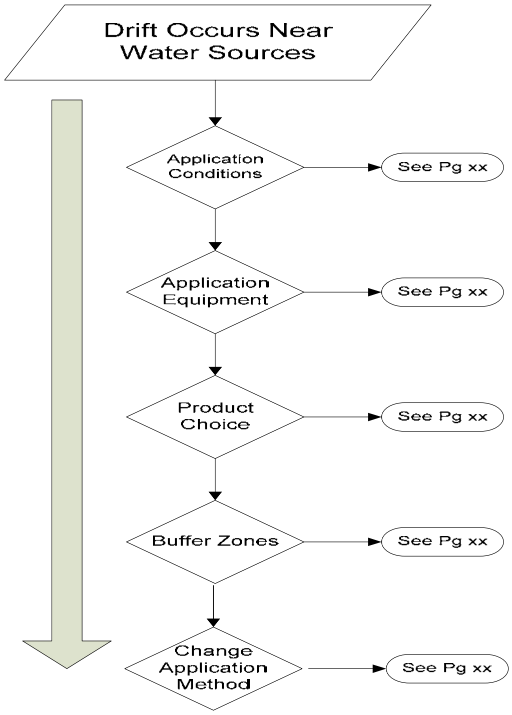
Topography: 0.15 percent slope
Soil: Hollenbeck silty clay loam soil, soil tends to crust limiting the water infiltration rate.
Irrigation system: Border-check irrigation
Irrigation Runoff: Runoff is about 17% of the applied water.
Irrigation water: pH 7.5, EC 0.2 dS/m
Drainage: Runoff moves to a drain at edge of field; then, on to a larger creek
Pesticide mixing and loading: A pesticide mixing & loading area is located about 40 feet from the drainage ditch.
Pest: Egyptian Alfalfa Weevil

We begin the risk assessment with Flowchart number 1 (FC1), considering possible routes by which pesticide could move off the field and the operations or conditions that may contribute to the movement. The three possible areas of concern taken in the order of risk after application are:

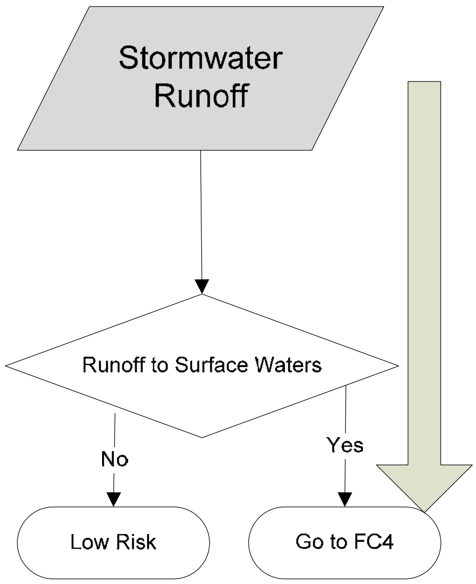
1) FC1. During spray applications, pesticides may drift into the drainage ditch along the edge of the field; Go to FC5.



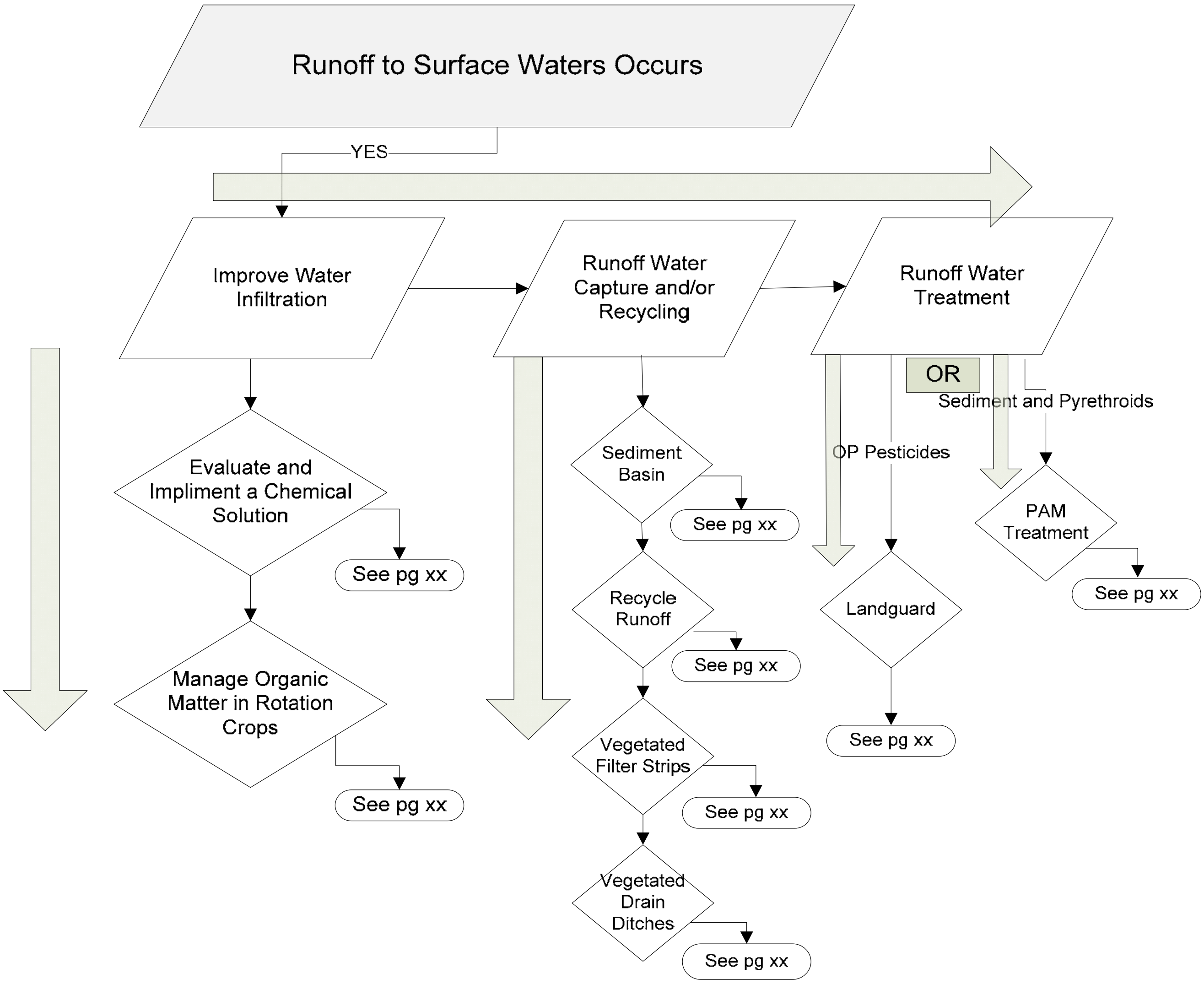
Flowchart 5 (FC5) presents various factors related to drift control. Each factor leads to a portion in the management information section of the manual where drift management practices are discussed.



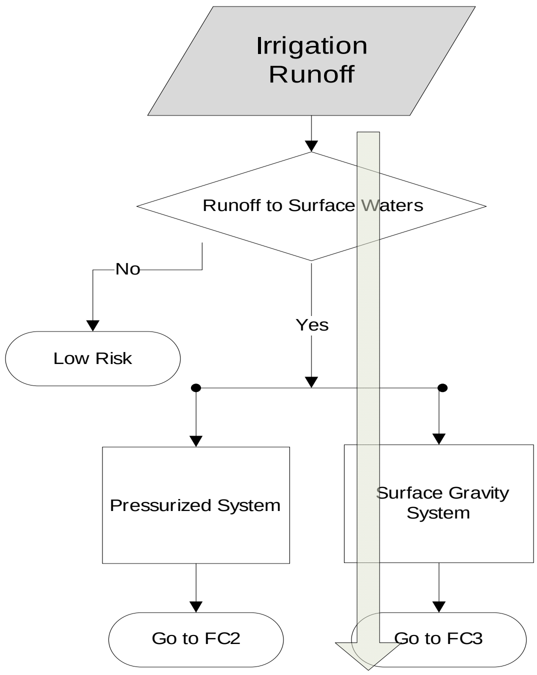
2) Beginning again at FC1. Pesticides may be carried in the stormwater runoff since the timing of the weevil control pesticide may coincide with rainfall; Go to FC4.



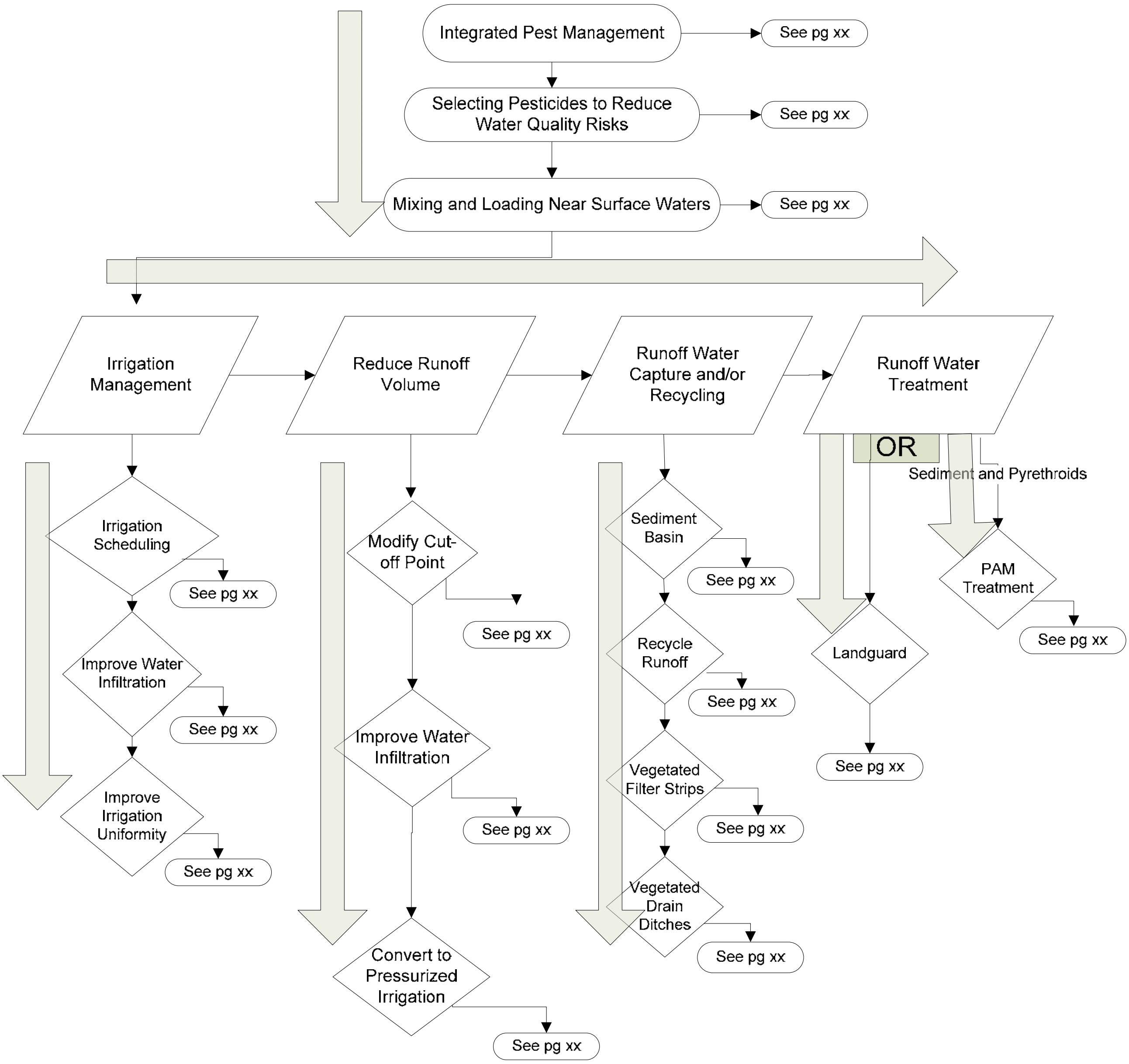
Flowchart 4 (FC4) presents various factors related to stormwater runoff risks. Each factor leads to a portion in the management information section of the manual where management practices are discussed to reduce pesticide residues in stormwater runoff.



3) Beginning at FC1. Pesticides may be carried in the runoff that occurs during irrigation after the pesticide application. Go to FC3.



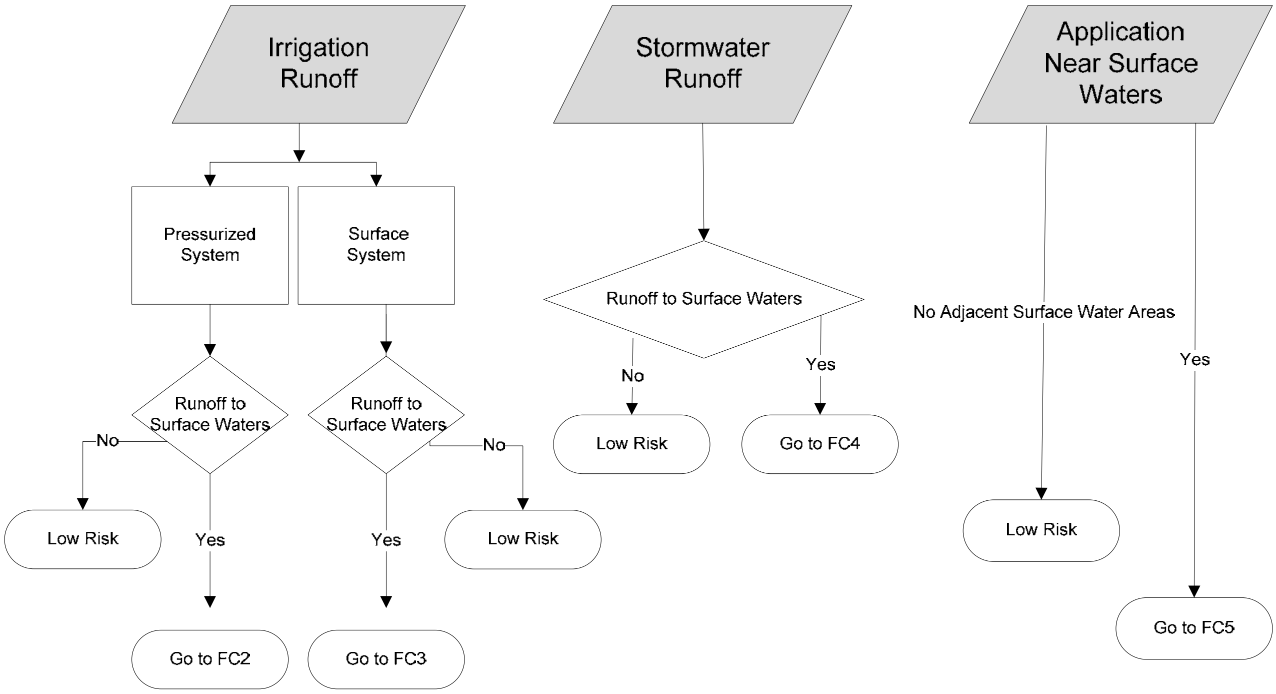
Flowchart 3 (FC3). This leads us first to an assessment of IPM practices, pesticide selection, mixing and loading practices and, in the management section, ways these can be improved. Following this, the flowchart leads us to consider the irrigation system—capturing or recycling runoff, modifying the irrigation system or soil characteristics to reduce runoff volume, irrigation scheduling, and, finally, ways that runoff water – if it still occurs - could be treated to reduce any pesticide residues it may contain.

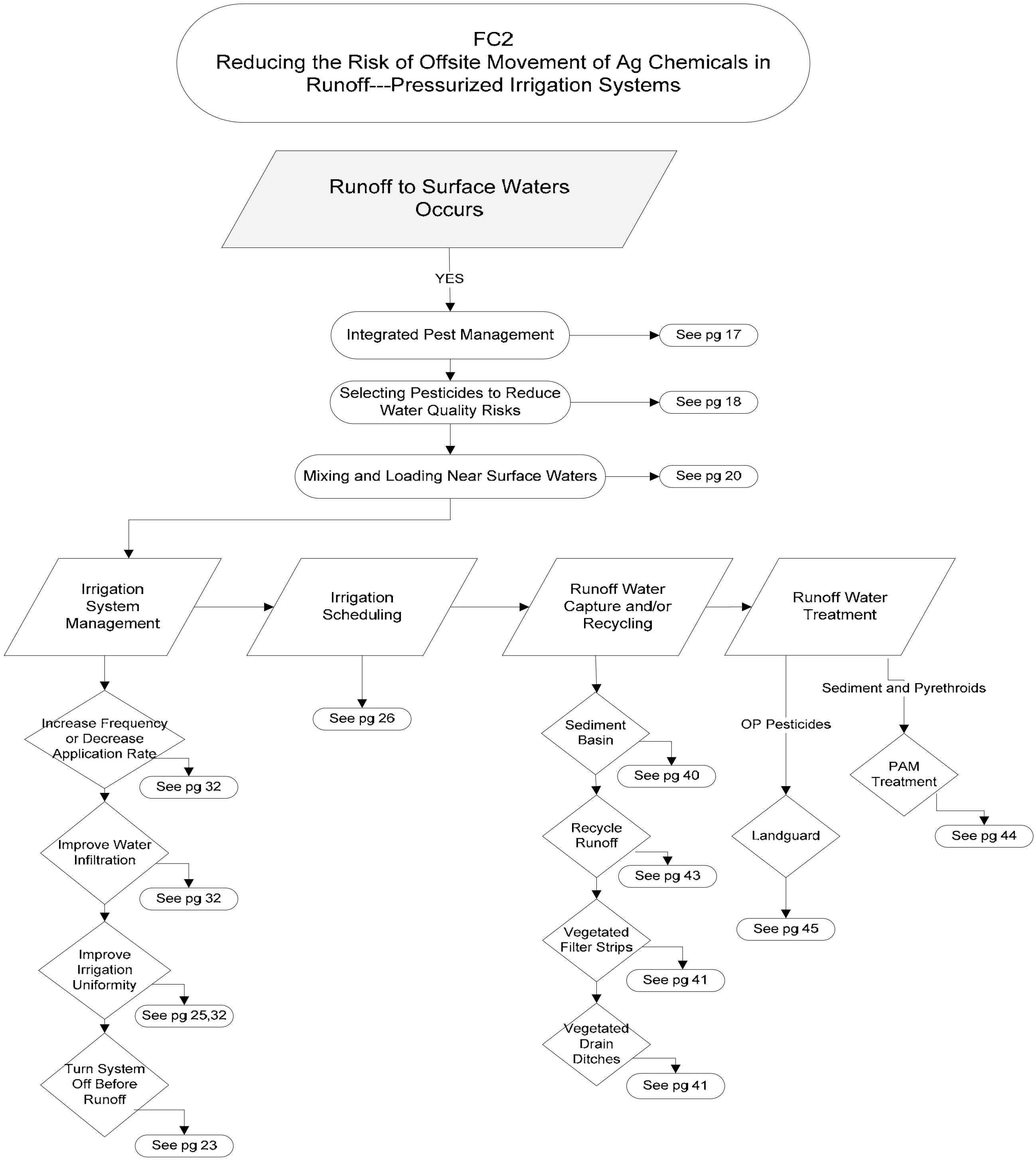


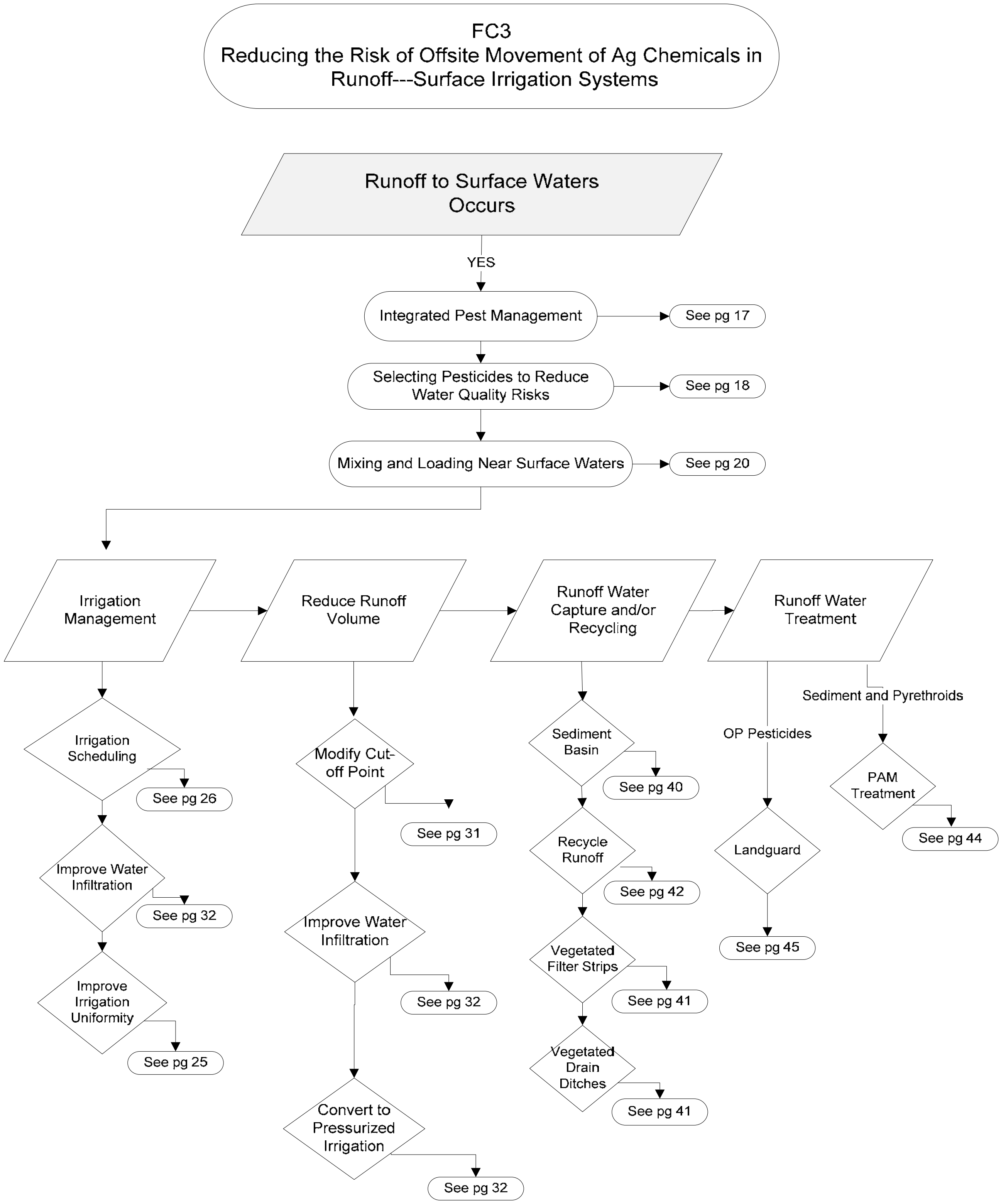
Risk Evaluation Flowcharts

FC1
Assessing the Risk of Offsite Movement of Ag Chemicals to Surface Waters

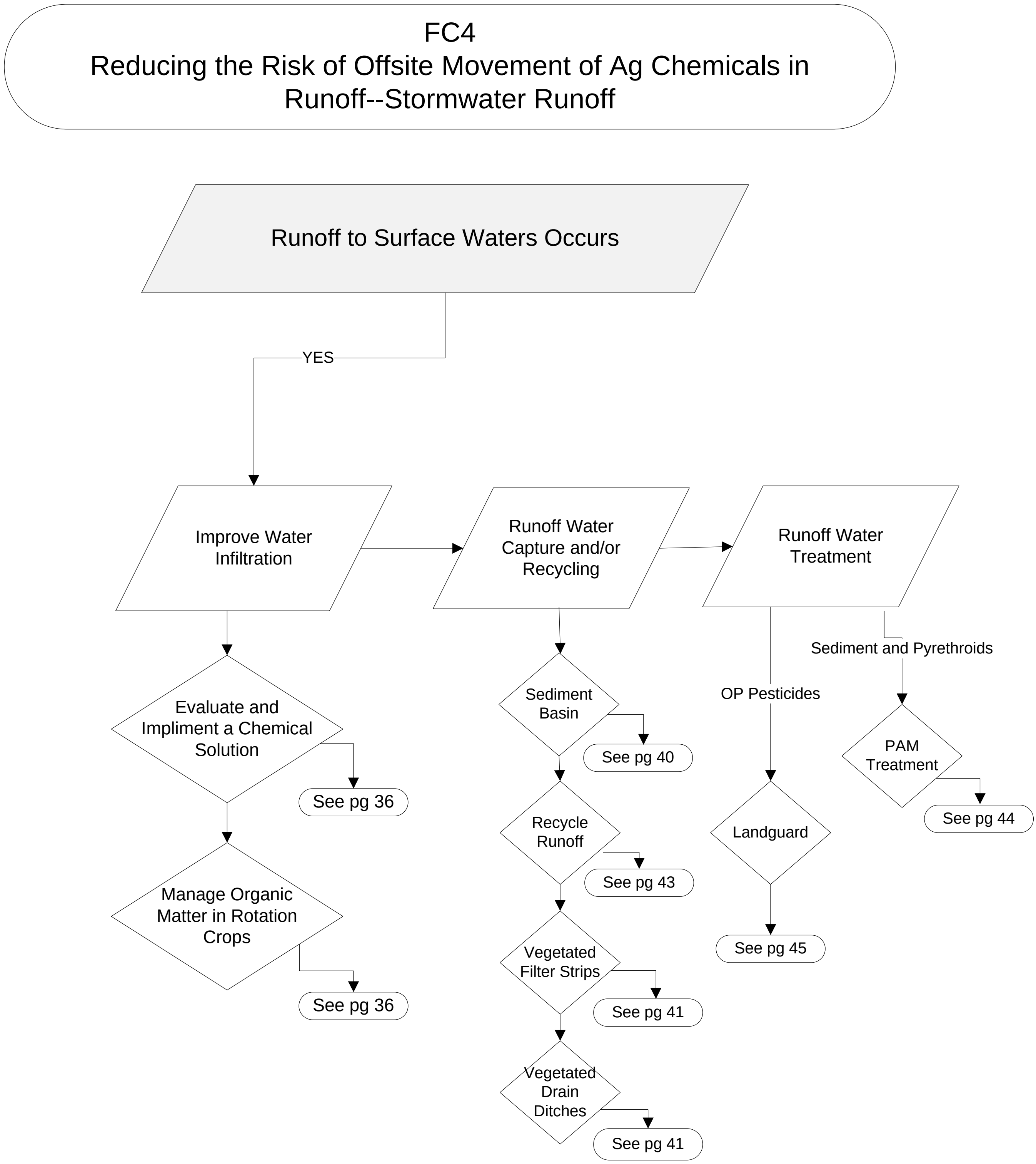
Follow the decision tree from each shaded box below to assess risk, based on your conditions. If the risk is significant, continue on to view management practices that may reduce the risk of offsite movement.

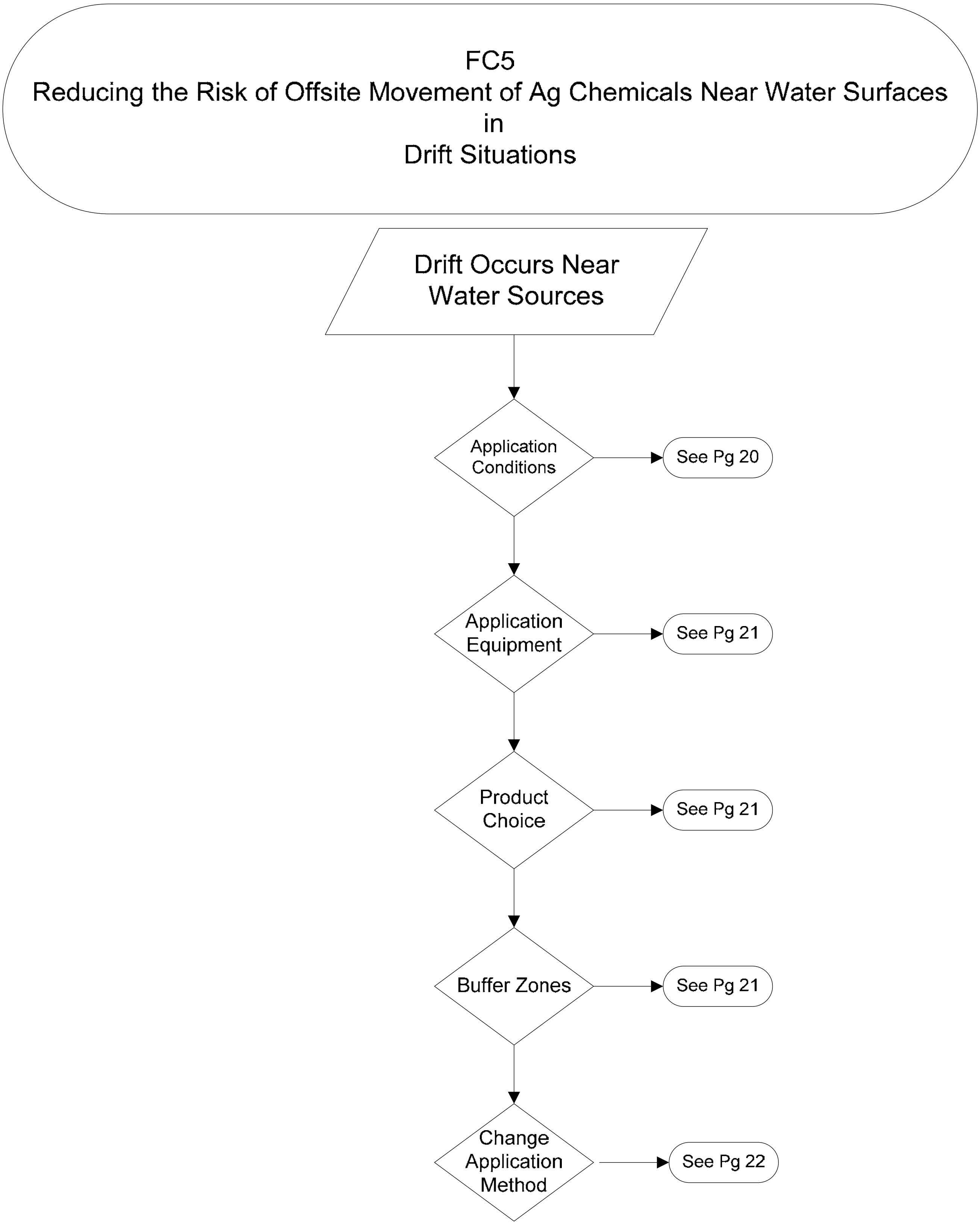



FC2
Reducing the Risk of Offsite Movement of Ag Chemicals in Runoff---Pressurized Irrigation Systems
Runoff to Surface Waters Occurs
YES
Integrated Pest Management
See pg 17
Selecting Pesticides to Reduce Water Quality Risks
See pg 18
Mixing and Loading Near Surface Waters
See pg 20
Irrigation System Management
Irrigation Scheduling
Runoff Water Capture and/or Recycling
Runoff Water Treatment
Increase Frequency or Decrease Application Rate
See pg 32
Improve Water Infiltration
See pg 32
Improve Irrigation Uniformity
See pg 25,32
Turn System Off Before Runoff
See pg 23
See pg 26
Sediment Basin
See pg 40
Recycle Runoff
See pg 43
Vegetated Filter Strips
See pg 41
Vegetated Drain Ditches
See pg 41
OP Pesticides
Landguard
See pg 45
Sediment and Pyrethroids
PAM Treatment
See pg 44



FC3
Reducing the Risk of Offsite Movement of Ag Chemicals in Runoff---Surface Irrigation Systems
Runoff to Surface Waters Occurs
YES
Integrated Pest Management
See pg 17
Selecting Pesticides to Reduce Water Quality Risks
See pg 18
Mixing and Loading Near Surface Waters
See pg 20
Irrigation Management
Reduce Runoff Volume
Runoff Water Capture and/or Recycling
Runoff Water Treatment
Irrigation Scheduling
See pg 26
Improve Water Infiltration
See pg 32
Improve Irrigation Uniformity
See pg 25
Modify Cut-off Point
See pg 31
Improve Water Infiltration
See pg 32
Convert to Pressurized Irrigation
See pg 32
Sediment Basin
See pg 40
Recycle Runoff
See pg 42
Vegetated Filter Strips
See pg 41
Vegetated Drain Ditches
See pg 41
OP Pesticides
Landguard
See pg 45
Sediment and Pyrethroids
PAM Treatment
See pg 44


FC4
Reducing the Risk of Offsite Movement of Ag Chemicals in Runoff--Stormwater Runoff
Runoff to Surface Waters Occurs
YES
Improve Water Infiltration
Runoff Water Capture and/or Recycling
Runoff Water Treatment
Evaluate and Impliment a Chemical Solution
See pg 36
Manage Organic Matter in Rotation Crops
See pg 36
Sediment Basin
See pg 40
Recycle Runoff
See pg 43
Vegetated Filter Strips
See pg 41
Vegetated Drain Ditches
See pg 41
OP Pesticides
Landguard
See pg 45
Sediment and Pyrethroids
PAM Treatment
See pg 44


FC5
Reducing the Risk of Offsite Movement of Ag Chemicals Near Water Surfaces
in
Drift Situations
Drift Occurs Near Water Sources
Application Conditions
See Pg 20
Application Equipment
See Pg 21
Product Choice
See Pg 21
Buffer Zones
See Pg 21
Change Application Method
See Pg 22

MANAGEMENT PRACTICES TO REDUCE SURFACE WATER PESTICIDE CONTAMINATION

INTEGRATED PEST MANAGEMENT

The University of California Integrated Pest Management Programs defines IPM as:

> "…an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and non-target organisms, and the environment." http://ucipm.ucdavis.edu

IPM is a systematic approach to pest management. The decision process includes:

- select varieties that are well adapted to local conditions with a high degree of pest and disease resistance;
- use certified seed that is weed, insect, and disease free;
- proper pest identification;
- understanding pest life cycles and conditions conducive to infestation;
- monitoring for the presence, locations and abundance of pests and their natural enemies;
- treat when established action thresholds (economic, aesthetic, tolerance) are reached;
- consideration of multiple tactics for pest suppression – biological, cultural, and chemical—and selection of the lowest-risk practical and effective approach; and
- evaluate results.

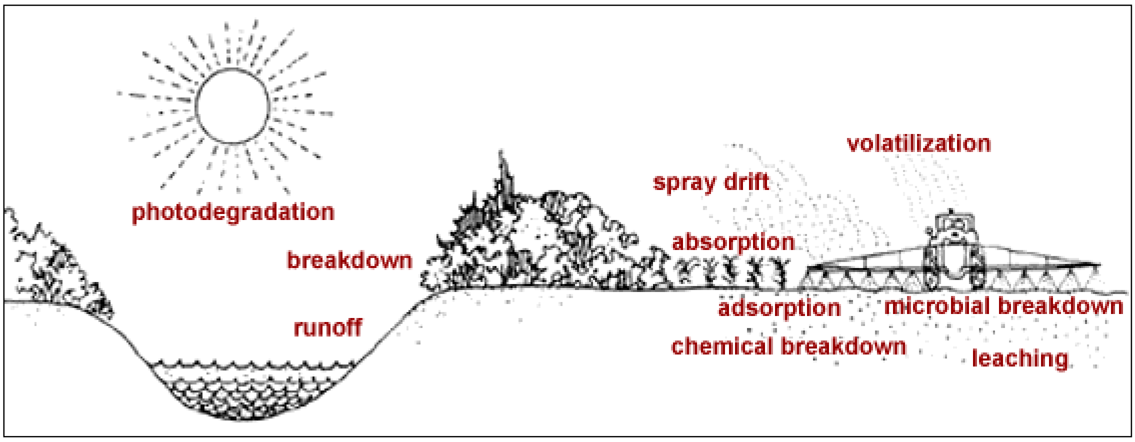
Because many print and on-line publications are available to help growers use IPM in their fields, they are not discussed in detail here. Pest and disease biology, monitoring, management, as well as water quality considerations in selecting and using pesticides, may be found in and from:

- The online UC IPM Pest Management Guidelines for alfalfa hay, http://ipm.ucdavis.edu/PMG/selectnewpest.alfalfa-hay.html
- The UC IPM Year Round Program for alfalfa hay, with annual checklist,
- UC Integrated Pest Management Guidelines for alfalfa hay,
- UC Integrated Pest Management for Alfalfa manual,
- UC Irrigated Alfalfa Management Publication http://alfalfa.ucdavis.edu
- Licensed Pest Control and Crop Advisors, and
- UC IPM Advisors and Farm Advisors.

SELECTING PESTICIDES TO REDUCE WATER QUALITY RISKS

Knowledge of how pesticides move and degrade in the environment is useful for product selection. Pesticides and pesticide residues can move along several different pathways, depending on properties of the pesticide, the application method, and conditions at the application site (Figure 1). This movement is a complex process and, combined with several other factors, influences a pesticide's fate and potential water quality impacts. From a surface water management perspective, keeping the pesticide on or in the soil by preventing runoff is the most desirable option.

Figure 1. Pesticide fate processes



Alfalfa pesticide active ingredients vary in water solubility, soil adsorption and half-life. Pesticides with high water solubility can move directly in runoff waters while those adsorbed to soil sediments move with the sediment. Half-life is an indication of the persistence in the environment, usually the number of days it takes for the chemical to degrade to one-half strength. USDA-NRCS has a model that determines a pesticide's tendency to move in dissolved form with water or move with adsorbed to the sediments.

Aquatic toxicity rankings were extracted from the US EPA ECOTOX database (http://cfpub.epa.gov/ecotox/). The toxicity for EPA indicator species was then used to rank the overall aquatic risk (Long et al. 2005). The potential to move offsite, either in solution or with the soil, was then categorized as high, intermediate, and low. The overall likelihood to cause negative impact (risk) on surface water quality is a product of the runoff potential and the aquatic toxicity of the pesticide. Table 2 indicates this relationship for commonly used insecticides in alfalfa production. The table can be used to select pesticides based on the risk of offsite movement to surface waters. A change in pesticide within a same class or to a different class can significantly reduce the environmental risk.

Table 2. California-registered alfalfa insecticides and their potential to move in solution or as adsorbed particles and overall pesticide runoff risk.

Insecticide active ingredient (common name)	Trade name	Chemical Class	Solution runoff potential[1]	Adsorption runoff potential[2]	Overall runoff risk[3]
chlorpyrifos	Lorsban, Lock-On	organophosphate	high	intermediate	very high
bifenthrin	Capture	pyrethroid	low	high	high
cyfluthrin	Baythroid	pyrethroid	low	intermediate	high
Zeta-cypermethrin	Mustang	pyrethroid	low	high	high
lambda-cyhalothrin	Warrior	pyrethroid	low	intermediate	high
permethrin	Ambush, Pounce	pyrethroid	low	high	high
carbaryl	Sevin	carbamate	intermediate	low	moderate
Methidathion[4]	Supricide	organophosphate	intermediate	low	moderate
malathion	Malathion	organophosphate	intermediate	low	moderate
methomyl	Lannate	carbamate	intermediate	low	moderate
phosmet	Imidan	organophosphate	intermediate	low	moderate
dimethoate	Dimethoate	organophosphate	low	low	low
Naled[4]	Dibrome	organophosphate	low	low	low
Methamidophos[4]	Monitor	organophosphate	low	low	low
Bacillis thuringiensis	Dipel, Javelin, XenTari	biological	low	low	low
methoxyfenozide	Intrepid	diacylhydrazine	high	intermediate	low
azadirachtin	Neemix	not classified			
chlorantraniliprole	Coragen	diamide	low	high	
indoxacarb	Steward	oxadiazine	low	intermediate	
Novaluron[4]	Rimon	benzoylurea			
formetanate hydrochloride	Carzol	carbamate			
spiromesifen	Oberon	keto-enol			

[1] Likelihood that the active ingredient will transport from the area of treatment as dissolved chemical in runoff.
[2] Likelihood that the active ingredient will transport from the area of treatment as attachment to soil or sediment particles in runoff.
[3] Overall likelihood to cause negative impact on surface water quality as a product of the runoff potential and the aquatic toxicity of the pesticide
[4] 24(c) registration for alfalfa seed

Source: Pesticide Choice: Best Management Practice for Protecting Surface Water Quality in Agriculture, Long et al. 2005, UCANR Publication 8161

HANDLING PESTICIDES TO REDUCE WATER QUALITY RISKS

The risk of offsite pesticide movement is great during mixing and loading due to the possible spillage of undiluted pesticides. Care should be taken to ensure all of the pesticide goes in the tank. Partially fill the tank with water prior to adding the pesticide to prevent high strength materials entering spray lines. Agitation and the use of a bypass can assist good mixing. Avoid over filling the tank, because spillage can move offsite aided by cleanup waters. Mix and load at a distance of greater than 50 feet from sensitive areas (open surface water)—more if there is a potential for movement in the direction of the sensitive area. Triple rinse pesticide containers and pour the rinsate into the sprayer tank for use on the field. Also apply tank rinse water to the field. The use of a concrete pad with a catchment sump is a good way to reduce risks from mixing and loading near surface water sources.

PESTICIDE APPLICATION PRACTICES TO REDUCE OFFSITE PESTICIDE MOVEMENT

Minimizing Spray Drift

Drift is the physical movement of pesticide droplets or particles through the air at the time of pesticide application or soon thereafter, from the target site to any non- or off-target site. All ground and aerial applications produce some drift. How much drift occurs depends on such factors as the formulation of the material applied, how the material is applied, the volume used, prevailing weather conditions at the time of application, and the size of the application job. Drift can impact surface water quality through direct contact with open ditches or surface water adjacent to the treated field.

Spray drift can be mitigated by management practices to reduce off-target drift. Application practices that take weather and other site conditions into consideration, appropriately equipped delivery systems (low-drift nozzles), appropriate product choice (low vapor pressure, low water solubility), and the use of buffer zones can significantly reduce the risk of offsite movement of pesticides.

Application Conditions

- Don't apply pesticides under dead calm or windy/gusty conditions; don't apply at wind speeds greater than 10 mph, ideally not over 5 mph. Read the label for specific instructions.
- Apply pesticides early in the morning or late in the evening; the air is often more still than during the day.
- Determine wind direction and take it into account when deciding whether or not or how to make an application.
- Calibrate and adjust sprayers to accurately direct the spray into the canopy “target.”
- Delay treatments near ditches and surface water bodies until wind is blowing away from these and other sensitive areas.
- Don't spray during thermal inversions, when air closest to the ground is warmer than the air above it.

Application Equipment

- Use as coarse a spray as possible (250 - 400 microns or larger) while still obtaining good coverage and control. Droplet size is one of the most important factors affecting drift.
- Use low drift nozzles that produce larger droplet sizes. Fitting a sprayer with air induction nozzles instead of standard nozzles will reduce spray drift up to 50 percent compared to standard nozzles.
- Check to verify the spray deposition pattern expected.
- Service and calibrate spray equipment regularly.
- Check the system for leaks. Small leaks under pressure can produce very fine droplets. Large leaks contaminate soil which can be moved offsite by water.
- Use low pressure and spray volumes appropriate for canopy size.

Product Choice

- Choose an application method and a formulation that are less likely to cause drift. After considering the drift potential of a product/formulation/application method, it may become necessary to use a different product to reduce the chance of drift.
- Use drift control/drift reduction spray additives/agents. These materials are generally thickeners designed to minimize the formation of droplets smaller than 150 microns. They also help produce a more consistent spray pattern and deposition.
- Use spray adjuvants, which can greatly reduce application volumes without compromising pesticide efficacy.
- Use maximum spray volume per acre and low pressure.
- Treat buffer zones with materials that are the least risk to aquatic life.

Buffer Zones

- Maintain adequate buffer zones around the treated site to ensure that pesticides don't drift onto sensitive areas. Read the label to determine the size of buffer zone required as related to the rate of active ingredient.
- Wolf et al. (2003) documented 75 to 95 percent reductions in drift deposits up to 98 feet downwind when setback distances were vegetated with grass or shrubs.

Change Application Method

- Air application has a larger drift potential than ground application equipment. When drift risk is present, changing to ground application equipment requires a smaller buffer zone.

SOIL AND WATER MANAGEMENT TO REDUCE RUNOFF

Any reduction in runoff volume or decrease in the velocity of runoff flow can reduce the amount of both soluble and sediment-attached residues. Managing the Irrigation to uniformly apply the correct amount of water to meet crop demand and by increasing water infiltration rates can minimize runoff rates and overall runoff volumes.

Irrigation Management

Irrigation management entails assessing the crops water needs and applying irrigation water to supplement stored winter moisture. Irrigation frequency and duration should ensure that all water infiltrates such that plant water use is met while preventing water loss through runoff and deep percolation. The extent of runoff depends on several factors, including: 1) the slope or grade of an area; 2) the texture and moisture content of the soil; 3) how well the soil surface supports water infiltration; 4) the amount and timing of irrigation or rainfall. Runoff containing pesticides can cause direct injury to non-target species, harm aquatic organisms in streams and ponds, and lead to groundwater contamination.

Alfalfa Irrigation Systems

Two basic types of irrigation systems are used in alfalfa production: surface systems (border-check), and pressurized systems (sprinkler). Each has distinct cultural, cost, and offsite movement advantages and disadvantages. However, some disadvantages can be overcome using specific management practices.

In *pressurized irrigation systems* water, should be applied at a slower rate than it is absorbed by the soil (infiltration rate), to prevent runoff. However, as irrigation progresses the infiltration rate declines, making runoff more likely. In order to prevent runoff, the system should be turned off before significant runoff occurs. When properly managed, pressurized irrigation systems can be free of water runoff, effectively reducing the risk of pesticide residue moving offsite.

In *surface systems* soil characteristics control the amount of water infiltrated and its distribution across the field as it travels down slope. Runoff is necessary to maximize distribution uniformity (how even the water is applied across the field) within the field. Limiting runoff after a reasonable uniformity has been achieved is a good practice to reduce the continued movement of residues offsite. An irrigation runoff return or tailwater return system can capture runoff and return it to the irrigation inflow, to be applied to adjacent sets or another field. At sites with runoff risks to surface waters, changing from surface irrigation to pressurized irrigation is recommended when possible.

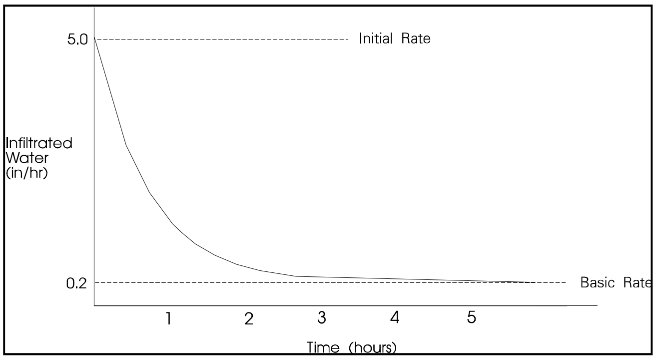
Alfalfa growers must determine the amount of irrigation water to apply, when to apply it, and the **most efficient** method of irrigation for a given set of conditions. This avoids problems associated with over- or under-irrigating.

Surface Irrigation Systems

Surface irrigation systems (border-check irrigation), while being the simplest irrigation systems with regard to hardware, are the most difficult ones to manage properly. Control of runoff water is essential for controlling offsite movement of pesticides, sediments, and nutrients.

With border-check irrigation, water is applied to the soil surface and gravity moves the water across the field. Soil characteristics control both the rate at which water enters the soil and its distribution across the irrigated area. As irrigation begins, the rate at which water enters the soil is high, primarily because of soil dryness and easy access to the soil pores. As irrigation proceeds, the infiltration rate declines rapidly to a basic or sustained rate. Figure 2 shows the typical relationship between the amount of water infiltrated into the soil and hours of irrigation.

Figure 2. Typical water infiltration characteristics.



A soil's water intake characteristics depend on both its physical and chemical composition as well as the chemical composition of the water. Irrigation water containing very low salt content or higher sodium and/or bicarbonate levels can reduce infiltration rates. For more information, see the section: “Reducing Runoff by Improving Water Infiltration.”

In general, the objective of any irrigation system is to have water infiltrating for the same length of time in all parts of the field. This is difficult to accomplish with border-check systems because it takes time for water to flow, starting from the head of field, down the check to the end of the field (called “advance time”) resulting in less time for infiltration. This shorter time in which water is in contact with the soil means less water is infiltrated at the tail end of the field. In border check irrigation, a large amount of water is stored during irrigation on the surface of the check. At irrigation cutoff time water remaining on the surface continues to infiltrate as it moves down slope until all the surface water disappears at the tail end of the field. The time from when the irrigation is cutoff and when the water at the tail end of the field disappears is called the irrigation “recession time”. The difference between the advance time and recession time is the infiltration time. Measuring distribution of infiltrated water under surface systems is difficult at best. The overall goal is to provide near equal opportunity time along the length of the check (Hanson and Schwankl, 1995). The controlling factor for advance time is the onflow volume in which more volume equals faster advance. The recession time is influenced by both the onflow rate (higher onflow rate results in more surface stored water at cutoff) as well as the irrigation cutoff time (earlier cutoff results in less infiltration time at the tail of the field).

In general, it is advantageous to keep checks as short as practical, which keeps irrigation uniformity high. The tradeoffs with short checks are increased labor and pipeline costs and increased runoff volumes. Tailwater return systems can be used with these irrigation systems to increase their efficiency and eliminate discharges.

One difficulty with managing surface irrigation systems is measuring the water going onto the field. If water supplies are from a pump, a flow meter such as a propeller meter can be installed in the outlet pipe. Following the manufacturer's recommended installation criteria is important for accurate measurements. If water is delivered from an open supply-ditch water measurement is difficult. Consulting the irrigation district may help in getting a good estimate of the flow rate onto the field.

The following formula may be used to determine the average amount of water applied to a field using a meter that indicated cubic feet per second (cfs).

$$D = Q \times T / A$$

Where D = depth of applied water (inches), Q = flow rate into the field (cubic feet per second), T = time required to irrigate the field (hours), and A = acres irrigated

Note: If the flow meter reads in gallons per minute (gpm) rather than in cubic feet per second (cfs), the conversion is as follows:

1cfs = 449 gpm

An example:

Flow = 4 cfs
Irrigation on time = 8 hours
Area = 6 acres

$$\frac{4.45\text{cfs} \times 8.6 \text{ hours}}{8 \text{ acres}} = 4.8 \text{ inches}$$

Pressurized irrigation systems

Pressurized irrigation systems include wheel-line systems, hand-move systems, and center-pivot and linear-move machines. Buried drip systems, also a pressurized system, are not common in alfalfa production due to important practical limitations including system costs and maintenance, especially rodent damage. Wheel-line and hand-move systems are classified as periodic-move systems while linear-move and center-pivots are considered continuous-move systems. Pressurized systems share the common trait of “designed in” uniformity that overcomes many of the disadvantages of border-check irrigation.

Irrigation Scheduling to Meet Crop Water Requirements

Alfalfa yield is directly related to crop evapotranspiration (ET). Evapotranspiration is the sum of plant water use (transpiration) and evaporation from the soil surface. Maximum yield occurs when the evapotranspiration is maximized, while reduced evapotranspiration caused by inadequate irrigation decreases crop yield. Climate factors affecting the crop evapotranspiration include solar radiation, temperature, wind, and humidity. Plant factors affecting evapotranspiration include plant type, stage of growth, and health of the plant and soil moisture. Seasonal ET of alfalfa varies by location in California from 48-49 inches for the Central Valley.

Crop water use begins at a low level in spring when climatic conditions are mild; this increases as the days lengthen and the weather warms, maximizing in mid-summer, then decreases as fall approaches. Water use is also influenced by time after harvest, as soil evaporation is the only water used until alfalfa regrowth begins. The best way to determine crop water use is to use climatic data and a specific crop's characteristics. Alfalfa ET can be estimated using the following formula:

$$ETc = ETo \times Kc$$

Where ETc is the crop water use, ETo is the reference evapotranspiration for a given area, and Kc is a crop coefficient.

The reference ET information is available from a network of nearly 100 California weather stations that provide daily reference evapotranspiration values. This information is made available to growers by the CIMIS Program in the California Department of Water Resources at http://www.cimis.water.ca.gov/cimis. Some newspapers and irrigation districts also provide CIMIS ETo data. The CIMIS program provides real time, current values. Historical or long-term average ETo can be more convenient than real-time ETo information and can be used to prepare an irrigation plan well ahead of the irrigation season. Table 3 lists historical daily values for ETo for selected Central Valley locations.

Table 3. Historical crop evapotranspiration reference (inches/day) for various California Central Valley locations

		Five Points	Manteca	Davis	Durham
Jan	1-15	0.04	0.04	0.03	0.03
	16-31	0.05	0.05	0.05	0.05
Feb	1-15	0.06	0.07	0.06	0.06
	16-28	0.09	0.09	0.09	0.09
Mar	1-15	0.11	0.11	0.09	0.09
	16-31	0.15	0.14	0.14	0.12
Apr	1-15	0.20	0.17	0.18	0.16
	16-30	0.22	0.19	0.28	0.17
May	1-15	0.23	0.22	0.23	0.21
	16-31	0.27	0.23	0.24	0.22
Jun	1-15	0.29	0.26	0.28	0.25
	16-30	0.30	0.27	0.29	0.26
Jul	1-15	0.30	0.27	0.29	0.27
	16-31	0.28	0.25	0.27	0.25
Aug	1-15	0.28	0.24	0.26	0.24
	16-31	0.25	0.22	0.24	0.21
Sep	1-15	0.23	0.19	0.21	0.19
	16-30	0.20	0.16	0.18	0.16
Oct	1-15	0.17	0.13	0.16	0.14
	16-31	0.13	0.10	0.12	0.10
Nov	1-15	0.10	0.07	0.09	0.07
	16-30	0.07	0.05	0.06	0.05
Dec	1-15	0.05	0.04	0.05	0.04
	16-31	0.03	0.04	0.04	0.03

Crop coefficients for alfalfa have been experimentally determined and may be calculated based on canopy coverage. The Kc depends on the alfalfa stage of growth. The Kc is smallest after harvest, about 0.4 to 0.5, and reaches a maximum of about 1.1 to 1.2 just prior to harvest (Hanson et al. 2008). A more practical method than accounting for changing Kc conditions is to use an average value during the irrigation season as shown in Table 4.

Table 4. Average crop coefficients for alfalfa.

Climatic Condition	Average Crop Coefficient (Kc)
Humid, light to moderate wind	0.85
Dry with light to moderate wind	0.95
Strong wind	1.05

Source: Doorenbos and Pruitt, 1977

An example of a bi-weekly irrigation schedule for alfalfa in the Manteca area of California is presented in Table 5. This uses the basic inputs of ETo (Table 3) beginning in April and the average crop coefficient (Table 4) to estimate the alfalfa water use (ETc).

Table 5. Historical ETo averages for Manteca from Table 3 in combination with the average crop coefficient(Table 4), the water use (ETc) can be estimated.

Period				Daily	Period	Crop	ETc
Begin Date		**End Date**	**Days**	**ETo**	**ETo**	**Coefficient Kc**	**Inches**
1-Apr	to	15-Apr	15	0.17	2.55	0.95	2.4
16-Apr	to	30-Apr	15	0.19	2.85	0.95	2.7
1-May	to	15-May	15	0.22	3.3	0.95	3.1
16-May	to	31-May	16	0.23	3.68	0.95	3.5
1-Jun	to	15-Jun	15	0.26	3.9	0.95	3.7
16-Jun	to	30-Jun	15	0.27	4.05	0.95	3.8
1-Jul	to	15-Jul	15	0.27	4.05	0.95	3.8
16-Jul	to	31-Jul	16	0.25	4	0.95	3.8
1-Aug	to	15-Aug	15	0.24	3.6	0.95	3.4
16-Aug	to	31-Aug	16	0.22	3.52	0.95	3.3
1-Sep	to	15-Sep	15	0.19	2.85	0.95	2.7
16-Sep	to	30-Sep	15	0.16	2.4	0.95	2.3
1-Oct	to	15-Oct	15	0.13	1.95	0.95	1.9
16-Oct	to	31-Oct	16	0.1	1.6	0.95	1.5

Although water use can be calculated on any time scale (bi-weekly in the above example), the scheduling of alfalfa irrigations is influenced by harvest practices. Harvest occurs about every 28 to 30 days with the first irrigation occurring after bales are removed from the field. The final irrigation must be applied at a time to allow the soil to sufficiently dry before the next harvest. Therefore, depending on the root zone water holding capacity and the time of the year, growers must choose between one and several irrigations between harvests. By multiplying the available soil moisture (Table 6) per foot by the root zone depth, the root zone water available can be calculated. In order to prevent water stress, irrigation usually takes place at about 50% of the calculated root zone available water holding capacity. An example for a 4-foot root zone with a loam texture would be:

1.8 inches per foot × 4 feet depth = 6.8 inches of available water × 0.5 (or 50%) = 3.6 inches

In this example, two irrigations per cutting would be adequate for most of the season. In areas with shallow groundwater significant water can be supplied to the alfalfa crop which will reduce the irrigation requirement.

Table 6. Available soil moisture for various soil textures

Soil Texture	Available Soil Moisture (in/ft)
Sand	0.7
Loamy sand	1.1
Sandy loam	1.4
Loam	1.8
Silt loam	1.8
Sandy clay loam	1.3
Sandy clay	1.6
Clay loam	1.7
Silty clay loam	1.9
Silty clay	2.4
Clay	2.2
Peat and muck	2.5 - 3.5

Applying the water

Once the amount of water needed to meet full ET is determined and irrigation timing selected, the amount of water to deliver to the field needs to be determined. Water in addition to ET is needed to account for non-uniformity in water distribution and soil infiltration variability. Additionally, if the irrigation onflow volume is known, the duration of irrigation can be determined.

Determining Irrigation Amount.

Once the crop water requirement has been determined, the irrigator must account for losses such as evaporation, lack of uniformity and deep percolation. These losses depend on both the irrigation system type and management. Border-check irrigation can have substantial runoff losses and has larger variability in the depth of infiltrated water than do pressurized systems. This variability in infiltration requires that additional water be applied to achieve a minimum amount of water to all parts of the field.

To account for differences between irrigation systems, we use the term irrigation efficiency to adjust the applied irrigation water amount to meet the water requirement of the crop. Irrigation efficiency is the amount of water stored in the root zone and beneficially used by the crop divided by the amount of water applied. To adjust the application amount for system efficiency, divide the amount to be applied by the system application efficiency factor (Table 7). For example, to supply a needed 3.6 inches of water to a border-check irrigated field would require $3.6 \div 0.75 = 4.8$ inches of water would need to be applied. This amount considers that the runoff is recycled using a tailwater recovery system. If such a system is not available reduce surface irrigation systems by 15%.

Table 7. Practical potential irrigation efficiencies of irrigation systems (Hanson 1995)

System Type	Estimated Efficiency*
Surface Irrigation	
Border-check*	70-80
Sprinkler	
Continuous-move	80-90
Periodic-move	70-90
Portable solid-set	70-80

**Efficiency reflects the use of a tailwater capture and return system. If not available reduce by 15%*

<u>Determine Irrigation On-Time (duration)</u>

The irrigation application time for a surface irrigation system is determined by simply dividing the amount of water applied by the land area it is applied to. For example the duration of irrigation can be calculated by:

$$T = (A \times D) / Q$$

Where T = time required to irrigate the field (hours), A = acres irrigated, D = depth of applied water (inches), and Q = flow rate into the field (cfs). 1cfs = 449 gallons per minute

Using our example of 4.8 inches and a 40-acre field with a 2000 gallon per minute supply the on time would be:

$$T = (40 \times 4.8) / 4.45 = 43 \text{ hrs}$$

If four checks each at two acres were irrigated at once:

$$T = (8 \times 4.8) / 4.45 = 8.6 \text{ hrs}$$

Once the irrigation amount and timing of irrigation is determined to meet the crop water use the application can be problematic and site specific. When using surface irrigation on high infiltration soils it may be difficult to apply the relatively small amount of water (3.6 inches in our example) due to the large amount of water required to move water down the checks and the time to advance the water to the end of the field. Excess infiltrated water would percolate below the rootzone. The selection of appropriate onflow volumes and cutoff times discussed below can minimize over application of water.

To determine the irrigation time for wheel-line and hand-move sprinklers:

$$T = D \times AR$$

Where = T = time of irrigation (hours), D = depth of water (inches), and AR = application rate (inches/hour).

Check Up on the Calculations and Applications

The climate-based method described above for determining crop water needs gives an estimate of demand which should be verified and fine-tuned by using soil based monitoring of soil water status.

There are many soil moisture-monitoring devices which measure soil moisture content and soil tension (Schwankl and Prichard 2009). If decreasing soil water occurs over the season or an increase in soil water tension is evident, too little irrigation was applied. If soil water content increases or tension is reduced progressively after each irrigation, too much applied water is indicated.

Managing Irrigation Systems to Reduce Runoff

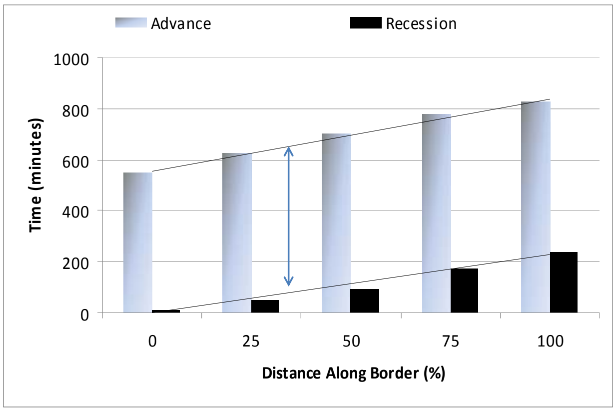
As a general rule, the depth of water applied in the above formula should match the amount of water used by the crop since the last irrigation, and is roughly equivalent to evapotranspiration (ET) (see section: "Irrigation Scheduling to Meet Crop Requirements). Remember that some additional water should be applied because no irrigation system is 100 percent efficient. The efficiencies of border-check fields are generally lower than those of pressurized irrigation systems.

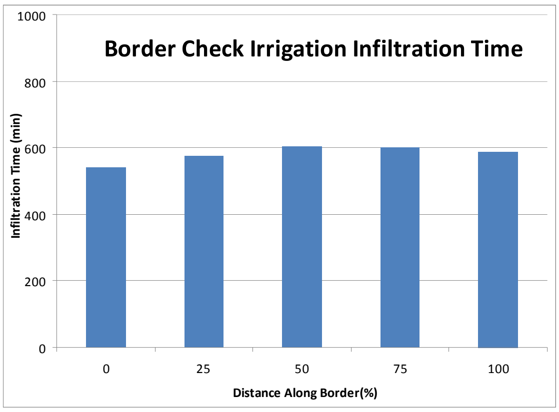
Border-check Irrigation Systems.

Irrigation runoff that enters surface waters can carry both dissolved and sediment-adsorbed pesticide residues. Soluble residue concentrations in runoff waters are fairly consistent for the entire runoff period. Therefore any reduction in the total runoff volume will reduce the amount of residues. The degree to which soils erode during irrigation will depend on a number of factors, with soil aggregate stability – the ability of soil particles to cling together and resist the forces of flowing water—being the most important. Aggregate stability can be enhanced by chemical and physical amendments and management practices discussed in the section: "Reducing Runoff by Improving Water Infiltration." Soil erosion rates will depend on the soil conditions, including the amount, size, and density of loose particles on the soil surface. The degree of soil erosion depends on the velocity of the water and the duration of runoff. Therefore, reducing the peak volume and duration of runoff will reduce sediment loss. Generally, in border checks with alfalfa stems and litter, the water velocity is too low to cause erosion. However, when the water exits the check into areas of little plant cover and into graded ditch areas, the increased velocity can lead to erosion.

The cutoff time is the time that an irrigation set is ended and no more water is applied to the field. Decreasing the cutoff time of the irrigation water (shortening the amount of time a field is irrigated) can reduce the amount of surface runoff. The cutoff time for a given field depends on the time needed to infiltrate sufficient water along the lower part of the field. It may need to be determined on a trial-and-error basis. Figure 3a illustrates a measured advance and recession in a border-check irrigated field (see section: Alfalfa Irrigation Systems for definition). Note the advance and recession are nearly linear and parallel to each other. This pattern indicates a uniform infiltration opportunity time as a result of the correct onflow rate and proper cutoff time (Figure 3b). A shorter cutoff time would have reduced runoff volume but also reduced the distribution uniformity across the field.

Figures 3a and 3b. Border-check irrigation advance and recession, and infiltration time as a percentage of the field length. (Hanson and Schwankl, 1995)





Converting to pressurized irrigation can reduce runoff. This option significantly reduces the chance of runoff, but requires a significant investment. See section: "Pressurized Irrigation Systems."

Capturing and recycling runoff by using a tailwater collection system can mitigate runoff and therefore offsite residue problems, and make irrigation more efficient. For more information see section: "Tailwater Runoff Collection and Recycling."

Pressurized Irrigation Systems.

Pressurized systems should be operated to meet the crop water requirement while eliminating any surface runoff. Uniformity is designed into pressurized irrigation systems, with management left to ensure not only efficiency but the elimination of runoff losses by turning off the system before runoff occurs. The primary factor effecting uniformity is the pressure differential between sprinkler nozzles within the area irrigated. Pressure losses within the system can be a result of poor design, nozzle wear, and sprinkler elevation differences. If runoff occurs before the necessary water is infiltrated, the frequency of irrigation can be increased or the application rate can be decreased. Decreasing the application rate will require increasing the duration or perhaps the frequency to apply the desired amount of water.

REDUCING RUNOFF BY IMPROVING WATER INFILTRATION

Poor water infiltration can increase runoff from irrigation or winter rains. Irrigation runoff is typically associated with surface irrigation, but can occur with pressurized systems on soils with poor infiltration soils or sloping land.

The first step in determining how to mitigate a water infiltration problem is to understand the soil and water factors that influence it.

At the onset of irrigation, water infiltrates at a high rate. Initially the soil is dry and may have cracks through which water can infiltrate rapidly. After the soil near the surface wets for a few hours, these factors become less important in sustaining infiltration rates. The clay particles swell, closing cracks and limiting access to soil pores and decreasing infiltration rates. As the wetting process continues, the salinity and salt composition of the soil-water (water contained between soil particles) begins to more closely reflect that of the irrigation water, which is generally less saline. This reduction in soil water salinity retards water infiltration.

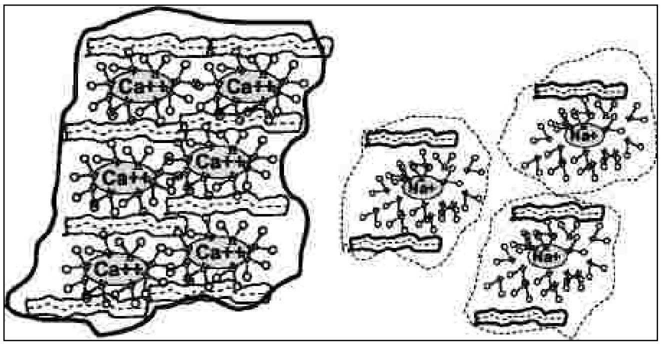
Water infiltration can only be improved by increasing soil total pore volume and/or individual pore size, and providing easy access to surface pores. Physical soil disruption practices and chemical and organic amendments are all attempts to influence one or more of these factors.

Soil Structure and its Impact on Water Infiltration

Pores are the spaces between mineral and organic particles in soils through which water and air move. Soils with a predominance of sands (larger spherical particles) tend to have larger pores, while clay-dominated soils (clays are plate-like particles) tend to be smaller. With some exceptions, soils with larger pores generally have higher infiltration rates. Water usually moves more slowly through small-pored soils because the smaller pores provide more surface area for water to adhere to. On the other hand, clay soils which form cracks as the soil dries and shrinks can help increase water infiltration.

Individual soil particles can clump together, forming larger structures called aggregates. The small pores between particles remain, and larger pores formed between the aggregates significantly enhance water infiltration and gas exchange (Figure 4). Soil water salinity and individual mineral constituents as well as organic matter content play a significant role in stabilizing soil aggregates and increasing pore size.

Figure 4. Conceptual illustration of soil aggregate stability: forming stable aggregates with plentiful calcium on clay exchange sites (left), compared to weak soil aggregates due to low salinity and/or excessive sodium in the soil pore water.



In fine-textured silty soils, soil crusts are often the result of sodic conditions caused by excess exchangeable sodium in the soil or irrigation water, and/or too little total salinity. In coarse- to medium-textured, nonsaline and nonsodic soils, continued cultivation can reduce pore size and number to the point where water infiltration is affected. This problem can be made worse where very low salinity irrigation water is used, such as from irrigation districts on the east side of the San Joaquin Valley.

Irrigation Water Quality

Irrigation water quality influences water infiltration rates through affecting whether soil particles tend to absorb water, stay together, or become separated by swelling. Swelling of soil particles causes aggregate breakdown and soil particle dispersion, resulting in surface crust formation.

Salinity

The higher the salinity of the irrigation water, the more likely the aggregates will remain stable, preserving infiltration rates. Salinity is measured by determining the electrical conductivity (EC) of the irrigation water (ECw) or soil water extracted from a saturated soil paste (ECe).

Sodicity

The index for sodicity is the sodium adsorption ratio (SAR), which depends on the relative amounts of sodium, calcium, and magnesium content of the irrigation water. SAR of a soil sample can also be used to estimate exchangeable sodium levels in the soil. With increasing levels of exchangeable sodium, the affinity of soil particles for water increases and aggregate stability decreases reducing water infiltration rates.

Combined Effect of Salinity and Sodicity

Since both salinity and sodicity of the irrigation water effect aggregate stability and water infiltration rate, both must be assessed when diagnosing an infiltration problem. In the top three inches of soil, salinity and sodicity of the irrigation water and soil are closely linked. Consequently both surface soil samples and water samples are necessary to diagnose the problem and evaluate the success of mediation practices. In general, aggregate stability increases as EC increases and the SAR decreases (Table 8). As a general guideline, the SAR should be less than 5 times the EC (Figure 6). The exception is low salt waters with EC values of less than 0.5 dS/m. They are corrosive and deplete surface soils of readily soluble minerals and all soluble salts. They often have a strong tendency to dissolve all sources of calcium rapidly from surface soils. The soils then break down, disperse, and seal, resulting in poor water infiltration.

The EC and SAR-based guidelines discussed above may not necessarily work for all California soils. Some soils contain a large amount of serpentine clays rich in magnesium (Mg) and low in calcium (Ca). In these soils, Mg may have the same soil-dispersing effect as sodium. Soils with a predominance of montmorillonite and illite clays are also easily dispersed by excess magnesium. Although the diagnostic criteria for such conditions have not been extensively tested, some studies suggest that when the Mg to Ca ratio of these soils exceeds 1:1, they may be prone to water infiltration problems. Some reports report that high soil potassium levels can also promote aggregate dispersion and soil crusting.

Table 8. Potential for a water infiltration problem

SAR*	Problem Likely ECe[1] or ECw[2] dS/m	Problem Unlikely ECe or ECw dS/m
0.0 – 3.0	< 0.3	> 0.7
3.1 – 6.0	< 0.4	> 1.0
6.1 – 12.0	< 0.5	> 2.0

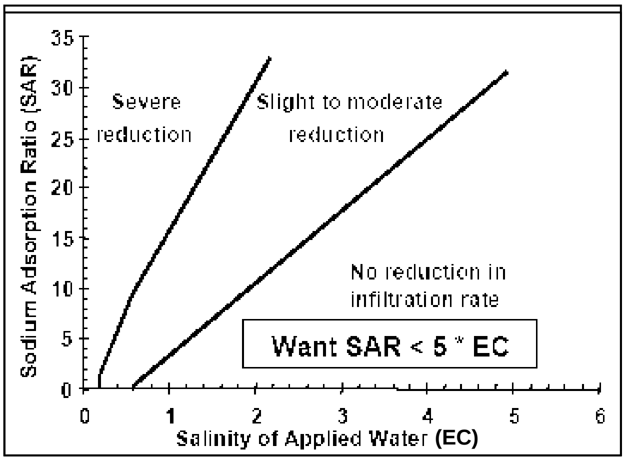
Source: Ayers and Westcot (1985).

* Sodium Adsorption Ratio.

[1] Electrical conductivity of extract indicates that soil is saturated paste soil salinity.

[2] Electrical conductivity of water indicates irrigation water salinity.

Figure 6. Interaction of total salinity as EC with the sodium adsorption ratio of applied water for causing potential infiltration problems. (Ayers and Westcott, 1985)



High carbonate (CO_3^-) and bicarbonate (HCO_3^-) levels in water increase the sodium hazard of the water to a level greater than that indicated by the SAR. In alkaline soils, high CO_3^- and HCO_3^- tend to precipitate calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) when the soil solution concentrates during soil drying. The concentrations of calcium and magnesium in soil solution are reduced relative to sodium, and the SAR of the soil solution tends to increase.

An adjusted SAR value may be calculated for water high in carbonate and bicarbonate if the soil being irrigated contains free lime (calcareous soil). The adjusted SAR and knowledge of soil properties help determine management practices when using high bicarbonate water.

Mitigating Water Infiltration Difficulties

Solving an infiltration problem by modifying irrigation practices – as discussed in other sections of this manual – should always be the starting point and will generally be less costly than the soil and water modifying treatments discussed below. Water infiltration problems not amenable to improvement by optimizing irrigation system design and operation may be mitigated by improved soil organic matter management, or use of chemical amendments as discussed later in this manual.

Managing Soil Organic Matter to Reduce Runoff

Soil organic matter helps stabilize soil aggregates by increasing the number of exchange sites in the soil matrix and encouraging microbial activity. Soil microbes that decompose soil organic matter produce polysaccharides and polyuronides, which act as binders to stabilize aggregates, thus improving porosity and water infiltration. Over time, continued cultivation and the use of herbicides reduces the organic matter content and aggregate stability of soils. These changes can reduce water infiltration and increase runoff potential.

It is difficult to increase and sustain soil organic matter under warm semiarid conditions that prevail in most of California, which favor rapid organic matter decomposition. Organic matter additions aimed at improving or sustaining aggregate stability and water infiltration must be incremental and continual to be effective. There are several ways for growers to achieve this as follows.

Crop Residues

Alfalfa does have a fair amount of plant matter which makes its way to the soil surface. However the residues of rotational crops offer a much greater opportunity to add significant amounts. Field crop residues, whether shredded or soil incorporated, can be left to decompose adding organic matter (and some nutrients) to the soil. Crop residue biomass in California's Central Valley ranged from 9,560 pounds per acre for corn following grain harvest to 570 pounds per acre for onions. Even within a specific crop biomass can vary. In tomato biomass varied due to harvest date but an intermediate value was 2880 pounds per acre. Wheat biomass after grain harvest was 4800 pounds per acre however after baling and removal only 670 pounds remained (Mitchell et al. 1999).

Manure and Other Organic Materials

With proper handing and management to avoid risk of crop contamination by human pathogens, animal manures or compost can help increase soil organic matter content and improve water infiltration. However, the application of manures is currently uncommon due to the limited availability of manures.

Chemical Amendments Used to Improve Water Infiltration

The addition of chemical amendments to water or soil can improve water infiltration by improving the chemical makeup of the water or soil. Most chemical amendments work by increasing the total salt concentration and/or decreasing the sodium adsorption ratio (SAR) of the soil-water. Both of these actions enhance aggregate stability and reduce soil crusting and pore blockage.

Four types of materials are used to ameliorate water infiltration problems: salts, as fertilizers; calcium materials; acids or acid-forming materials; and soil conditioners, including polymers and surfactants.

Salts

Any fertilizer salt or amendment that contains salts, when applied to the soil surface or dissolved in irrigation water, increases the salinity of the irrigation water and ultimately influences the soil-water. Whether increased salinity is advantageous depends on the SAR of the irrigation water. The largest effect of a salt addition is with very low salinity (less than 0.5 EC) irrigation water. Increasing salinity above an EC of 4 dS/m has little effect on infiltration.

Calcium Materials

Adding calcium (Ca) salts to soil and water increases both the total salinity and soluble calcium. Calcium salts commonly used on alkali (high pH) soils include gypsum ($CaSO_4$), calcium chloride ($CaCl_2$), and calcium nitrate ($CaNO_3$). These are fairly soluble and can easily be applied through the irrigation water or broadcast onto the soil surface. Lime and dolomite are used only for broadcast applications on acid soil, as they are virtually insoluble under alkali conditions.

Gypsum Injection Rates for Water

Amendment rates from 1.0 to 3.0 meq/L calcium in the irrigation water are considered low to moderate; rates that supply 3.0 to 6.0 meq/L calcium are considered moderate to high. The following example calculations show the reader how to estimate the quantity of gypsum required to improve infiltration. Table 9 lists the amount of gypsum and other products needed to increase the calcium (Ca) content of irrigation water by 1 meq/L per acre-foot.

It is rarely necessary to inject gypsum constantly. Injection every other or every third irrigation may be all that is necessary to end the season with the required amount

Table 9. Amounts of amendments required for calcareous soils
to increase the calcium content in the irrigation water by 1 meq/L.

Chemical Name	Trade Name and Composition	Pounds/Ac-ft of Water to Get 1 meq/L Free Ca*
Sulfur	100% S	43.6
Gypsum	$CaSO_4 \cdot 2H_2O$ 100%	234
Calcium polysulfide	Lime-sulfur 23.3% S	191
Calcium chloride	Electro-Cal 13% calcium	418
Potassium thiosulfate	KTS -- 25% K_2O, 26% S	256
Ammonium thiosulfate	Thio-sul 12% N, 26% S	110** 336***
Ammonium polysulfide	Nitro-sul 20% N, 40% S	69** 136***
Monocarbamide dihydrogen sulfate/ sulfuric acid	N-phuric, US-10 10% N, 18% S	148** 242***
Sulfuric Acid	100% H_2SO_4	133

* Salts bound to the soil are replaced on an equal ionic charge basis and not equal weight basis.

** Combined acidification potential from S and oxidation of N source to NO_3 to release free Ca from soil lime. Requires moist, biologically active soil.

*** Acidification potential from oxidation of N source to NO_3 only.

Gypsum Rates Broadcast to Soils

An alternative to water treatment is broadcasting amendments such as gypsum on the soil surface. The primary advantage of this approach is that it is often less expensive than water treatments. Surface applications are most effective when gypsum is applied at rates equivalent to 1 to 2 tons per acre during the time of year when the infiltration problem is noticed.

Acids and Acid-Forming Materials

Commonly applied acid or acid-forming amendments include sulfuric acid (H_2SO_4) products, soil sulfur, ammonium polysulfide, and calcium polysulfide. The acid from these materials dissolves soil-lime to form a calcium salt (gypsum), which then dissolves in the irrigation water to provide exchangeable calcium. The acid materials react with soil-lime the instant they come in contact with the soil. The materials with elemental sulfur or sulfides must undergo microbial degradation in order to produce acid. This process may take months or years depending on the material and particle size (in the case of elemental sulfur). Since these materials form an acid via the soil reaction, they will reduce soil pH if applied at sufficiently high rates.

Acids are applied to water to dissolve soil lime (the soil must contain lime if acids are used), increasing free calcium in the soil/water matrix and improving infiltration.

Table 9 indicates that it takes 133 lbs/ac-ft of 100 percent pure sulfuric acid to release 1 meq/L Ca. This assumes the acid contacts lime ($CaCO_3$) in the soil, neutralizing the carbonate molecule and releasing Ca. This is the same amount of acid required to neutralize 1 meq/L of HCO_3 in the water. If the water contains bicarbonate the acid will neutralize it, converting it to carbon dioxide which is released to the atmosphere. Acid applications must exceed the bicarbonate level of the water before the pH of the water decreases to dissolve lime in the soil.

Soil Conditioners

There are two types of amendments in this category, organic polymers and surfactants. Other amendments include synthetic and natural soil enzymes and microbial soups. Although there is a long history of soil conditioner development and testing, not enough data exists on the materials to conclude that they are uniformly effective. For an in-depth analysis of water infiltration problems and solutions see: "Water Penetration Problems in California Soils: Diagnosis and Solutions," Singer et al. 1992.

Organic Polymers

Organic polymers, mainly water-soluble polyacrylamides (PAM) and polysaccharides, are used to stabilize aggregates at the soil surface. These extremely long-chain molecules wrap around and through soil particles to bind aggregates together. This action helps resist the disruptive forces of droplet impact and decrease soil erosion and sediment load in surface irrigation systems. Since alfalfa is not furrow irrigated PAM is not recommended for use.

Surfactants

Surfactants *or "wetting agents"* are amendments that reduce the surface tension of water. They are not effective in agricultural soils.

For an in-depth analysis of water infiltration problems and solutions see: "Water Penetration Problems in California Soils: Diagnosis and Solutions," Singer et al. 1992.

CAPTURING AND FILTERING SURFACE WATER AND SEDIMENTS

Reducing the volume or velocity of runoff waters can reduce offsite movement of residues whether they be in solution or sediment-attached. There are several methods of capturing and filtering surface water and sediment with the most common being the use of basins for collection and or recycling or the use of vegetation at the tail of the field or in the drainage ditch.

Capturing Runoff

Storage of runoff waters from storm events in impoundments is often suggested as a mitigation practice. The sheer volume of runoff makes this a poor option. Storms are rated as to the frequency at which a particular amount of rainfall in a given duration is expected to return, on average. A 2-year 24-hour storm would be the rainfall event one could expect during a 24-hour period on the average of every 2 years. For example, a 2-year 24-hour storm in Stockton, CA falling on a 40-acre parcel would produce over 1,700,000 gallons or 5.3 acre feet of water—equivalent to a one acre pond over 5 feet deep. A hundred-year storm would require three times that volume for just a single storm. Of course, some of the water would infiltrate into the field. However, if one storm came on the heels of another, most of the rainfall would run off. For more information on runoff storage and storm precipitation rates, see: "Storing Runoff from Winter Rains," Schwankl et al. 2007a, ANR Publication 8211.

Sediment Basins

A sediment basin or trap is created by constructing an embankment, a basin emergency spillway, and a perforated pipe-riser release structure. The basin may be located at the bottom of a slope where drainage enters a swale or waterway. These basins can be designed by the Natural Resources Conservation Service (NRCS) or a civil engineer on a site-specific basis, and installed using proper construction and compaction for the berm, and correct sizing and construction for water release structures and spillways. When runoff volumes are small, basins can be effective for reducing offsite movement of sediment containing adsorbed pesticide residues. If runoff is high enough to cause low retention times, sediment removal efficiency declines rapidly.

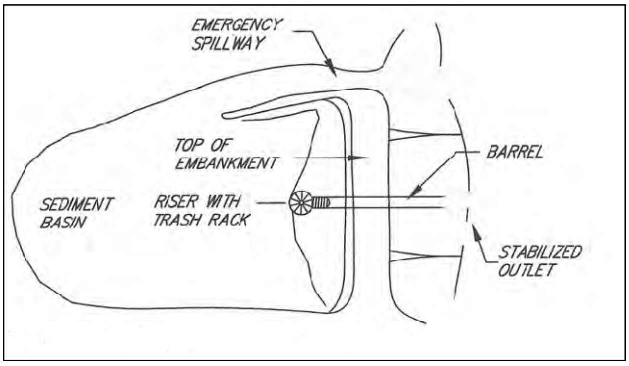


Diagram of a sediment basin with spillway and release structure

Effectiveness in Removing Pesticide Residues

Long et al. (2010b) found that 60 to 90 minute retention times effectively removed particles coarser than fine silts. The sediment basin was 1.4 percent of the irrigated area. Finer soil particles, which generally adsorb pyrethroid pesticide residues, were not removed from the runoff. During the first irrigation of the season, soon after cultivation, 39 percent of the sediment load entering the pond was removed. In second, measured irrigation sediment removal was insignificant. The effectiveness of sediment traps was found to be limited by the time available for suspended sediments to settle out of the runoff. Sediment basins may be ineffective with finer soils at higher runoff rates. Long (2010a) suggests various size settling basins based on Stokes Law. Clay particles carry the bulk of the adsorbed pesticide residues. In order to provide enough holding time to settle out these small particles from a 50 gallon per minute tailwater runoff rate, a settling basin of 57 acre feet would be required.

A study was conducted in the Central Valley of California to measure pyrethroid removal by a tailwater recovery pond. The field was a border-check irrigated almond orchard to which a pyrethroid, lambda-cyhalothrin was applied at the rate of 0.04 lb ai/acre. Runoff waters were measured for volume, sediment, and pyrethroid residue concentration as inflow to a recycling pond and as outflow. About 15 percent of the irrigation onflow water exited the field as runoff. The pond was 19 feet by 16 feet by 7 feet deep. Sediment in the water was reduced by 80 percent, inflow to outflow. Pyrethroid residues were reduced by 61 percent. The difference in the removal efficiencies for sediment and pyrethroid residues was most probably due to the absorption of lambda-cyhalothrin residues to lighter weight clay particles, which did not have a chance to settle out in this trial. Removal efficiency may have been further improved with lower flow rates or longer retention times in the ponds (Markle 2009).

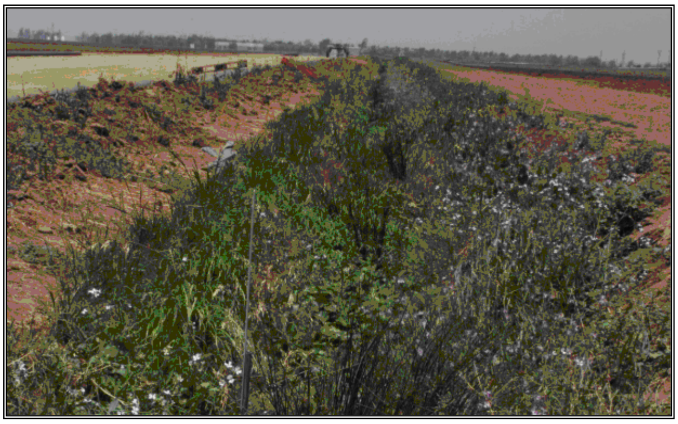
Vegetated Filter Strips

The tail ends of alfalfa fields are often weak due to over or under watering during irrigation, resulting in plant losses. These weak areas often have higher soil erosion problems due to the lack of vegetation holding the soil. To help stabilize the soil and prevent offsite movement of pesticides used in alfalfa hay production, the tail ends of fields can be overseeded with other forages, such as grasses or legumes, creating a vegetated filter strip. Some suggested perennial forages that would work well as filter strips in alfalfa include orchardgrass, fescues, and red clover, as described in Canevari et al. 2000. These forages are best seeded during early fall after the ground has been lightly harrowed to form a seedbed. Grasses are a good fit for the horse hay market while clovers are suitable for dairies. If the alfalfa stand will be in for less than a year, annual forages that would work well for overseeding in alfalfa include oats or berseem clover.

Vegetated ditch

A vegetative drainage ditch (VDD) is a drain planted with dense grass or other vegetation that is designed to capture and filter surface runoff from crops to protect water quality. In alfalfa fields, standard V-shaped drainage ditches can be vegetated with plant material that will help capture sediments and other sediment-absorbed pollutants, as well as provide for some water infiltration. Short, sturdy, and hardy perennial grasses such as the dwarf fescues and perennial ryegrass are preferred, since once established they withstand the force of runoff waters and summer drought conditions. The width and depth of the VDD required to effectively remove sediments depends upon the slope of the area draining into the strip as well as the volume and velocity of the tailwater. To be most effective, the tailwater has to flow at or below the height of the vegetation to trap particulates.

The common type of VDD is typically a “V”-shaped ditch, 2-3 feet deep and 4 feet wide at the top. Vegetation in the VDD can also be resident, such as rushes and bermudagrass. Vegetated ditches can help reduce chemical contaminants as does a VFS, by infiltration, direct adsorption of chemicals to plant surfaces, and promoting sedimentation of particle-bound contaminants. Residue removal efficiency is strongly influenced by runoff flow rate per unit ditch wetted area. Higher flow rates reduce the removal efficiency.



Vegetated Ditch

Effectiveness in Removing Pesticide Residues

The chemical characteristics of different pesticides determine the type and amount of residue reduction achievable with vegetation systems. Organophosphate pesticides tend to be water-soluble, while pyrethroids are virtually non-soluble in water and are primarily adsorbed to sediments. Diazinon, an organophosphate of high solubility in water, can be expected to remain in solution for long periods (Bondarenko and Gan, 2004). Previous evaluations of the effectiveness of vegetation for removing diazinon from water have shown mixed results. Watanabe and Grismer (2001) evaluated diazinon removal by vegetated filter strips under controlled laboratory conditions and found that the majority of diazinon removal occurred via infiltration into the root zone and adsorption to vegetated matter. However, 73 percent of the applied diazinon was detected in the runoff water after the VFS. Anderson et al. (2008) found that a vegetated ditch containing aquatic vegetation removed only 4 percent of diazinon in contaminated runoff.

Chlorpyrifos, another organophosphate, is more hydrophobic than diazinon. Gill et al. (2008) applied chlorpyrifos at 1 pt/ac and found a 40 percent reduction in the water column concentration after passage through a vegetated ditch, though the outflow water was still at 33 times the water quality standard of 15 ppt. Anderson et al. (2008) found an average 35 percent reduction of chlorpyrifos concentration in two evaluations after passage through a vegetative ditch containing aquatic vegetation. On the other end of the spectrum, Cole et al. (1997), found VFS's effective in reducing 62-99 percent of chlorpyrifos residues in runoff waters. Local conditions including runoff flow rates, size of the vegetated area, and the initial residue concentration appear to have strongly influenced the effectiveness of these studies.

Because of their hydrophobic nature, pyrethroids adsorb readily to plant surfaces and soil particles and are therefore easier to remove from runoff waters than organophosphates (Moore et al. 2001; Schulz, 2004). Moore et al. (2008), for example, found that vegetation was much more effective at removing the pyrethroid pesticide permethrin than the organophosphate diazinon. Anderson et al. (2008) found nearly 100 percent reduction of permethrin after treatment in a vegetated ditch. Additionally, Gill et al. (2008) found a 25 percent reduction of pyrethroid (lambda-cyhalothrin) residues after moving runoff waters through a vegetated ditch.

Long et al. (2010b) found that reduction in sediment load was directly related to pyrethroid residue removal in VFS. Sediment runoff was reduced by 62 percent when furrow runoff waters passed through a well-established VFS planted to either tall fescue or a perennial ryegrass and tall fescue mixture that represented 2.8 percent of the field being irrigated. They recommend 0.03 acres of vegetated filter per 100 gallons per minute of tailwater to significantly improve the water quality of field runoff (Long et al. 2010b). It should be noted that the vegetated filter strip is used once per irrigation, not for successive sets.

<u>Tailwater Collection and Recycling</u>

Water running off the tail end of a field, part of normal irrigation, is referred to as tailwater or runoff water. Tailwater is most often associated with surface irrigation (furrow and border-check irrigation), since well-designed sprinkler and drip irrigation systems should not produce tailwater runoff. Their use is an excellent management practice to improve irrigation efficiency and minimize tailwater runoff impacts.

Tailwater collection system.

If a new tailwater return system is being planned, the planned management approach must be a key factor in its design. Tailwater generated by irrigation practices is most often, pumped from the capture pond and conveyed via a pipeline system to where it will be reapplied. Such a system, well operated, maximizes irrigation efficiency and minimizes environmental impacts.

Advantages and Disadvantages of Tailwater Return Systems

Advantages:

- Offsite environmental impacts of tailwater potentially containing pesticide and fertilizer residues or sediment are minimized.
- Irrigation efficiency is improved since tailwater is beneficially re-used as irrigation water.
- Water costs may be reduced by re-using tailwater.
- Tailwater collection systems remove standing water that can cause crop loss and weed infestations from the tail end of the field.

Disadvantages:

- Cost of installation, maintenance, and operation of the tailwater return system. However, in many areas NRCS cost share programs available.
- Land must be taken out of production for the pond and other tailwater recovery system components.
- Good management, requiring timely recycling of tailwater pond contents, is necessary to prevent groundwater pollution by chemicals in the tailwater.

Tailwater Return System Management

There are numerous ways of managing tailwater return systems, and their management is often constrained by the system design. If a new tailwater return system is being planned, the planned management approach must be a key factor in the design. See ANR publication 8225, "Tailwater Return Systems" Schwankl et al. 2007b. for information on design, construction, costs and operation, and National Conservation Practice Standard, Irrigation System, Tailwater Recovery, Standard 447-1, USDA Natural Resources Conservation Service, 2006.

TREATMENT OF RUNOFF WATERS

Alfalfa runoff water can be chemically treated to reduce pesticide residues. This treatment can be done in a tailwater ditch, or in a holding basin. Two products are available and have been shown effective for this purpose: Polyacrylamide (PAM), for treatment of pyrethroid-laden sediments, and Landguard OP-A Enzyme®, for treatment of most soluble organophosphate pesticides. Work is underway to develop enzymes to treat pyrethroid residues, however they are unavailable at this time.

Polyacrylamide (PAM)

PAM is effective in controlling pesticide residues which are attached to soil particles (pyrethroids) that leave the field or are generated in the tailwater ditch through erosion during irrigation. Studies have shown that this erosion occurs along the field length for furrow irrigation. However, for alfalfa, little or no erosion occurs as water advances down the field. Suspended solids in the irrigation water are filtered out as the water flows across the field because of the filtering effect of the alfalfa and the residual organic matter on the soil surface. Observations made during alfalfa irrigations found that erosion occurs at the end of the field mainly due to the surface runoff flowing into and down the tailwater ditch. Some erosion also occurs during the last 15 to 20 feet of the field, where bare soil usually exists in alfalfa fields. Suspended solids were measured in source and tailwaters during alfalfa border check irrigation at fifteen sites (Long et al., 2002). Tailwater was found to be not significantly degraded by sediment. However, when increased volumes of runoff enter tailwater ditches as runoff maximizes the increased velocity can cause erosion. If tailwater ditches are not treated with pesticides the risk of offsite movement from the ditch is significantly reduced.

PAM is a solid or liquid water-soluble polymer that flocculates sediments–binding them together and causing them to drop out of the water. When added to runoff waters, PAM can mitigate transport of sediment-adsorbed pesticides from irrigated fields. Liquid PAM can be constantly injected into the tailwater ditch, or deposited in granular form into turbulent water in the tailwater ditch where it is slowly dissolved by irrigation water. PAM is more effective in finer texture soils and in irrigation waters that contain calcium and little sodium.

Effectiveness in Removing Pesticide Residues

PAM has been shown to be effective in reducing sediments from furrow irrigation fields when applied to irrigation furrows (Sojka et al. (2007), Trout et al. 1995, and Long et al. 2010b). Although these results are based on furrow or head ditch applications, it is reasonable to expect similar results with a tailwater ditch application if the runoff water velocity is low enough to allow particle settling. Results are mixed as to the effectiveness of tail ditch applied Pam to control sediment loss. Poor results have been reported when applying PAM into the ditch with a high runoff water velocity and quick discharge time. Good results were obtained with a ditch application combined with short-term sediment basin use before discharge.

Landguard OP-A Degradation Enzyme

Runoff waters containing organophosphate insecticide residues can be treated with a degradation enzyme, Landguard OP-A, to reduce or eliminate residues in runoff water before water exits the farm. This product promotes the breakdown of most organophosphate pesticides into less toxic metabolites. The powder-like enzyme is mixed with water into a stock solution and applied to runoff water usually in the tail water ditch but can be applied to a holding basin. The enzyme treatment rate, residue concentration, and the time available before runoff discharge are all important to for ensuring degradation at a minimum material cost. Greater time available before runoff discharge allows a lower enzyme application rate.

The key factor in determining the correct dosing rate is the maximum expected runoff rate. Runoff rate is typically not constant over time. When using a single dosing rate based on the maximum estimated flow rate, over-dosing is likely at the lower flows that typically occur at the beginning and end of a runoff event. Additionally, the practice of irrigating more checks during a nighttime set can lead to different peak flows of different duration.

A comparison was made of the amount of enzyme required for single maximum rate dosing for the entire runoff period and for a variable rate dosed as required by flow rate—essentially keeping the dosing rate constant (Prichard and Antinetti 2009). A single rate setting to dose for the maximum volume during the first irrigation set resulted in a dosage that was more than double the amount actually needed. Estimating that the next set would be near the same runoff flow rate and using the same dosing rate, the second set required over 6 times that of a correctly dosed variable system do to the lower amount of runoff.

Effectiveness in Removing Pesticide Residues

A field trial in California found chlorpyrifos in runoff at a concentration near 10 ppb prior to Landguard OP-A treatment. Twelve minutes after the enzyme was added at a rate of 4.3 oz to one acre foot runoff water, the chlorpyrifos concentration declined to 0.4 ppb. At higher enzyme dosages, chlorpyrifos became undetectable. The effects of the enzyme on chlorpyrifos-related toxicity are equally dramatic. The enzyme reduces chlorpyrifos toxicity to *H. azteca* (a test organism) by at least 70 fold compared with untreated water (Weston and Jackson, 2010). Without enzyme, the concentration of chlorpyrifos required to kill half the test organisms was 141 ppb. With enzyme, they saw no ill effects to the test organisms.

A team led by Brian Anderson of the UC Davis Marine Pollution Studies Laboratory dosed Landguard OP-A at the rate of 4.3 oz/acre foot runoff water directly into a drainage ditch containing diazinon residues (Anderson et al. 2008). Samples of runoff water were collected from the ditch before dosing and 107 feet downstream from the electronic dosing unit (Figure 7).

Figure 7. Anderson trial showing vegetated ditch and electronic dosing unit, 2008.

In multiple trials, Anderson found that samples treated with Landguard OP-A demonstrated no detectable diazinon and all were non-toxic to *C. dubia*, another aquatic arthropod test organism.

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APPENDIX I

A RISK ANALYSIS CASE STUDY

Let's expand the example we introduced in the "How To Use This Manual" to better understand how the management practices presented in this manual can be used to prevent or correct water quality problems arising from field operations.

Crop: Alfalfa, 40 acres
***Topography*:** 0.15 percent slope
Soil: Hollenbeck silty clay loam soil, soil tends to crust limiting the water infiltration rate.
***Irrigation system*:** Border check irrigation, 53 foot wide checks
Irrigation Runoff: Runoff is about 17% of the applied water
Drainage: Runoff moves to a drain at edge of field; then, on to a larger creek
***Irrigation water*:** pH 7.5, EC 0.2 dS/m
Pesticide mixing and loading: A pesticide mixing & loading area is located about 40 feet from the drainage ditch.
***Pest*:** Egyptian alfalfa weevil, 20 per sweep

We begin the risk assessment with Flowchart number 1 (FC1), considering possible routes by which pesticide could move off the field and the operations or conditions that may contribute to the movement. The three possible areas of concern taken in the order of risk after application are: irrigation water runoff, stormwater runoff, and application to near surface water sources (drift). We will determine if a risk exists for each concern, and then review management practices to mitigate the risk.

THE IRRIGATION RUNOFF RISK

We begin with flowchart 1 (FC1) to evaluate risks associated with irrigation runoff using a surface irrigation system. The time of application coincides with the irrigation period. Border-check irrigation in our example has about 17% of the applied water as runoff which discharges into a field ditch then on to a creek. After evaluating the irrigation runoff risks and review management practices we will revisit FC1 to evaluate the other risks. Go to FC3.

Proceeding next to FC3, the next step is to evaluate **IPM practices** used to determine a control for Egyptian alfalfa weevil.

(The following was adapted from the UC IPM Guidelines available at:
(http://ucipm.ucdavis.edu)

The Weevil Pest

Young larvae damage alfalfa by feeding on terminal buds; larger larvae feed on the leaflets. Feeding by older larvae is the most damaging and is characterized as skeletonization and bronzing of the leaves in spring. Under severe pressure, complete defoliation can occur.

Damage from both weevils is most commonly seen on the first cutting of hay. However, if a second generation occurs, significant damage can result in later cuttings. Adult weevils feed on alfalfa but generally do not cause significant damage.

Begin monitoring for weevils in early January in southern and central areas of the state and in April in the far northern intermountain area. If the alfalfa is too short to sweep, look for signs of feeding damage on the leaves.

Weevil Monitoring

Sweep fields with adequate plant height weekly after weevil larvae begin to appear in late winter or early spring. As thresholds are approached, monitor every 2 to 4 days to determine if populations decline or a treatment is required. (For details on sweep net sampling, see http://ipm.ucdavis.edu). Research is underway to reevaluate threshold levels, but currently the recommendation is that a treatment is warranted when weevil larvae count reaches an average of 20 or more larvae per sweep.

Continue to monitor weekly during the spring through June or after a treatment through in the Central Valley, March in the southern deserts and mid-June in the northern intermountain areas.

Management Options

Weevil management in alfalfa is focused on the period before the first cutting. Control options are insecticides and early harvest. Biological control is not effective at preventing economic damage in most areas because populations of natural enemies are not sufficient to provide control in the spring.

Cultural Control

After alfalfa weevil larvae begin to appear, check fields at 2- to 4-day intervals. Cutting the crop as soon as most of the plants are in the bud stage can sometimes prevent serious damage by the weevil. Also, most weevils are killed by the harvest and curing process. However, early cutting to control weevils concentrates the survivors in the windrows. Closely monitor alfalfa regrowth for the second cutting to detect feeding damage because both larvae and adults can cause injury.

Organically Acceptable Methods

The primary organically acceptable management method is cutting the crop early if damage seems imminent.

Chemical Control

In our example, Egyptian alfalfa weevil levels have reached the threshold level at a critical period before the first cutting. A chemical control spray is warranted to avoid yield losses due to feeding. After this initial spray, continued monitoring will be needed to determine if further applications are needed.

Continuing to work our way through FC3, the next step is to select an effective control pesticide that has minimum risk to water quality. Treatment options are derived from the UCIPM Pest Management Guidelines for Weevils (Table A1) with the potential for runoff risk and overall risk from Table 2 (http://www.ipm .ucdavis.edu/PMG/selectnewpest.alfalfa-hay.html) which includes three organophosphates, two pyrethroids, and one oxadiazine.

Table A1. Common treatment options for Egyptian alfalfa weevil their potential to move in solution or as adsorbed particles and overall pesticide runoff risk

Chemical	Trade Name	Chemical Class	Solution runoff potential[1]	Adsorption runoff potential[2]	Overall runoff risk[3]
indoxicarb	Steward	oxadiazine	low	intermediate	?
phosmet	Imidan	organophosphate	intermediate	low	moderate
lambda-cyhalothrin	Warrior	pyrethroid	low	intermediate	high
cyfluthrin	Baythroid/ Renounce	pyrethroid	low	intermediate	high
chlorpyrifos	Lorsban/ Lock-On	organophosphate	high	intermediate	V high
malathion	Malathion	organophosphate	intermediate	low	moderate

[1] Likelihood that the active ingredient will transport from the area of treatment as dissolved chemical in runoff.

[2] Likelihood that the active ingredient will transport from the area of treatment as attachment to soil or sediment particles in runoff.

[3] Overall likelihood to cause negative impact on surface water quality as a product of the runoff potential and the aquatic toxicity of the pesticide

Having read the sections of this manual about the water quality risks associated with various classes of chemicals, we know that many organophosphates are highly water soluble and subject to solution runoff risk while pyrethroids are highly hydrophobic and adsorb readily to soil sediments which can also be subject to offsite movement at the tail ends of fields where stands are often weak. If sediment does not leave the field from pesticide treated areas pyrethroids offer a reduced risk to surface waters. The use of indoxacarb offers a similar risk reduction.

The final consideration in FC3 for managing weevil is to consider pesticide mixing and loading practices and their impact on surface water quality

The mixing and loading site in our example field is within 50 feet of a surface water ditch. Mixing and loading practices include not over-filling the tank, triple rinsing containers and adding the rinsate to the tank, and rinsing the tank and applying the rinsate to the field. The use of a concrete pad with catchment sump is also a good solution to reduce risks from mixing and loading near surface water sources.

The next step in our assessment in FC3 is to consider changes in irrigation management.

In our example field, runoff to a drainage ditch and nearby creek occurs during irrigation. Potential solutions related to irrigation might include:

> *Capturing runoff.* Sediment basins can be used to capture runoff and reduce sediment load. Recycling of runoff waters to the delivery system can completely eliminate the runoff.
>
> *Filtering runoff*. Overseeding weakened tail ends of alfalfa fields can help reduce soil erosion and help infiltrate runoff water by serving as a vegetated filter strip. Planting vegetation in drains at the tail ends of alfalfa fields (vegetated drainage ditches) will also help to trap sediments and agricultural pollutants.
>
> *Reducing runoff volume.* Runoff volumes can be reduced in border-check irrigation by matching the inflow rate to the infiltration rate and optimizing the irrigation cutoff point to achieve good uniformity at a reduced runoff volume
>
> *Improve water infiltration.* The irrigation water in our example field has a salinity (ECw) of 0.2 dS/m, indicating a "pure water" infiltration problem. Applying gypsum broadcast to be dissolved by the irrigation water—would help improve water infiltration potentially reducing irrigation runoff. Applications are most effective during the part of the season when infiltration problems are more difficult.
>
> *Modifying the irrigation schedule.* Matching the crop use to irrigation applications can potentially reduce the applied volume and therefore the amount of runoff. Scheduling using this method applies to both border-check and pressurized irrigation systems; however, the application of the desired amount is much easier with pressurized systems.
>
> *Runoff water treatment*. Runoff waters containing residues of organophosphates can be treated with enzymes which rapidly degrade the material.

Now that we have evaluated the irrigation runoff risks, we go back to FC1 to evaluate the stormwater runoff risk.

THE STORMWATER RUNOFF RISK

Since in the case study the pesticide application in the spring, there is a risk that of rainfall will cause soluble residues or sediment to runoff to surface water sources. Sediments can contain adsorbed pesticides, most likely pyrethroids. Go to **FC4** "Reducing the Risk of Offsite Movement of Ag Chemicals in Stormwater Runoff."

Improving Water Infiltration

Managing Soil Organic Matter in Rotation Crops to Reduce Runoff

Soil organic matter helps stabilize soil aggregates by increasing the number of exchange sites in the soil matrix and encouraging microbial activity. Soil microbes that decompose soil organic matter produce polysaccharides and polyuronides, which act as binders to stabilize aggregates, thus improving porosity and water infiltration. Over time, continued cultivation and the use of herbicides reduces the organic matter content and aggregate stability of soils. These changes can reduce water infiltration and increase runoff potential.

It is difficult to increase and sustain soil organic matter under warm semiarid conditions that prevail in most of California, which favor rapid organic matter decomposition. Organic matter additions aimed at improving or sustaining aggregate stability and water infiltration must be incremental and continual to be effective. There are several ways for growers to achieve this:

Crop Residues

Alfalfa does have a fair amount of plant matter which makes its way to the soil surface however the residues of rotational crops offer a much greater opportunity to add significant amounts. Field crop residues, whether shredded or soil incorporated, can be left to decompose adding organic matter (and some nutrients) to the soil. Crop residue biomass in California's Central Valley ranged from 9,560 pounds per acre for corn following grain harvest to 570 pounds per acre for onions. Even within a specific crop biomass can vary. In tomato biomass varied due to harvest date but an intermediate value was 2880 pounds per acre. Wheat biomass after grain harvest was 4800 pounds per acre however after baling and removal only 670 pounds remained (Mitchell et al. 1999).

Manure and Other Organic Materials

With proper handing and management to avoid risk of crop contamination by human pathogens, animal manures or compost can help increase soil organic matter content and improve water infiltration. However, the application of manures is currently uncommon due to the limited availability of manures.

Chemical Amendments Used to Improve Water Infiltration

The addition of chemical amendments to water or soil can improve water infiltration by improving the chemical makeup of the water or soil. Most chemical amendments work by increasing the total salt concentration and/or decreasing the sodium adsorption ratio (SAR) of the soil-water. Both of these actions enhance aggregate stability and reduce soil crusting and pore blockage.

Calcium Materials

Adding calcium (Ca) salts to soil and water increases both the total salinity and soluble calcium. Calcium salts commonly used on alkali (high pH) soils include gypsum ($CaSO_4$), calcium chloride ($CaCl_2$), and calcium nitrate ($CaNO_3$). Gypsum is the most common calcium material applied when low salt (EC < 0.5) water are used. Surface applications are most effective when gypsum is applied at rates equivalent to 1 to 2 tons per acre during the time of the season when water infiltration an issue. On ton of spread gypsum has been to be effective in improving infiltration for up to 11 inches of low salt irrigation water.

Acids and Acid-Forming Materials

Commonly applied acid or acid-forming amendments include sulfuric acid (H_2SO_4) products, soil sulfur, ammonium polysulfide, and calcium polysulfide. The acid from these materials dissolves soil-lime to form a calcium salt (gypsum), which then dissolves in the irrigation water to provide exchangeable calcium. The acid materials react with soil-lime the instant they come in contact with the soil. The materials with elemental sulfur or sulfides must undergo microbial degradation in order to produce acid. This process may take months or years depending on the material and particle size (in the case of elemental sulfur). Since these materials form an acid via the soil reaction, they will reduce soil pH if applied at sufficiently high rates.

Runoff Capture, filtering, or Treatment

Sediment Basins

A sediment basin or trap is created by constructing an embankment, a basin emergency spillway, and a perforated pipe-riser release structure. The basin may be located at the bottom of a slope where drainage enters a swale or waterway. These basins can be designed by the Natural Resources Conservation Service (NRCS) or a civil engineer on a site-specific basis, and installed using proper construction and compaction for the berm, and correct sizing and construction for release structures and spillways. When runoff volumes are small as in spring storms, basins can be effective for reducing offsite movement of sediment containing adsorbed pesticide residues. If runoff is high enough to cause low retention times, sediment removal efficiency declines rapidly.

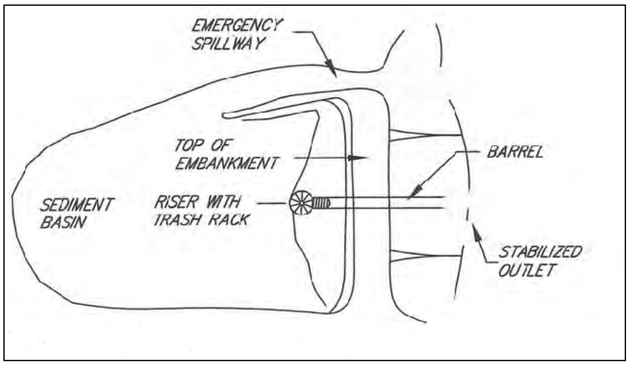

Diagram of a sediment basin with spillway and release structure

Vegetative Filter Strips

A vegetative filter strip (VFS) is any area of dense grass or other vegetation—natural or planted- between the field and a nearby waterway. Overseeding the tail ends of alfalfa checks (where the stand has declined) fits the VFS definition. Filter strips help capture and remove water-borne sediments before they reach the waterway. Perennial grass forages including orchardgrass and endophyte free fescues or red clover are good choices for alfalfa.

Vegetative filter strips function in three distinct layers—surface vegetation, root zone, and subsurface horizon (Grismer et al. 2006). As surface flow enters the VFS, water is infiltrated until the shallow surface and shallow subsurface is saturated. This infiltration phase is most important for reducing offsite movement of residues. The pesticide residues are trapped by soil constituents and organic matter, allowing pesticide degradation to occur. The remaining flow volume and velocity is decreased, reducing sediment transport. Sediment particles are trapped on the surface litter layer, which is high in organic matter. As the process continues, water continues to move through the subsurface horizon, further decreasing the volume of runoff.

Vegetated Drainage Ditches

A typical "V"-shaped ditch, 2-3 feet deep and 4 feet wide at the top can either be planted to vegetation (such as ryegrass and fescues) or the vegetation can be resident, such as rushes and bermudagrass. Vegetated ditches can help reduce chemical contaminants as does a VFS, by infiltration, direct adsorption of chemicals to plant surfaces, and promoting sedimentation of particle-bound contaminants. Residue removal efficiency is strongly influenced by runoff flow rate per unit ditch wetted area. Higher flow rates reduce the removal efficiency.

Runoff Treatment

Alfalfa runoff water can be chemically treated to reduce pesticide residues. This treatment can be done in a tailwater ditch, or in a holding basin. Landguard OP-A Enzyme® has been shown to be effective for treatment of most soluble organophosphate pesticides. Work is underway to develop enzymes to treat pyrethroid residues; however they are unavailable at this time.

Now that we have evaluated the stormwater risks, we go back to FC1 to evaluate the risk of applications near surface waters (drift).

THE APPLICATION NEAR SURFACE WATER SOURCES RISK

Our example field is located near a drainage ditch which contains water draining to a surface water source and therefore is significant risk; we consider ways of reducing **spray drift** that could enter the drainage ditch or creek near the example field. This leads us to **FC5** (Evaluating the Risk of Chemical Applications near Surface Waters) and the following drift management options:

Application Conditions

- Delay treatments near ditches and surface water bodies, until wind is blowing away from these and other sensitive areas.

Application Equipment

- Use as coarse a spray as possible (250 - 400 microns or larger) without sacrificing good canopy coverage. Droplet size is one of the most important factors affecting drift.
- Use low-drift nozzles that produce larger droplet sizes. Fitting a sprayer with air induction nozzles instead of standard nozzles will reduce spray drift up to 50 percent compared to standard nozzles.

Product Choice

- Use drift control/drift reduction spray additives agents. These materials are generally thickeners designed to minimize the formation of droplets smaller than 150 microns. They also help produce a more consistent spray pattern and aid in deposition.
- Treat buffer zones with materials that are least disruptive to aquatic life.

Buffer Zones

- Maintain adequate buffer areas or zones between the treated site and sensitive areas to ensure that pesticides don't drift from the target area. Read the label as to the size of buffer zone required as related to the rate of active ingredient.
-

Change Application Method

- Air application has a larger drift potential than ground application equipment. When drift risk is present, changing to ground application equipment requires a smaller buffer zone.

Controlling Offsite Movement of Agricultural Chemical Residues -- Tomatoes

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Prepared as a Component of:
California Department of Pesticide Regulation-- Pesticide Management Alliance Grant in Cooperation with the San Joaquin County and Delta Water Quality Coalition. 2010

Table of Contents

Controlling Offsite Movement of Agricultural Chemical Residues---Tomatoes

INTRODUCTION

WHAT'S IN THIS PUBLICATION?

The goal of this publication is to provide tomato growers with information on farming practices to help reduce the occurrence of organophosphate and synthetic pyrethroid pesticides in surface waters, which include streams, lakes, ponds, rivers, and drainage ditches. An assessment of the potential risk of offsite movement of an insecticide after a field application is performed using a flowchart for specific management practices and field conditions in tomato. This risk self-assessment focuses on issues that affect either the number of pesticide applications containing these active ingredients, or the offsite movement of pesticides as drift, attached to sediment, or in water that carries pesticide active ingredients.

If a significant risk is determined, a grower is able to consult the information in this manual about an array of science-based management practices to mitigate the risk that pesticides will leave the site of application and enter surface waters.

WHY IS THIS PUBLICATION NEEDED?

The Central Valley occupies about 40 percent of the land area in California and provides much of the State's agricultural production. Maintaining this productivity has required the use of about 132 million pounds of pesticides annually. Water quality in the Central Valley's rivers and streams has been impacted in part due to pesticide movement from agricultural lands into these waters. The list of impaired water bodies recently proposed for listing under the Clean Water Act Section 303(d) includes nearly a hundred water body segments in which impairment is due to agriculture. Agriculture is identified more often than any other source in the State as the likely cause of impairment.

Agricultural pesticides reach surface water bodies directly as spray drift or indirectly through irrigation or stormwater runoff from treated fields, vineyards, and orchards. Runoff waters may transport pesticides as dissolved or soil particle-adhering residues. Among the pollutants often attributable to agriculture is the organophosphate insecticide chlorpyrifos. California agriculture uses 1,425,000 pounds of chlorpyrifos annually, more than any other insecticide. Approximately half of the hundred 303(d) listed water body segments impaired due to agriculture in the Central Valley are impaired in whole or in part by chlorpyrifos. Total Maximum Daily Load is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards. The presence of chlorpyrifos in surface water and its toxicity to aquatic life has been responsible for multiple Total Maximum Daily Load (TMDL) projects in California, including one for the San Joaquin River, another for the Sacramento-San Joaquin Delta, and many other TMDLs elsewhere in the State where the process is less developed. In one study, chlorpyrifos was responsible for mortality to the test organism, *Ceriodaphnia dubia*, in seven of ten toxic samples (de Vlaming et al. 2004).

Synthetic pyrethroids are another group of pesticides emerging as a concern. Pyrethroids are a cause for 303(d) listing of about 10 percent of agriculture-impaired water bodies in California. In a study of toxicity of sediments collected from agricultural waterways, 54 out of 200 sediment samples caused acute toxicity to the test organism, *Hyalella azteca*, and pyrethroids were responsible for the toxicity in 61 percent of those cases (Weston et al. 2009). Chlorpyrifos was the second most common contributor to toxicity, responsible for toxicity in 20 percent of the samples. Recent data also indicate that pyrethroids are present at toxic levels in the water column of irrigation tailwater samples. In a study just completed, the pyrethroid lambda-cyhalothrin was responsible for toxicity to *H. azteca* in three out of six toxic samples collected at California agricultural pump stations where tailwater was being returned to nearby rivers. Chlorpyrifos was responsible for toxicity in the remaining three samples (Weston and Lydy 2010). As analyses of environmental samples for pyrethroids become more frequent, it is likely that the water quality effects of pyrethroids will be even more broadly recognized in future years.

The continued use of these effective agricultural pesticides is dependent on measures to prevent offsite movement of residues into surface waters. A listing of the active ingredients and trade names for pesticides used in tomato production can be found in Table 1. The table is restricted to those materials with reported use in California during 2008 with use over 500 pounds annually. Organophosphates and pyrethroids represent 43% of this list with dimethoate, an organophosphate, being the highest use product based on pounds applied per year.

Table 1. Tomato pesticides used in California in 2008 that are registered for use in 2011 (CDPR, California Department of Pesticide Regulation).

Active Ingredient/Common Name	Trade Name(s)	Lbs/Year	Chemical Class
dimethoate	Dimethoate	48,920	organophosphate
carbaryl	Sevin bait	31,468	carbamate
methoxyfenozide	Intrepid	17,620	diacylhydrazine
diazinon	Diazinon	16,847	organophosphate
bifenthrin	Fanfare and others	14,657	pyrethroid
imidacloprid	Various	14,315	neonicotinoid
Bacillus thuringiensis subsp. aizawai	Xentari, Agree	13,153	biological
methomyl	Lannate	12,288	carbamate
Bacillus thuringiensis subsp. kurstaki	Javelin, Dipel	12,070	biological
endosulfan	Thionex	8,274	organochlorine
oxamyl	Vydate	7,234	carbamate
indoxacarb	Avaunt	5,450	oxadiazine
malathion	Malathion	4,865	organophosphate
methamidophos	Monitor	3,393	organophosphate
esfenvalerate	Asana	3,364	pyrethroid

Active Ingredient/Common Name	Trade Name(s)	Lbs/Year	Chemical Class
thiamethoxam	Platinum	2,706	neonicotinoid
chlorantraniliprole	Coragen	2,467	anthranilic diamide
lambda-cyhalothrin	Warrior	1,724	pyrethroid
fenpropathrin	Danitol	1,621	pyrethroid
permethrin	Perm-up	1,149	pyrethroid
spinosad	Success, Entrust	1,052	spinosyn
cypermethrin	Mustang, Fury	989	pyrethroid
spinetoram	Radiant	865	spinosyn
dinotefuran	Venom	682	neonicotinoid
pyrethrins	Pyganic	655	pyrethrin
acetamiprid	Assail	597	neonicotinoid
cyfluthrin, beta-cyfluthrin	Baythroid	561	pyrethroid

CURRENT REGULATORY APPROACH TO SURFACE WATER PROTECTION

All growers farm under the requirement not to pollute surface and groundwater. Water leaving agricultural lands, as irrigation or stormwater runoff, can contain pesticide residues, sediment, or nutrients. These discharges are regulated by California's Central Valley Regional Water Quality Control Board (Water Board) under a program called the Irrigated Lands Regulatory Program. Essentially, the Board is enforcing the California Water Code of 1969 (CWC) and the Federal Clean Water Act of 1972. To this end the FC5, Reducing the Risk of Offsite Movement of Ag Chemicals from Drift to Open Water Board has:

- Established surface water quality standards in each watershed basin plan
- Enforced waste discharge requirements

THE AG WAIVER

In 1982 the Board adopted a resolution "*Waiving Waste Discharge Requirements for Specific Types of Discharge.*" The resolution contained 23 categories of waste discharges, including *irrigation return flows and stormwater runoff* from agricultural lands. The resolution also listed the conditions required to comply with the waiver, hence the term '**Conditional Ag Waiver**.' However, due to a shortage of resources at the time, the Water Board did not impose measures to verify compliance with these conditions.

The waiver, set to sunset in 2003, was amended by adopting two conditional waivers for discharges from irrigated lands. **One** was for *coalition groups* of individual dischargers that comply with the California Water Code and Water Board. **The other** was for growers to comply as individual entities. To be covered by the waivers, the coalition or individual must have filed with the Water Board by November 1, 2003 a Notice of Intent and General Report that contained specific information about their farm and then must have adhered to a plan and timeline that includes, among other things, a farm management plan and surface water monitoring plan.

WATER QUALITY COALITIONS

Water quality coalitions are generally formed by growers on a sub-watershed basis, although some are based on a specific commodity. The San Joaquin County and Delta Water Quality Coalition, for example, encompasses all of San Joaquin County and portions of Contra Costa and Calaveras Counties. The Coalition includes about 500,000 acres of irrigated lands and 4500 individual members. The Coalition monitors and analyzes the water quality of sub-watersheds in surface waters and facilitates the implementation of management plans. Coalitions provide outreach and support to growers in response to water quality exceedances at sub-watershed monitoring sites, in order to enhance the water quality of those water bodies affected.

Water Quality Monitoring

The Coalition currently monitors water quality at numerous sites in both large and small sub-watersheds within the coalition watershed. Water samples are collected monthly, and sediment samples are collected twice per year. During 2008, water quality standards were exceeded many times. At some locations, as many as 40 percent of the samples exceeded water quality standards for pesticide residues (Management Plan, San Joaquin County Delta Water Quality Coalition, Karkoski 2008). When more than one exceedance of water quality limits occurs for any contaminant, a management plan must be developed by the Coalition to address it. In addition, any single exceedance of either chlorpyrifos or diazinon triggers the requirement for a management plan.

Management Plans

The overall goal of water quality management plans, whether developed by individuals or coalition groups, is to reduce agricultural impacts on water quality in the plan area. Management plans evaluate the frequency and magnitude of exceedances and prioritizes locations for outreach.

To achieve the goal of improving water quality, a management plan must include:

- Source identification of constituents causing water quality impairments
- Outreach to growers about irrigation and dormant season management practices to protect water quality
- Evaluation of water quality improvements achieved by monitoring and implementation of management practices

Under the management plan landowners/growers must:

- Help the Coalition succeed by participating in efforts to solve water quality impairments identified through water monitoring
- Staying informed – read mailings and updates, respond as necessary
- Attending grower water-quality information meetings
- Implementing management practices that mitigate the identified water quality concerns

HOW TO USE THIS MANUAL

This manual is designed to be used in a two-step process. The first step is to make a "risk assessment" of field conditions or operations to identify those farming practices that may increase the risk of offsite pesticide movement. To aid in doing this, a series of "flowcharts" are presented. Once avenues of possible pesticide movement from a particular field are identified in the first flowchart, succeeding flowcharts help "zero in" on specific conditions and operations that can be used to reduce offsite movement. When followed systematically from beginning to end, the flowcharts will guide one through a stepwise evaluation of a farming operation to identify potential problem areas.

The second step is to understand and implement management practices to address the problem areas that were identified. These management practices, presented beginning on page 18 of this publication, are divided into three broad categories:

USE INTEGRATED PEST MANAGEMENT (IPM) APPROACHES, HANDLE, APPLY, AND STORE PESTICIDES CORRECTLY

Integrated Pest Management (IPM) is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used **only** after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Coupling use of IPM techniques with proper pesticide selection, handling, application, and storage can go a long way towards preventing offsite movement and protecting water quality.

These practices should be the foundation of any water quality protection program. Implementing at least some of them can also reduce risks to human health, beneficial and non-target organisms, and the environment.

USE SOIL AND WATER MANAGEMENT PRACTICES

Use soil and water management practices that reduce runoff potential. Runoff occurs when using surface (furrow) irrigation or when rainfall occurs faster than it can enter the soil. Runoff water can carry pesticides in the water itself or adsorbed to eroding soil particles. Proper irrigation method selection, design, and operation, coupled with water treatments that maximize water infiltration, help ensure that the water needs will be met and runoff kept at a minimum.

CAPTURE, FILTER, RECYCLE OR TREAT RUNOFF WATERS

When IPM and soil and water management do not adequately address a water quality problem, techniques for physically intercepting, recycling, or chemically treating runoff water can be used to reduce offsite transport of water pesticides in water.

QUICK OVERVIEW OF THE RISK EVALUATION PROCESS

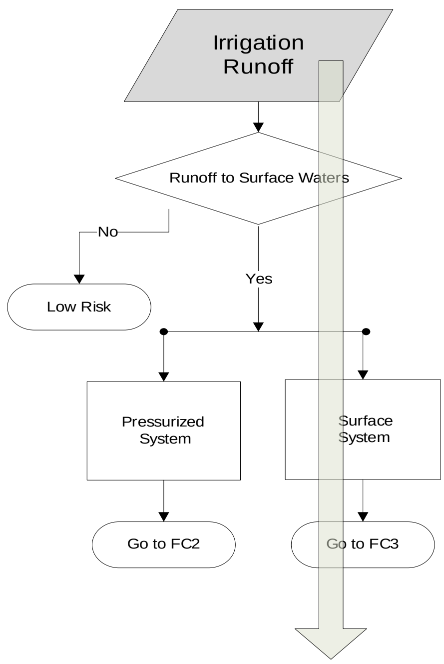
For a quick overview of the process, let's consider an example tomato field to illustrate how the flowcharts and management information in this manual could be used to identify and correct an offsite insecticide movement problem. We'll return to a more detailed discussion of this scenario in the case study presented in Appendix I located at the end of this manual. The opaque arrows in these flowcharts indicate the logical progression in considering the most cost effective management practices.

Crop: Tomato, 40 acres—conventional tomato production-
Site:

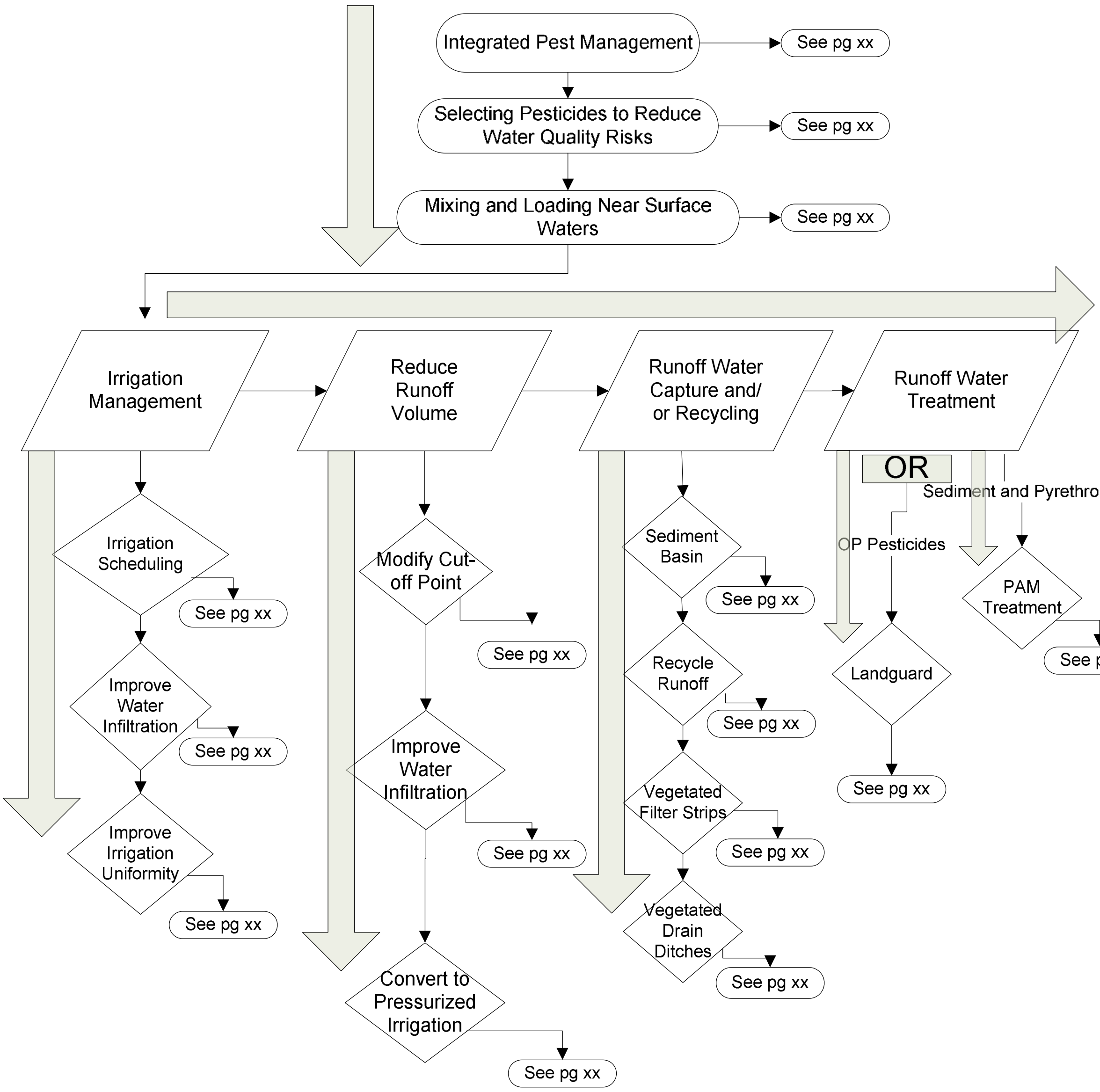
> ***Topography*****:** 0.15 percent slope
> ***Soil:*** Hollenbeck silty clay loam soil, soil tends to crust limiting the water infiltration rate.
> ***Irrigation Runoff:*** Runoff is about 17% of the applied water.
> ***Irrigation system*****:** furrow irrigation
> ***Irrigation water*****:** pH 7.5, EC 0.2 dS/m
> ***Drainage:*** Runoff moves to a drain at edge of field; then, on to a larger creek
> ***Pesticide mixing and loading:*** A pesticide mixing & loading area is located about 40 feet from the drainage ditch.
> ***Pest*****:** Potato aphid, 60% of leaves sampled from below the highest flower are infested on July 15, 9 weeks prior to harvest.

We begin the risk assessment with Flowchart number 1 (FC1), considering possible routes by which pesticide could move off the field and the operations or conditions that may contribute to the movement. The two possible areas of concern are:

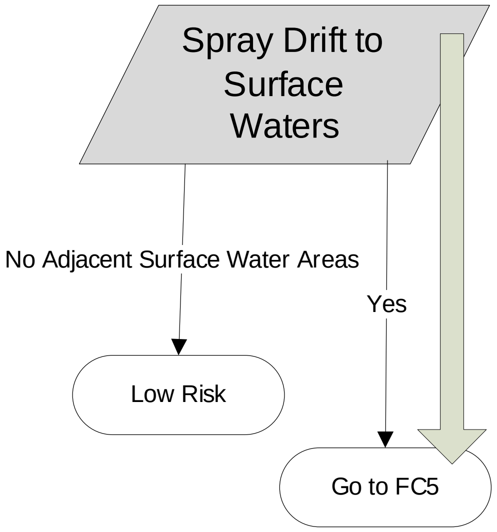
1) **FC1. Irrigation runoff risk.** Pesticides may be carried in the runoff that occurs during surface irrigation after the pesticide application. Go to FC3.



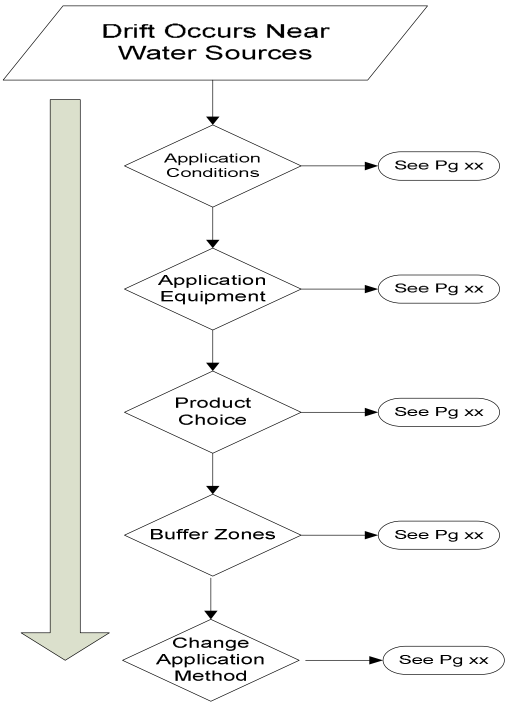
Flowchart 3 (FC3). Surface Irrigation Runoff Risk. This leads us first to an assessment of IPM practices, pesticide selection, mixing and loading practices and, in the management section, ways these can be improved. Following this, the flowchart leads us to consider the irrigation system—capturing or recycling runoff, modifying the irrigation system or soil characteristics to reduce runoff volume, irrigation scheduling, and, finally, ways that runoff water–if it still occurs, could be treated to reduce any pesticide residues it may contain.



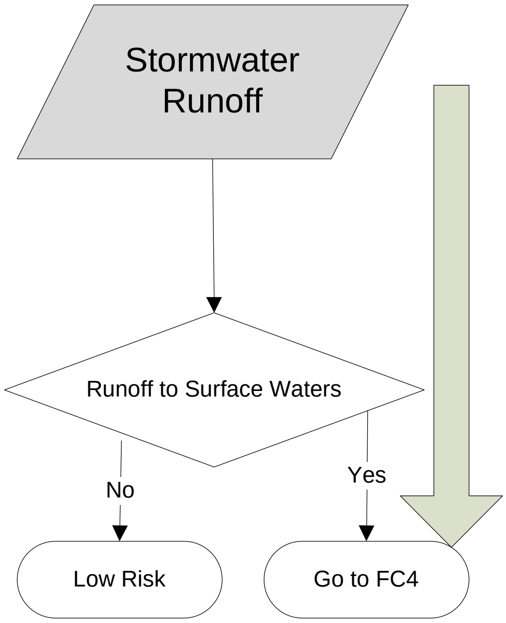
2) **FC1. Spray Drift to Open Water Risk.** During spray applications, pesticides may drift into the drainage ditch along the edge of the field; Go to FC5.



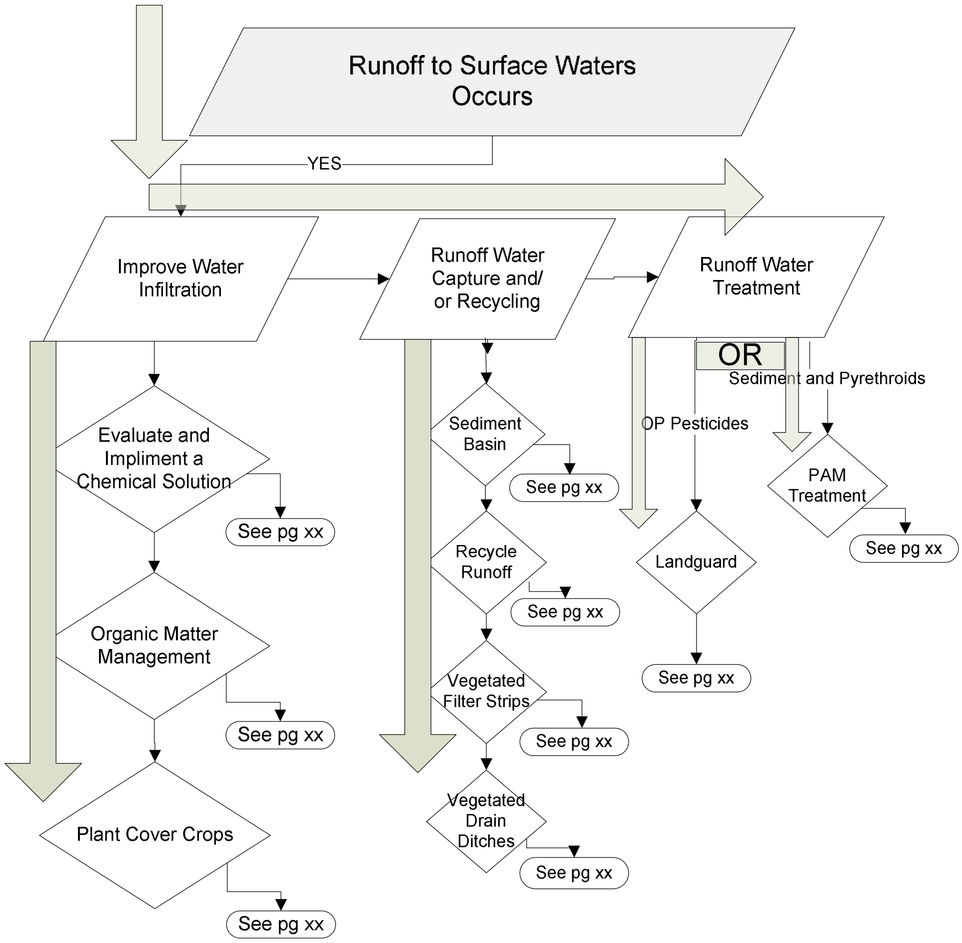
Flowchart 5 (FC5) Spray Drift to Open Water Risk presents various factors related to drift control. Each factor leads to a portion in the management information section of the manual where drift management practices are discussed.



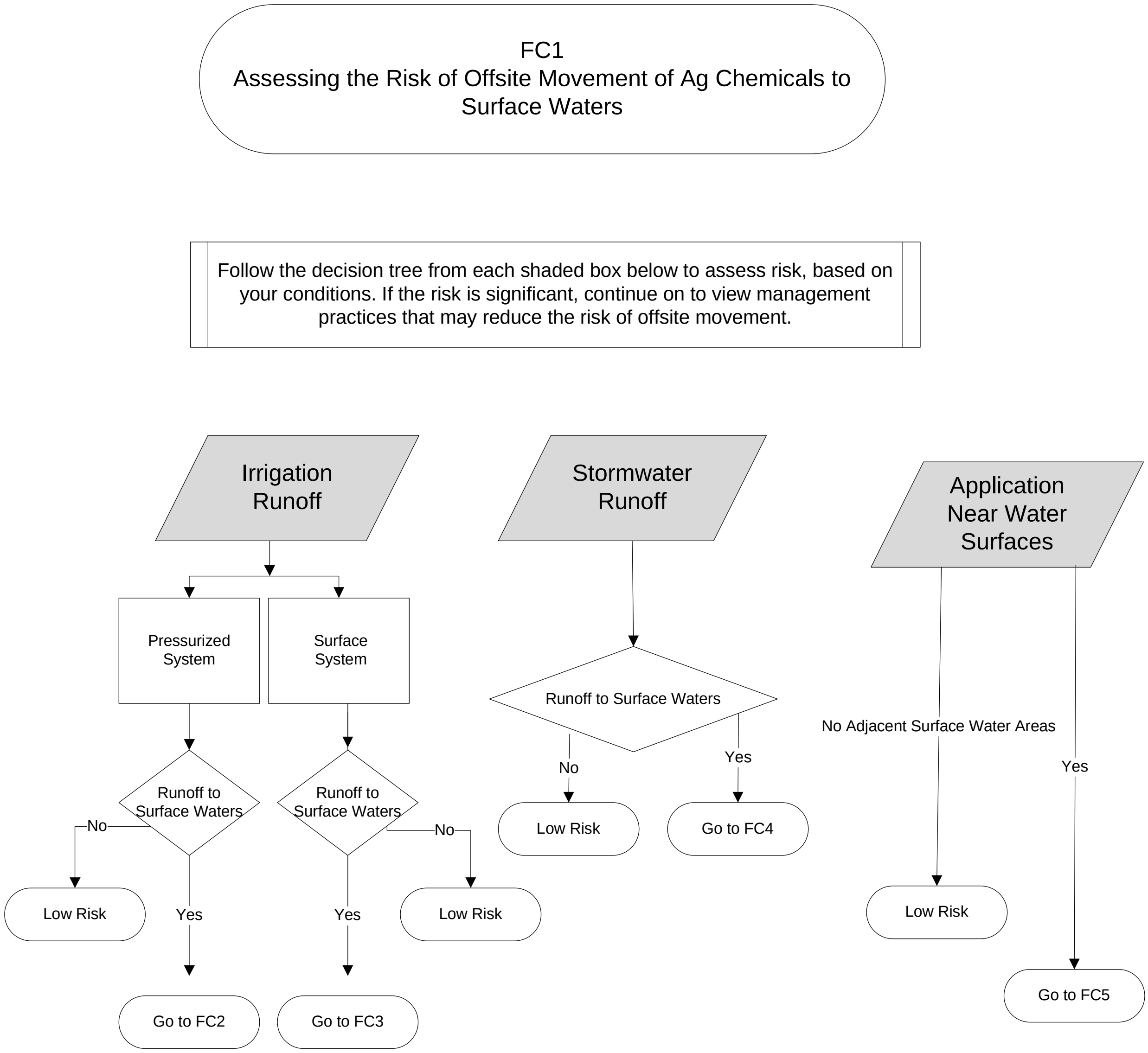
3) Beginning again at FC1. Stormwater Runoff Risk. Pesticides may be carried in the stormwater runoff as dissolved and sediment adsorbed residues. Since applications occur during the crop season the risk is generally low, however persistent insecticides can still contribute to surface water degradation during stormwater runoff; Go to FC4.

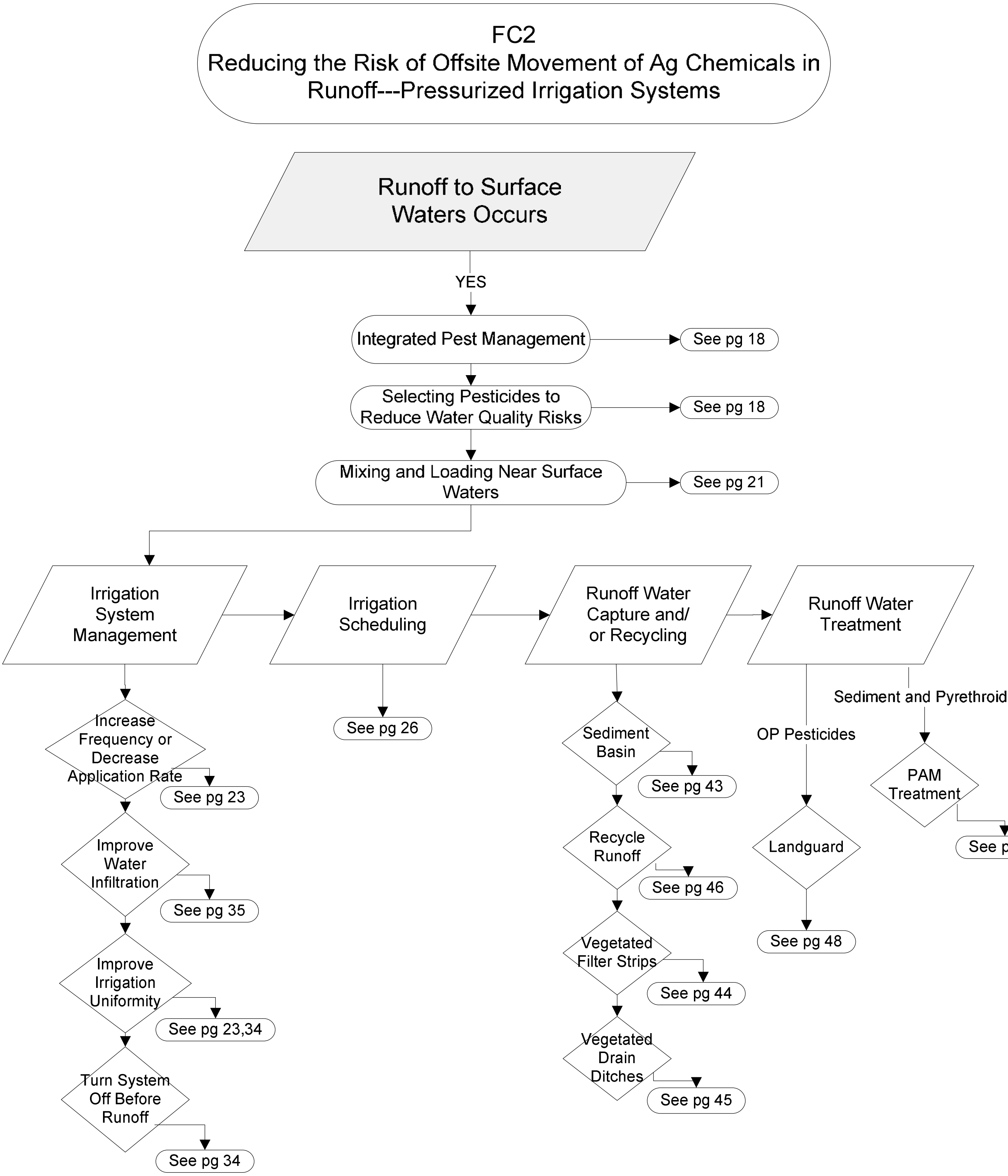


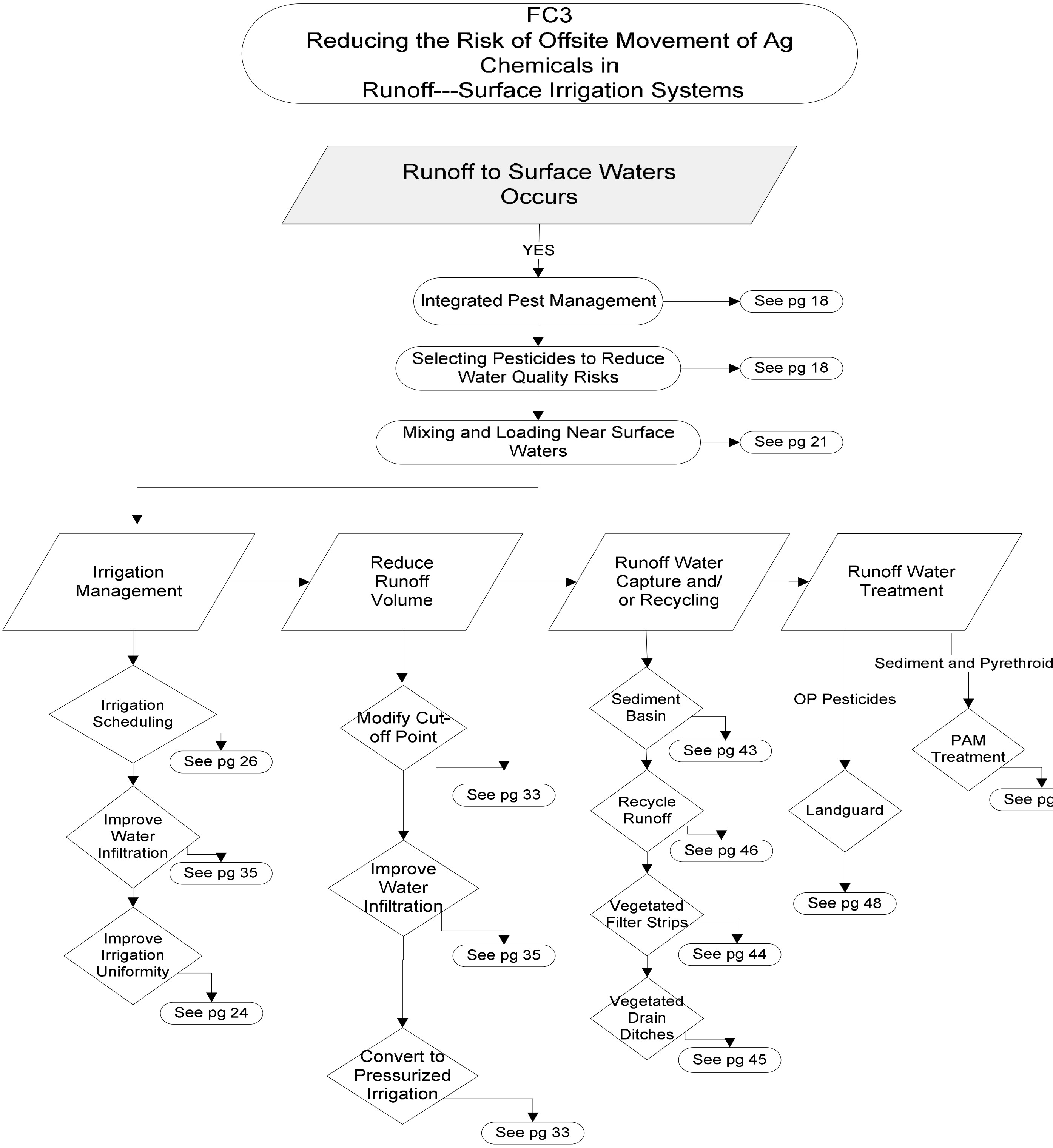
Flowchart 4 (FC4) Stormwater Runoff Risk presents various factors related to stormwater runoff risks. Each factor leads to a portion in the management information section of the manual where management practices are discussed to reduce pesticide residues in stormwater runoff.


Runoff to Surface Waters Occurs
YES
Improve Water Infiltration
Runoff Water Capture and/ or Recycling
Runoff Water Treatment
OR
Sediment and Pyrethroids
OP Pesticides
Evaluate and Impliment a Chemical Solution
See pg xx
Organic Matter Management
See pg xx
Plant Cover Crops
See pg xx
Sediment Basin
See pg xx
Recycle Runoff
See pg xx
Vegetated Filter Strips
See pg xx
Vegetated Drain Ditches
See pg xx
Landguard
See pg xx
PAM Treatment
See pg xx

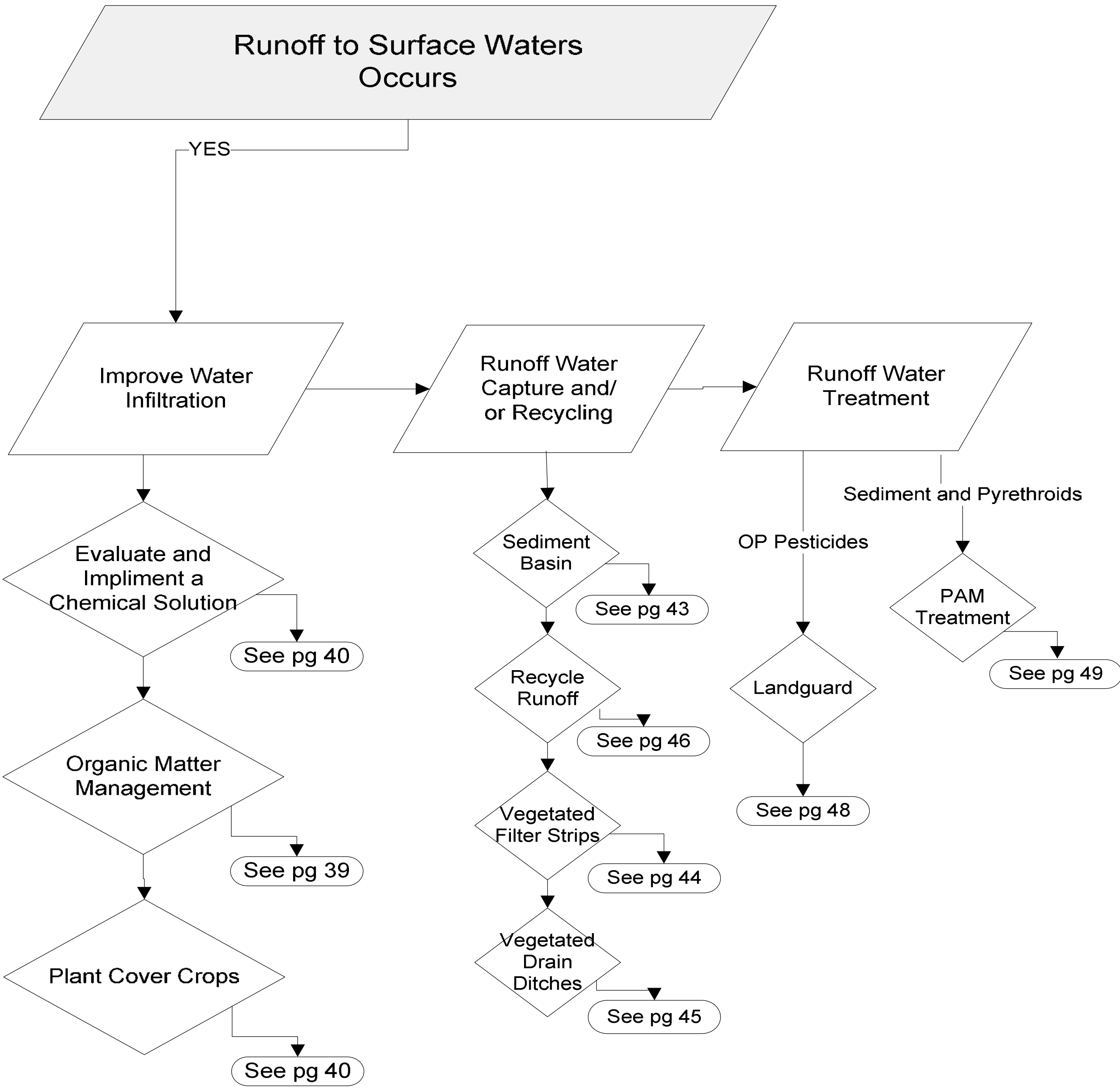
Risk Evaluation Flowcharts



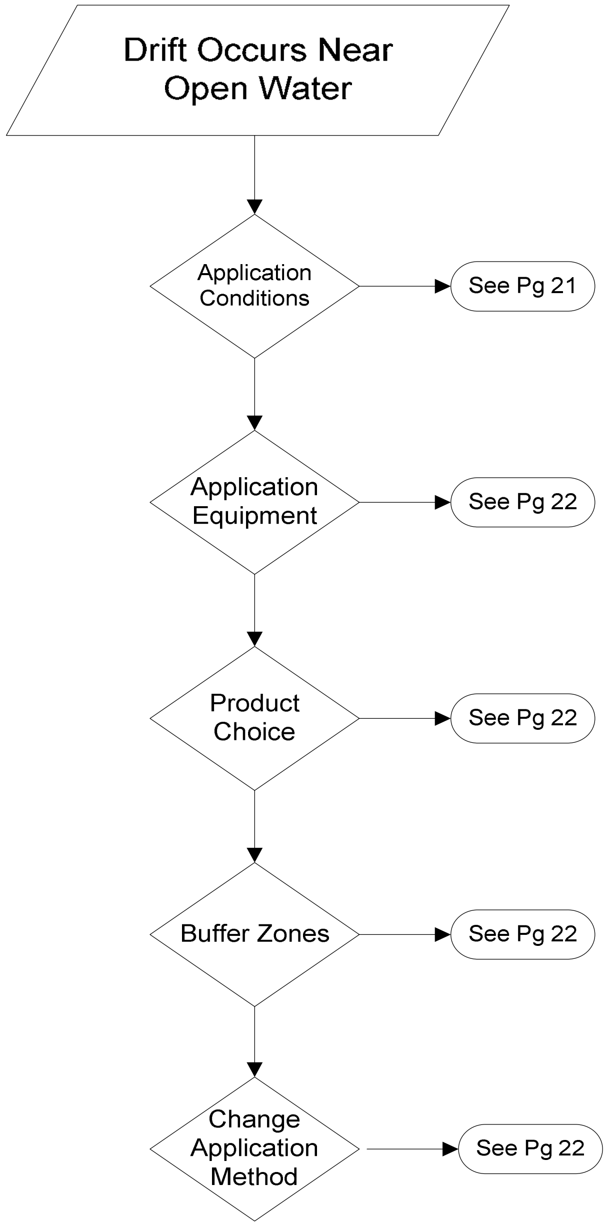

FC2
Reducing the Risk of Offsite Movement of Ag Chemicals in Runoff---Pressurized Irrigation Systems
Runoff to Surface Waters Occurs
YES
Integrated Pest Management
See pg 18
Selecting Pesticides to Reduce Water Quality Risks
See pg 18
Mixing and Loading Near Surface Waters
See pg 21
Irrigation System Management
Irrigation Scheduling
Runoff Water Capture and/ or Recycling
Runoff Water Treatment
Increase Frequency or Decrease Application Rate
See pg 23
Improve Water Infiltration
See pg 35
Improve Irrigation Uniformity
See pg 23,34
Turn System Off Before Runoff
See pg 34
See pg 26
Sediment Basin
See pg 43
Recycle Runoff
See pg 46
Vegetated Filter Strips
See pg 44
Vegetated Drain Ditches
See pg 45
OP Pesticides
Landguard
See pg 48
Sediment and Pyrethroid
PAM Treatment


FC3
Reducing the Risk of Offsite Movement of Ag Chemicals in
Runoff---Surface Irrigation Systems
Runoff to Surface Waters Occurs
YES
Integrated Pest Management
See pg 18
Selecting Pesticides to Reduce Water Quality Risks
See pg 18
Mixing and Loading Near Surface Waters
See pg 21
Irrigation Management
Reduce Runoff Volume
Runoff Water Capture and/ or Recycling
Runoff Water Treatment
Irrigation Scheduling
See pg 26
Improve Water Infiltration
See pg 35
Improve Irrigation Uniformity
See pg 24
Modify Cut-off Point
See pg 33
Improve Water Infiltration
See pg 35
Convert to Pressurized Irrigation
See pg 33
Sediment Basin
See pg 43
Recycle Runoff
See pg 46
Vegetated Filter Strips
See pg 44
Vegetated Drain Ditches
See pg 45
OP Pesticides
Landguard
See pg 48
Sediment and Pyrethroid
PAM Treatment
See pg

FC4
Reducing the Risk of Offsite Movement of Ag Chemicals in Runoff--Stormwater Runoff



FC5
Reducing the Risk of Offsite Movement of Ag Chemicals Near Water Surfaces in Drift Situations



MANAGEMENT PRACTICES TO REDUCE SURFACE WATER PESTICIDE CONTAMINATION

INTEGRATED PEST MANAGEMENT

The University of California Integrated Pest Management Programs defines IPM as:

> "…an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and non-target organisms, and the environment." http://ucipm.ucdavis.edu

IPM is a systematic approach to pest management. The decision process includes:

- select varieties that are well adapted to local conditions with a high degree of pest and disease resistance;
- proper pest identification;
- understanding pest life cycles and conditions conducive to infestation;
- monitoring for the presence, locations and abundance of pests and their natural enemies;
- treat when established action thresholds (economic, aesthetic, tolerance) are reached;
- consideration of multiple tactics for pest suppression – biological, cultural, and chemical—and selection of the lowest-risk practical and effective approach; and
- evaluate results.

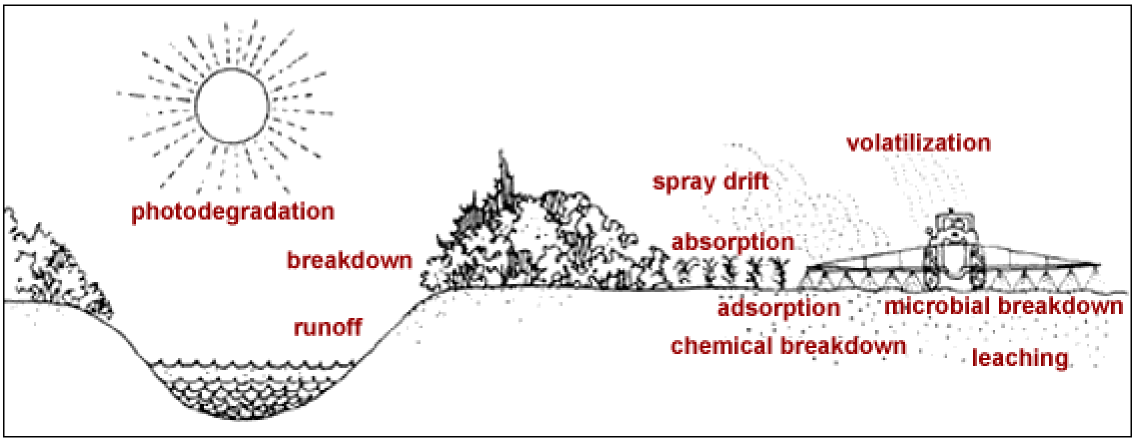
Because many print and on-line publications are available to help growers use IPM in their fields, they are not discussed in detail here. Pest and disease biology, monitoring, management, as well as water quality considerations in selecting and using pesticides, may be found in and from:

- The online UC IPM Pest Management Guidelines for tomatoes http://ipm.ucdavis.edu/PMG/selectnewpest.tomatoes.html
- The online UC IPM Year Round Program for tomatoes with annual checklist. http://ipm.ucdavis.edu/PMG/C783/m783yi01.html
- UC Integrated Pest Management for Tomatoes manual,
- Licensed Pest Control and Crop Advisors, and
- UC IPM Advisors and Farm Advisors.

SELECTING PESTICIDES TO REDUCE WATER QUALITY RISKS

Knowledge of how pesticides move and degrade in the environment is useful for product selection. Pesticides and pesticide residues can move along several different pathways, depending on properties of the pesticide, the application method, and conditions at the application site (Figure 1). This movement is a complex process and, combined with several other factors, influences a pesticide's fate and potential water quality impacts. From a surface water management perspective, keeping the pesticide on or in the soil by preventing runoff is the most desirable option.

Figure 1. Pesticide fate processes



Tomato pesticide active ingredients vary in water solubility, soil adsorption and half-life. Pesticides with high water solubility can move directly in runoff waters while those adsorbed to soil sediments move with the sediment. Half-life is an indication of the persistence in the environment, usually the number of days it takes for the chemical to degrade to one-half strength. USDA-NRCS has a model that determines a pesticide's tendency to move in dissolved form with water or move with adsorbed to the sediments.

Aquatic toxicity rankings were extracted from the US EPA ECOTOX database (http://cfpub.epa.gov/ecotox/). The toxicity for EPA indicator species was then used to rank the overall aquatic risk (Long et al. 2005). The potential to move offsite, either in solution or with the soil, was then categorized as high, intermediate, and low. The overall likelihood to cause negative impact (risk) on surface water quality is a product of the runoff potential and the aquatic toxicity of the pesticide. Table 2 indicates this relationship for commonly used insecticides in tomato production; products without a risk category listed here are new and/or not yet categorized in this system. The table can be used to select pesticides based on the risk of offsite movement to surface waters. A change in pesticide within a same class or to a different class can significantly reduce the environmental risk.

Table 2. California-registered tomato insecticides and their potential to move in solution or as adsorbed particles and overall pesticide runoff risk.

Insecticide active ingredient (common name)	Trade name	Chemical Class	Solution runoff potential[1]	Adsorption runoff potential[2]	Overall runoff risk[3]
acetamiprid	Assail	neonicotinoid			
azadirachtin	Neemix	not classified			
bifenthrin	Capture	pyrethroid	low	high	high
buprofezin	Courier	none (chitin biosynthesis inhibitor)			
carbaryl	Sevin	carbamate	intermediate	low	moderate
chlorantraniliprole	Coragen	diamide			
cyfluthrin	Baythroid	pyrethroid	low	intermediate	high
cypermethinr	Mustang	pyrethroid	low	high	high
diazinon	Diazinon	organophosphate	high	high	very high
dimethoate	Dimethoate	organophosphate	low	low	low
dinotefuran	Venom	neonicotinoid			
endosulfan	Thionex	organochlorine	high	high	very high
esfenvalerate	Asana	pyrethroid	low	high	high
fenpropathrin	Danitol	pyrethroid	low	intermediate	moderate
imidacloprid	Admire	neonicotinoid	high	intermediate	low
indoxacarb	Avaunt	not classified			
lambda-cyhalothrin	Warrior	pyrethroid	low	intermediate	high
malathion	Malathion	organophosphate	intermediate	low	moderate
methamidophos	Monitor	organophosphate	low	low	low
methomyl	Lannate	carbamte	intermediate	low	moderate
methyoxfenozoide	Intrepid	diacylhydrazine			
novaluron	Rimon	benzoylurea			
oxamyl	Vydate	carbamate	low	low	low
permethrin	Perm-Up	pyrethroid	low	high	high
pymetrozine	Fulfill	not classified (feeding blocker)			
pyrethrins	Pyganic	pyrethroid			
pyriproxyfen	Knack	pyridine			
spinetoram	Radiant	spinosyn			
spinosad	Success	spinosyn	intermediate	intermediate	low
spiromesifen	Oberon	keto-enol			
tebufenozide	Confirm	diacylhydrazine	high	intermediate	low
thiamethoxam	Platinum	neonicotinoid			

[1] Likelihood that the active ingredient will transport from the area of treatment as dissolved chemical in runoff.
[2] Likelihood that the active ingredient will transport from the area of treatment as attachment to soil or sediment particles in runoff.
[3] Overall likelihood to cause negative impact on surface water quality as a product of the runoff potential and the aquatic toxicity of the pesticide
Source: Pesticide Choice: Best Management Practice for Protecting Surface Water Quality in Agriculture, Long et al. 2005, UCANR Publication 8161, http://anrcatalog.ucdavis.edu/pdf/8161.pdf

HANDLING PESTICIDES TO REDUCE WATER QUALITY RISKS

The risk of offsite pesticide movement is great during mixing and loading due to the possible spillage of undiluted pesticides. Care should be taken to ensure all of the pesticide goes in the tank. Partially fill the tank with water prior to adding the pesticide to prevent high strength materials entering spray lines. Agitation and the use of a bypass can assist good mixing. Avoid over filling the tank, because spillage can move offsite aided by cleanup waters. Mix and load at a distance of greater than 50 feet from sensitive areas (open surface water)—more if there is a potential for movement in the direction of the sensitive area. Triple rinse pesticide containers and pour the rinsate into the sprayer tank for use on the field. Also apply tank rinse water to the field. The use of a concrete pad with a catchment sump is a good way to reduce risks from mixing and loading near surface water sources.

PESTICIDE APPLICATION PRACTICES TO REDUCE OFFSITE PESTICIDE MOVEMENT

Minimizing Spray Drift

Drift is the physical movement of pesticide droplets or particles through the air at the time of pesticide application or soon thereafter, from the target site to any non- or off-target site. All ground and aerial applications produce some drift. How much drift occurs depends on such factors as the formulation of the material applied, how the material is applied, the volume used, and prevailing weather conditions at the time of application, and the size of the application job. Drift can impact surface water quality through direct contact with open ditches or surface water adjacent to the treated field.

Spray drift can be mitigated by management practices to reduce off-target drift. Application practices that take weather and other site conditions into consideration, appropriately equipped delivery systems (low-drift nozzles), appropriate product choice (low vapor pressure, low water solubility), and the use of buffer zones can significantly reduce the risk of offsite movement of pesticides.

Application Conditions

- Don't apply pesticides under dead calm or windy/gusty conditions; don't apply at wind speeds greater than 10 mph, ideally not over 5 mph. Read the label for specific instructions.
- Apply pesticides early in the morning or late in the evening; the air is often more still than during the day.
- Determine wind direction and take it into account when deciding whether or not or how to make an application.
- Calibrate and adjust sprayers to accurately direct the spray into the canopy "target."
- Delay treatments near ditches and surface water bodies until wind is blowing away from these and other sensitive areas.
- Don't spray during thermal inversions, when air closest to the ground is warmer than the air above it.

Application Equipment

- Use as coarse a spray as possible (250 - 400 microns or larger) while still obtaining good coverage and control. Droplet size is one of the most important factors affecting drift.
- Use low drift nozzles that produce larger droplet sizes. Fitting a sprayer with air induction nozzles instead of standard nozzles will reduce spray drift up to 50 percent compared to standard nozzles.
- Use a directed spray on young plants to minimize the contact with soil in the furrow
- Check to verify the spray deposition pattern expected.
- Service and calibrate spray equipment regularly.
- Check the system for leaks. Small leaks under pressure can produce very fine droplets. Large leaks contaminate soil which can be moved offsite by water.
- Use low pressure and spray volumes appropriate for canopy size.

Product Choice

- Choose an application method and a formulation that are less likely to cause drift. After considering the drift potential of a product/formulation/application method, it may become necessary to use a different product to reduce the chance of drift.
- Use drift control/drift reduction spray additives/agents. These materials are generally thickeners designed to minimize the formation of droplets smaller than 150 microns. They also help produce a more consistent spray pattern and deposition.
- Use spray adjuvants, which can greatly reduce application volumes without compromising pesticide efficacy.
- Use maximum spray volume per acre and low pressure.
- Treat buffer zones with materials that are the least risk to aquatic life.

Buffer Zones

- Maintain adequate buffer zones around the treated site to ensure that pesticides don’t drift onto sensitive areas. Read the label to determine the size of buffer zone required as related to the rate of active ingredient.
- Wolf et al. (2003) documented 75 to 95 percent reductions in drift deposits up to 98 feet downwind when setback distances were vegetated with grass or shrubs.

Change Application Method

- Aerial application has a larger drift potential than ground application equipment. When drift risk is present, changing to ground application equipment requires a smaller buffer zone.

SOIL AND WATER MANAGEMENT TO REDUCE RUNOFF

Any reduction in runoff volume or decrease in the velocity of runoff flow can reduce the amount of both soluble and sediment-attached residues. Managing the irrigation to uniformly apply the correct amount of water to meet crop demand and by increasing water infiltration rates can minimize runoff rates and overall runoff volumes.

Irrigation Management

Irrigation management entails assessing the crops water needs and applying irrigation water to supplement stored winter moisture. Irrigation frequency and duration should ensure that all water infiltrates such that plant water use is met while preventing water loss through runoff and deep percolation. The extent of runoff depends on several factors, including: 1) the slope or grade of an area; 2) the texture and moisture content of the soil; 3) how well the soil surface supports water infiltration; 4) the amount and timing of irrigation or rainfall. Runoff containing pesticides can cause direct injury to non-target species, harm aquatic organisms in streams and ponds, and lead to groundwater contamination.

Tomato Irrigation Systems

Two basic types of irrigation systems are used in tomato production: surface systems (furrow) and pressurized systems (drip). Each has distinct cultural, cost, and offsite movement advantages and disadvantages. Some disadvantages can be overcome using specific management practices.

In *pressurized irrigation systems,* water should be applied at a slower rate than it is absorbed by the soil, to prevent runoff. However, as irrigation progresses the infiltration rate declines, making runoff more likely. In order to prevent runoff, the system should be turned off before significant runoff occurs. This is especially important in drip systems which are in the furrow bottom. When properly managed, pressurized irrigation systems cause no irrigation water runoff, effectively reducing the risk of pesticide residue moving offsite.

In *surface systems,* soil characteristics control the amount of water infiltrated and its distribution across the field as it travels down slope. Runoff is necessary to maximize distribution uniformity (how even the water is applied across the field) within the field. Limiting runoff after a reasonable uniformity has been achieved is a good practice to reduce the continued movement of residues offsite. Closed-end furrows used on relatively flat ground can also eliminate runoff. The successful use of this practice relies on a high infiltration rate and precise irrigation cutoff. Lastly, the irrigation system can capture runoff and return it to the irrigation inflow, to be applied to adjacent sets or another field. At sites with runoff risks, changing from surface gravity irrigation to pressurized irrigation is recommended when possible.

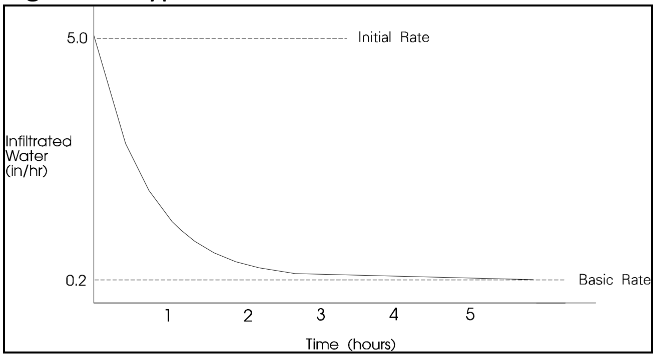
Tomato growers must determine the amount of irrigation water to apply, when to apply it, and the **most efficient** method of irrigation for a given set of conditions. That avoids problems associated with over- or under-irrigating.

Surface Irrigation Systems

Surface irrigation systems (furrow irrigation), while being the simplest irrigation systems with regard to hardware, are the most difficult ones to manage properly. Control of runoff water is essential for controlling offsite movement of pesticides, sediments, and nutrients.

With furrow irrigation, water is applied to the soil surface and gravity moves the water across the field. Soil characteristics control both the rate at which water enters the soil and its distribution across the irrigated area. As irrigation begins, the rate at which water enters the soil is high, primarily because of soil dryness and easy access to the soil pores. As irrigation proceeds, the infiltration rate declines rapidly to a basic or sustained rate. Figure 2 shows the typical relationship between the amount of water infiltrated into the soil and hours of irrigation.

Figure 2. Typical water infiltration characteristics.



A soil's water intake characteristics depend on both its physical and chemical composition as well as the chemical composition of the water. Irrigation water containing very low salt content or higher sodium and/or bicarbonate levels can reduce infiltration rates. For more information, see the section: “Reducing Runoff by Improving Water Infiltration.”

In general, the objective of any irrigation system is to have water infiltrating for the same length of time in all parts of the field. This is difficult to accomplish with furrow systems because it takes time for water to flow, starting from the head of field, down the furrow to the end of the field (called “advance time”) resulting in less time for infiltration. This shorter time that water is in contact with the soil means less water is infiltrated.

For furrow irrigation, the head of the field irrigation run almost always has more water applied to it than the tail of the run. The exception is if water is allowed to pond at the end of the row. The part of the field which gets the least water applied to it is frequently at approximately 2/3 to 3/4 of the distance down the row. Often, water onflow rate to the furrow is increased to get water down the row more quickly and improve irrigation uniformity. Unfortunately, this practice will increase runoff volume.

In general, it is advantageous to keep furrows as short as practical, which keeps irrigation uniformity high. The tradeoffs with short furrows are increased labor and pipeline costs and increased runoff volumes. Tailwater return systems can be used with furrow irrigation systems to increase their efficiency and eliminate discharges.

One difficulty with managing surface irrigation systems is measuring the water going onto the field. If water supplies are from a pump, a flow meter such as a propeller meter can be installed in the outlet pipe. Following the manufacturer's recommended installation criteria is important for accurate measurements. If water supplies are from an open ditch, etc., water measurement is difficult. Consulting the irrigation district may help in getting a good estimate of the flow rate to the field.

The following formula may be used to determine the average amount of water applied to a field using a meter that indicated cubic feet per second (cfs).

$$D = Q \times T / A$$

Where D = depth of applied water (inches), Q = flow rate into the field (cubic feet per second), T = time required to irrigate the field (hours), and A = acres irrigated

Note: If the flow meter reads in gallons per minute (gpm) rather than in cubic feet per second (cfs), the conversion is as follows:

1cfs = 449 gpm

An example:

Flow = 4 cfs
Irrigation on time = 8 hours
Area = 6 acres

$$\frac{4.45\text{cfs} \times 8.6\text{ hours}}{8\text{ acres}} = 4.8\text{ inches}$$

Depth of water applied in the above formula should match the amount of water used by the crop since the last irrigation and is roughly equivalent to evapotranspiration (ET) (see section: “Irrigation Scheduling to Meet Crop Requirements). Remember that some additional water should be applied because no irrigation system is 100 percent efficient. The efficiencies of furrow-irrigated fields are generally lower than with pressurized irrigation systems.

Measuring distribution of infiltrated water under surface systems is difficult at best. The overall goal is to provide near equal opportunity time along the length of the furrow.

Pressurized Irrigation Systems

Pressurized irrigation systems include both sprinkler and drip systems. Pressurized systems share the common trait of “designed in” uniformity that overcomes many of the disadvantages of furrow irrigation. Drip irrigation systems are both buried in the bed and “laid on the surface” types—usually in the furrow. Runoff is more likely using the furrow types; however, good management can minimize or eliminate runoff by reducing irrigation duration, blocking the furrow ends, of capturing runoff in a holding pond or sediment basin.

Irrigation Scheduling to Meet Crop Water Requirements

Crop water use or evapotranspiration (ET) is the sum of plant water use (transpiration) and evaporation from the soil surface. Climate factors affecting the crop evapotranspiration include solar radiation, temperature, wind, and humidity. Plant factors affecting evapotranspiration include plant type, stage of growth, and health of the plant and soil moisture. Seasonal ET of tomato varies by location in California from 24-27 inches for the Central Valley.

Water use begins at a low level after planting in spring when climatic conditions are mild; it increases as the canopy develops and the climatic demand increases, maximizing at around 70 to 80 days after emergence. Water use declines after this period, through leaf senescence and reduced climatic demand.

Estimating water requirements

The best way to determine crop water use is using climatic data and a specific crop’s characteristics. Tomato ET can be estimated using the following formula:

$$ETc = ETo \times Kc$$

Where ETc is the crop water use, ETo is the reference evapotranspiration for a given area, and

Kc is a crop coefficient.

The reference ET information is available from a network of nearly 100 California weather stations that provide daily reference evapotranspiration values. This information is made available to growers by the CIMIS Program in the California Department of Water Resources at http://www.cimis.water.ca.gov/cimis. Some newspapers and irrigation districts also provide CIMIS ETo data. The CIMIS program provides real time, current values. Historical or long-term average ETo can be more convenient than real-time ETo information and can be used to prepare an irrigation plan well ahead of the irrigation season. Table 3 lists historical daily values for ETo for selected Central Valley locations.

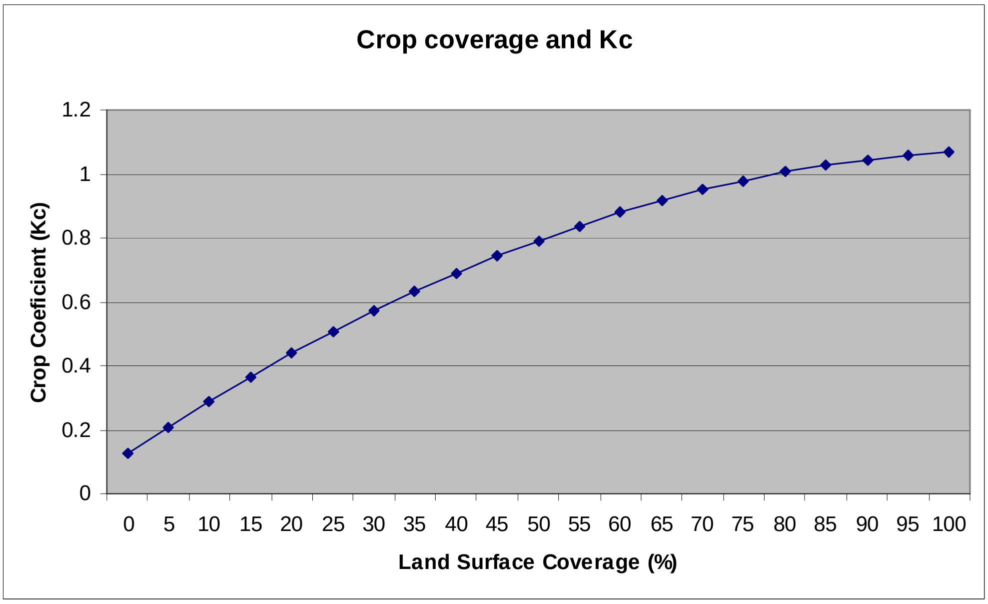
Table 3. Historical crop evapotranspiration reference (inches/day)
for various California Central Valley locations

		Five Points	Manteca	Davis	Durham
Jan	1-15	0.04	0.04	0.03	0.03
	16-31	0.05	0.05	0.05	0.05
Feb	1-15	0.06	0.07	0.06	0.06
	16-28	0.09	0.09	0.09	0.09
Mar	1-15	0.11	0.11	0.09	0.09
	16-31	0.15	0.14	0.14	0.12
Apr	1-15	0.20	0.17	0.18	0.16
	16-30	0.22	0.19	0.28	0.17
May	1-15	0.23	0.22	0.23	0.21
	16-31	0.27	0.23	0.24	0.22
Jun	1-15	0.29	0.26	0.28	0.25
	16-30	0.30	0.27	0.29	0.26
Jul	1-15	0.30	0.27	0.29	0.27
	16-31	0.28	0.25	0.27	0.25
Aug	1-15	0.28	0.24	0.26	0.24
	16-31	0.25	0.22	0.24	0.21
Sep	1-15	0.23	0.19	0.21	0.19
	16-30	0.20	0.16	0.18	0.16
Oct	1-15	0.17	0.13	0.16	0.14
	16-31	0.13	0.10	0.12	0.10
Nov	1-15	0.10	0.07	0.09	0.07
	16-30	0.07	0.05	0.06	0.05
Dec	1-15	0.05	0.04	0.05	0.04
	16-31	0.03	0.04	0.04	0.03

Crop coefficients for tomatoes have been experimentally determined and may be calculated based on canopy coverage. Figure 4 indicated how the Kc changes as canopy cover increases. At full canopy, the ETc would be 110% of ETo. Figure 5 shows a tomato field with a canopy coverage measured at 62%. Using historical ETo averages for the Manteca CIMIS station (# 70) in combination with the crop coefficient (via the canopy coverage), the weekly crop water use can be determined (Table 4). Historical ETo daily and summed values are available for the

Manteca (#70) CIMIS stations based on the past 20 years of data:
http://cesanjoaquin.ucdavis.edu/Custom_Program/Publications_Available_for_Download.htm

Figure 4. The relationship between crop coverage and crop coefficient.



Hanson et al. 2008

Figure 5. Tomato field with canopy coverage measured at 62 percent.

Table 4. Weekly tomato water use.
April 1 planting, Manteca (CIMIS Station # 70) historical ETo

Begin Date	Period	End Date	Canopy % Coverage	Crop Coefficient Kc	ETo Inches	ETc Inches
4/1	to	4/7	0	0.1	1.13	0.14
4/8	to	4/14	2	0.2	1.25	0.20
4/15	to	4/21	3	0.2	1.22	0.22
4/22	to	4/28	4	0.2	1.38	0.27
4/29	to	5/5	5	0.2	1.53	0.32
5/6	to	5/12	8	0.3	1.53	0.40
5/13	to	5/19	15	0.4	1.51	0.55
5/20	to	5/26	28	0.5	1.65	0.90
5/27	to	6/2	43	0.7	1.63	1.18
6/3	to	6/9	59	0.9	1.72	1.50
6/10	to	6/16	74	1.0	1.86	1.81
6/17	to	6/23	86	1.0	1.89	1.94
6/24	to	6/30	96	1.1	1.82	1.94
7/1	to	7/7	100	1.1	1.93	2.06
7/8	to	7/14	100	1.1	1.88	2.01
7/15	to	7/21	100	1.1	1.78	1.91
7/22	to	7/28	100	1.1	1.73	1.85
7/29	to	8/4	100	1.1	1.73	1.85
8/5	to	8/11	100	1.1	1.70	1.82
8/12	to	8/18	100	1.1	1.64	1.75
				Seasonal Demand		24.62

If rainfall occurs that increases the soil water content (called effective rainfall) during these periods, it must be subtracted from the ETc, effectively reducing the irrigation requirement. Most feel that, for rainfall to be effective, it must occur in a quantity that exceeds the daily ETo by a factor of three. As an example, a rainstorm on April 25 would have to be 0.6 inch to exceed the 0.2-inch ETo average for that date. The method used to approximate the effective in-season rainfall in this case is: (inches of rainfall -0.6 = inches of effective rainfall).

Irrigation Frequency with Furrow Irrigation

With drip irrigation, the general guidelines are to deplete no more than 20 to 30% of available soil moisture in the active root zone (allowable depletion of 0.2 to 0.3 inches in a sandy loam, 0.3 to 0.6 inches in loam and 0.4 to 0.6 inches in a clay loam). While irrigation frequency with drip irrigation can vary from once a week early in the season to daily in light textured soils at full canopy, typical frequency is every other day at full canopy.

Determining Irrigation Amount.

Once the crop water requirement has been determined, the irrigator must account for losses such as evaporation, runoff, or deep percolation and the lack of irrigation uniformity. These losses depend on both the irrigation system type and management. Furrow irrigation can have substantial runoff losses and has larger variability in infiltration than pressurized systems. This variability in infiltration requires additional water be applied to achieve a minimum amount of water to all parts of the field. Sprinkler irrigation systems have greater application uniformity, less deep percolative losses and little if any runoff when compared to furrow irrigation systems. Drip systems have the advantages of sprinkler systems and additionally have less evaporative losses. To account for these differences between systems, we use a term application efficiency to adjust the applied irrigation water amount to meet the water requirement.

To account for differences between irrigation systems, we use the term irrigation efficiency to adjust the applied irrigation water amount to meet the water requirement of the crop. Irrigation efficiency is the amount of water stored in the root zone and beneficially used by the crop divided by the amount of water applied. To adjust the application amount for system efficiency, divide the amount to be applied by the system application efficiency factor (Table 5).

Furrow irrigation. For example, to supply a needed 3.6 inches of water to a furrow irrigated field would require 3.6 ÷ 0.75 = 4.8 inches of water would need to be applied. This amount considers that the runoff is recycled using a tailwater recovery system. If such a system is not available reduce surface irrigation systems by 15%.

Drip irrigation. For example, to supply a needed 2.0 inches of water to a drip-irrigated field would require that 2 ÷ 0.90 = 2.2 inches of water be applied.

Table 5. Estimated application efficiency (percent)of irrigation systems (Hanson 1995)

System Type	**Estimated Efficiency**
Surface Irrigation	70-85*
Sprinkler	70-80
Microirrigation	80-90

**Efficiency reflects the use of a tailwater capture and return system. If not available reduce by 15%*

<u>*Determine Irrigation On-Time (duration)*</u>

The irrigation application time for a surface irrigation system is determined by simply dividing the amount of water applied by the land area it is applied to. For example the duration of irrigation can be calculated by:

$$T= (A \times D) / Q$$

Where T = time required to irrigate the field (hours), A = acres irrigated, D = depth of applied water (inches), and Q = flow rate into the field (cfs). 1cfs = 449 gallons per minute

Furrow irrigation. Using our example of 4.8 inches and a 40-acre field with a 2000 gallon per minute supply the on time would be:

$$T= (40 \times 4.8) / 4.45 = 43 \text{ hrs}$$

If an 8 acre set were irrigated:

$$T= (8 \times 4.8) / 4.45 = 8.6 \text{ hrs}$$

Once the irrigation amount and timing of irrigation is determined to meet the crop water use, the application can be problematic and site-specific. When using surface irrigation on high infiltration soils, it may be difficult to apply the relatively small amount of water (3.6 inches in our example) due to the large amount of water required to move water down the furrow and the time to advance the water to the end of the field. Excess infiltrated water would percolate below the rootzone. The selection of appropriate onflow volumes and cutoff times discussed below can minimize over application of water.

Sprinkler and drip irrigation. To determine the irrigation time for hand-move sprinklers:

$$T = D / AR$$

Where = T = time of irrigation (hours), D = depth of water (inches), and AR = application rate (inches/hour).

Using our example of 2.2 inches and a 0.052 inch per hour application rate the on time would be:

$$T = 2.2 / 0.052 = 42 \text{ hrs}$$

Deficit Irrigation of Processing Tomatoes

Once fruit set is complete (roughly the time that the earliest fruits are reaching the mature green stage, typically 5-6 weeks preharvest), a substantial level of moisture stress can be imposed with minimal loss of productivity. (Note that even moderate levels of soil moisture deficit during fruit set can substantially reduce that set, and induce blossom end rot). Deficit irrigation after the fruit set period may result in a yield decline of a few tons per acre; but an increase in soluble solids concentration usually results in little or no decline in brix yield (Hanson et al. 2008). The degree of deficit irrigation possible without loss of brix yield depends on a number of factors, primarily soil water holding capacity and the presence or absence of a shallow water table. Most fields can tolerate irrigation of only 40-60% of ET^o during the fruit ripening period with minimal problem; fields with high water holding capacity and good rooting depth may be able to deal with as little as 25% of ET_o over the final 6 weeks.

The ability to precisely control irrigation during the fruit ripening period depends on the irrigation system used. For drip fields, controlling deficit irrigation is easy; simply reduce the hours of run to deliver the desired % of ET_o. Within the last 10-14 days before scheduled harvest drip irrigation can be terminated in most fields without severe stress. During deficit irrigation, root intrusion in buried drip systems can be a problem, so be vigilant. If harvest is delayed, small irrigations can be made to keep the vines up.

With furrow irrigation, it is more difficult to precisely control irrigation volume, and consequently the primary tool for late season water management has been manipulating the irrigation cutoff date, thereby saving one or more irrigations. Extensive trials in clay loam soils in Fresno County have shown that cutting off furrow irrigation as much as 40 days preharvest will have minimal effect on brix yield (although, as previously stated, fruit yield may suffer a small decline). Even on these forgiving soils, however, earlier cutoff can lead to substantial yield loss. In fields with soil of lower water holding capacity even 40 days preharvest can be too severe a treatment. Using an early cutoff strategy can be risky, particularly if harvest is substantially delayed.

In fields with a water table within 2-3 feet of the surface, deficit irrigation can result in the crop drawing as much as several inches of water from the water table, allowing for a more severe irrigation cutback or earlier cutoff than would otherwise be appropriate for the field. If the water table is non-saline, late-season deficit irrigation poses little risk of serious yield decline. However, if the water table is saline, a much larger yield loss is possible with an aggressive irrigation cutback; also, deficit irrigation at the end of the season will leave the root zone with high EC, thereby increasing next year's water requirement.

Check Up on the Calculations and Applications

The climate-based method described above for determining crop water needs gives an estimate of demand which should be verified and fine-tuned by soil based monitoring of actual soil water status.

There are many soil moisture-monitoring devices which measure soil moisture content and soil tension (Schwankl and Prichard 2009). If decreasing soil water occurs over the season or an increase in soil water tension is evident, too little irrigation was applied. If soil water content increases or tension is reduced progressively after each irrigation, too much applied water is indicated.

Managing Irrigation Systems to Reduce Runoff

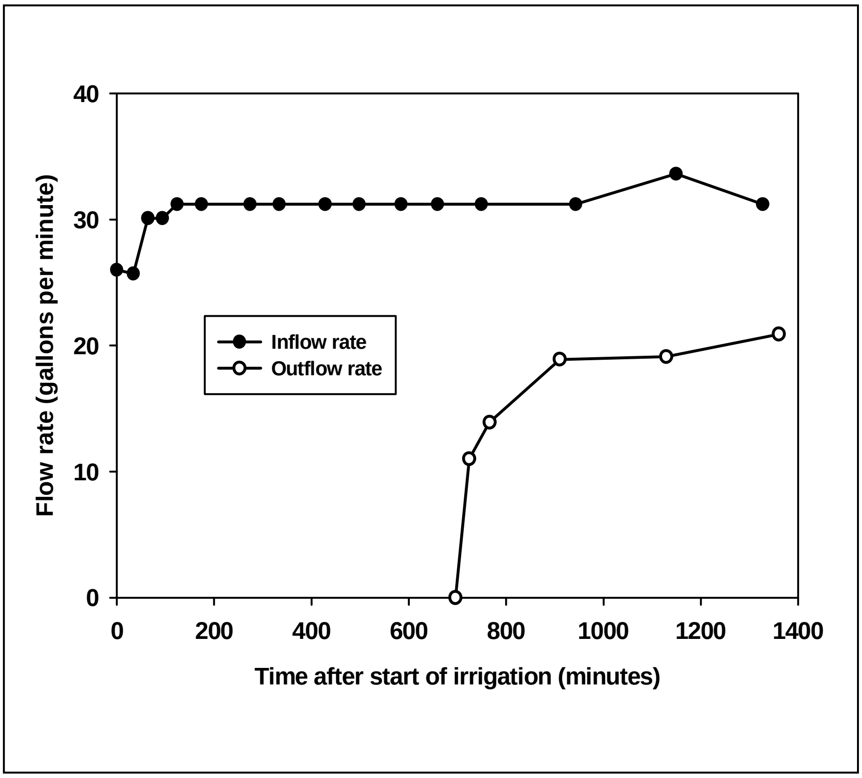
As a general rule, the depth of water applied in the above formula should match the amount of water used by the crop since the last irrigation and is roughly equivalent to evapotranspiration (ET) (see section: "Irrigation Scheduling to Meet Crop Requirements). Remember that some additional water should be applied because no irrigation system is 100 percent efficient. The efficiencies of furrow irrigated fields are lower than those of pressurized irrigation systems.

Surface Irrigation Systems.

Irrigation runoff that enters surface waters can carry both dissolved and sediment-adsorbed pesticide residues. Soluble residue concentrations in runoff waters are fairly consistent for the entire runoff period. Therefore any reduction in the total runoff volume will reduce the amount of residues. The degree to which soils erode during irrigation will depend on a number of factors, with soil aggregate stability – the ability of soil particles to cling together and resist the forces of flowing water—being the most important. Aggregate stability can be enhanced by chemical and physical amendments and management practices discussed in the section: "Reducing Runoff by Improving Water Infiltration." Soil erosion rates will depend on the soil conditions, including the amount, size, and density of loose particles on the soil surface. For example, erosion increases after cultivation. The degree of soil erosion depends on the velocity of the water and the duration of runoff. Therefore, reducing the peak volume and duration of runoff will reduce sediment loss.

The cutoff time is the time that an irrigation set is ended and no more water is applied to the furrow. Decreasing the cutoff time of the irrigation water (shortening the amount of time a field is irrigated) can reduce the amount of surface runoff from furrow-irrigated fields. The cutoff time for a given field depends on the time needed to infiltrate sufficient water along the lower part of the field. It may need to be determined on a trial-and-error basis. In cracking clay soils, infiltration times of only two to three hours may be adequate because water flow into the cracks results in a very high initial infiltration rate. After the cracks close, infiltration rates become very small. Thus, in cracked soils the cutoff time should occur about two to three hours after water reaches the end of the field (Hanson and Schwankl 1995). Figure 3 illustrates inflow and outflow rates in a field using furrow irrigation. Note the 700 minutes of water advancing to field end (before runoff begins) and the nearly equal time the irrigation is allowed to continue in order to have equal intake opportunity time at the tail end of the field. The result is significant – about 2/3 of the inflow water running off for 500 minutes. A shorter cutoff time would have reduced runoff volume but may also slightly reduce the distribution uniformity across the field.

Figure 3. Furrow irrigation inflow and outflow rates over the term of irrigation.



Source: Hanson and Schwankl 1995

Blocking furrows by making small dams in the length of the furrow using soil, or plastic dams can increase infiltration and help uniformity. This practice of monitoring each furrow during irrigation is labor intensive can reduce runoff volumes.

Converting to pressurized irrigation can reduce runoff. This option significantly reduces the chance of runoff, but requires a significant investment. See section: “Pressurized Irrigation Systems.”

Capturing and recycling runoff by using a tailwater collection system can mitigate runoff and therefore offsite residue problems, and make irrigation more efficient. For more information see section: “Tailwater Runoff Collection and Recycling.”

Pressurized irrigation systems include full coverage sprinkler and buried or surface drip systems. Sprinkler systems are used for early season irrigation; however, they rarely used for season long irrigation. Drip systems allow small amounts of water to be applied slowly and frequently through emitters spaced along polyethylene tubing. When properly designed and operated these systems apply water uniformly to a relatively small volume of soil.

Unlike surface gravity irrigation systems or full coverage sprinklers where soil water is recharged on an infrequent basis and then drawn down by plant use, drip irrigation, by virtue of frequent applications, can be operated to replace water used by the crop. The process occurs on a time scale of days.

Pressurized Irrigation Systems.

Pressurized systems should be operated to meet the crop’s water requirement while eliminating any surface runoff. Uniformity is designed into pressurized irrigation systems, with management left to ensure not only efficiency but the elimination of runoff losses by turning off the system before runoff occurs. When using in-furrow surface drip irrigation in fields with some slope, a small amount of runoff tends to accumulate, potentially causing offsite movement. Unfortunately, most of these highly engineered irrigation systems are not managed to their full potential because they need constant monitoring and maintenance. Problems such as clogged emitters decrease uniformity, leading to under application in some areas and over application in others.

REDUCING RUNOFF BY IMPROVING WATER INFILTRATION

Poor water infiltration can increase runoff from irrigation or winter rains. Irrigation runoff is typically associated with surface irrigation, but can occur with pressurized systems on soils with poor infiltration or sloping land.

The first step in determining how to mitigate a water infiltration problem is to understand the soil and water factors that influence it.

At the onset of irrigation, water infiltrates at a high rate. Initially the soil is dry and may have cracks through which water can infiltrate rapidly. After the soil near the surface wets for a few hours, these factors become less important in sustaining infiltration rates. The clay particles swell, closing cracks and limiting access to soil pores and decreasing infiltration rates. As the wetting process continues, the salinity and salt composition of the soil-water (water contained between soil particles) begins to more closely reflect that of the irrigation water, which is generally less saline. This reduction in soil water salinity retards water infiltration.

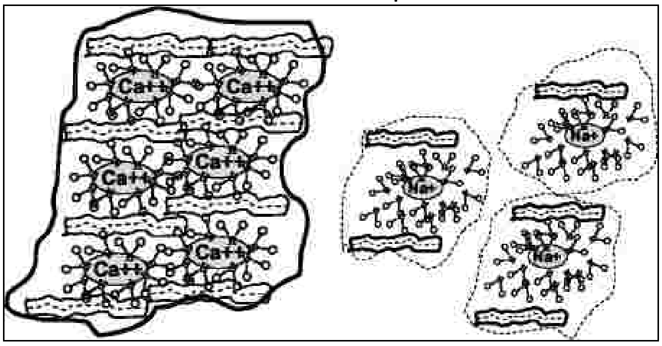
Water infiltration can only be improved by increasing soil total pore volume and/or individual pore size, and providing easy access to surface pores. Physical soil disruption practices and chemical and organic amendments are all attempts to influence one or more of these factors.

Soil Structure and its Impact on Water Infiltration

Pores are the spaces between mineral and organic particles in soils through which water and air move. Soils with a predominance of sands (larger spherical particles) tend to have larger pores, while clay-dominated soils (clays are plate-like particles) tend to be smaller. With some exceptions, soils with larger pores generally have higher infiltration rates. Water usually moves more slowly through small-pored soils because the smaller pores provide more surface area for water to adhere to. On the other hand, clay soils which form cracks as the soil dries and shrinks can help increase water infiltration.

Individual soil particles can clump together, forming larger structures called aggregates. The small pores between particles remain, and larger pores formed between the aggregates significantly enhance water infiltration and gas exchange (Figure 6). Soil water salinity and individual mineral constituents as well as organic matter content play a significant role in stabilizing soil aggregates and increasing pore size.

Figure 6. Conceptual illustration of soil aggregate stability: forming stable aggregates with plentiful calcium on clay exchange sites (left), compared to weak soil aggregates due to low salinity and/or excessive sodium in the soil pore water.



Soil Crusting

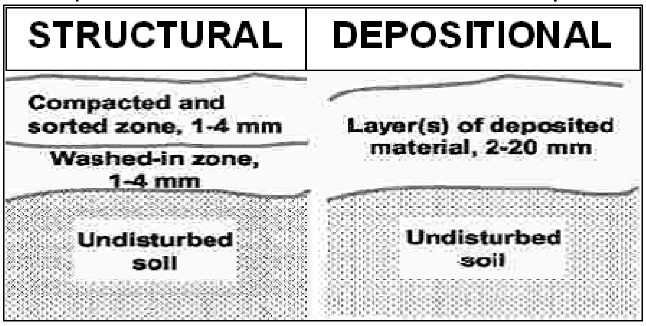
Soil crusts or surface seals reduce infiltration by impeding water access to soil pores beneath the crust layer. Crusts form at the soil surface when the soil aggregates become dispersed, causing a loss of porosity at the soil surface. Weak cementation of the crust often follows when the soil dries, slowing water penetration during succeeding irrigations.

Soil surface crusts can be divided into either structural crusts or depositional crusts, as defined below.

> Structural crusts form when surface soil aggregates are destroyed by the impact of rain or sprinkler droplets. The mechanical breakdown of soil aggregates tends to sort soil particles, leaving a film of finer particles on top (sealing layer) that blocks the entry of water into the larger intact pores beneath. Another type of structural crust forms under furrow irrigation, through a process is called “slaking.” As the soil is wetted, a combination of mechanical and chemical dispersion of soil aggregates occurs, causing the structure to collapse. Upon drying the crust becomes hard.
>
> Depositional crusts form when small (usually clay- and silt-sized) soil particles, suspended and transported in flowing water, settle out of suspension and form a thin low-porosity surface layer. In agricultural settings, this type of soil crust is most often the result of high-velocity water in the head end of the furrow or check eroding fine particles that settle out when the water slows.

Both structural and depositional crusts are thin, characterized by higher density, greater strength and smaller pores than the underlying soil. These crusts are usually less than one tenth of an inch thick but often limit infiltration for the entire root zone (Figure 7).

Figure 7. Conceptual illustration of structural and depositional crusts.



In fine-textured silty soils, soil crusts are often the result of sodic conditions caused by excess exchangeable sodium in the soil or irrigation water, and/or too little total salinity. In coarse- to medium-textured, nonsaline and nonsodic soils, continued cultivation can reduce pore size and number to the point where water infiltration is affected. This problem can be made worse where very low salinity irrigation water is used, such as from irrigation districts on the east side of the San Joaquin Valley. Additionally, wells that contain high bicarbonates and relatively low calcium levels encourage crusting.

Irrigation Water Quality

Irrigation water quality influences water infiltration rates through affecting whether soil particles tend to absorb water, stay together, or become separated by swelling. Swelling of soil particles causes aggregate breakdown and soil particle dispersion, resulting in surface crust formation.

Salinity

The higher the salinity of the irrigation water, the more likely the aggregates will remain stable, preserving infiltration rates. Salinity is measured by determining the electrical conductivity (EC) of the irrigation water (ECw) or soil water extracted from a saturated soil paste (ECe).

Sodicity

The index for sodicity is the sodium adsorption ratio (SAR), which depends on the relative amounts of sodium, calcium, and magnesium content of the irrigation water. SAR of a soil sample can also be used to estimate exchangeable sodium levels in the soil. With increasing levels of exchangeable sodium, the affinity of soil particles for water increases and aggregate stability decreases reducing water infiltration rates.

Combined Effect of Salinity and Sodicity

Since both salinity and sodicity of the irrigation water effect aggregate stability and water infiltration rate, both must be assessed when diagnosing an infiltration problem. In the top three inches of soil, salinity and sodicity of the irrigation water and soil are closely linked. Consequently both surface soil samples and water samples are necessary to diagnose the problem and evaluate the success of mediation practices. In general, aggregate stability increases as EC increases and the SAR decreases (Table 6). As a general guideline, the SAR should be less than 5 times the EC (Figure 8). The exception is low salt waters with EC values of less than 0.5 dS/m. They are corrosive and deplete surface soils of readily soluble minerals and all soluble salts. They often have a strong tendency to dissolve all sources of calcium rapidly from surface soils. The soils then break down, disperse, and seal, resulting in poor water infiltration.

The EC and SAR-based guidelines discussed above may not necessarily work for all California soils. Some soils contain a large amount of serpentine clays rich in magnesium (Mg) and low in calcium (Ca). In these soils, Mg may have the same soil-dispersing effect as sodium. Soils with a predominance of montmorillonite and illite clays are also easily dispersed by excess magnesium. Although the diagnostic criteria for such conditions have not been extensively tested, some studies suggest that when the Mg to Ca ratio of these soils exceeds 1:1, they may be prone to water infiltration problems. Some reports report that high soil potassium levels can also promote aggregate dispersion and soil crusting.

Table 6. Potential for a water infiltration problem

SAR*	Problem Likely ECe[1] or ECw[2] dS/m	Problem Unlikely ECe or ECw dS/m
0.0 – 3.0	< 0.3	> 0.7
3.1 – 6.0	< 0.4	> 1.0
6.1 – 12.0	< 0.5	> 2.0

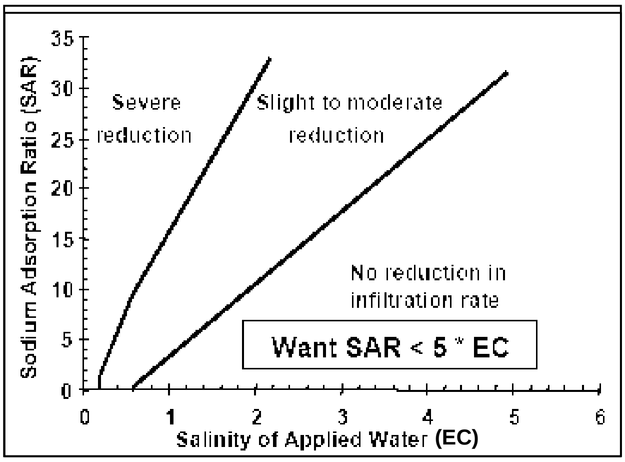
Source: Ayers and Westcot (1985).

* Sodium Adsorption Ratio.

[1] Electrical conductivity of extract indicates that soil is saturated paste soil salinity.

[2] Electrical conductivity of water indicates irrigation water salinity.

Figure 8. Interaction of total salinity as EC with the sodium adsorption ratio of applied water for causing potential infiltration problems. (Ayers and Westcott, 1985)



High carbonate (CO_3^-) and bicarbonate (HCO_3^-) levels in water increase the sodium hazard of the water to a level greater than that indicated by the SAR. In alkaline soils, high CO_3^- and HCO_3^- tend to precipitate calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) when the soil solution concentrates during soil drying. The concentrations of calcium and magnesium in soil solution are reduced relative to sodium, and the SAR of the soil solution tends to increase.

An adjusted SAR value may be calculated for water high in carbonate and bicarbonate if the soil being irrigated contains free lime (calcareous soil). The adjusted SAR and knowledge of soil properties help determine management practices when using high bicarbonate water.

Mitigating Water Infiltration Difficulties

Solving an infiltration problem by modifying irrigation practices – as discussed in other sections of this manual – should always be the starting point and will generally be less costly than the soil and water modifying treatments discussed below. Water infiltration problems not amenable to improvement by optimizing irrigation system design and operation may be mitigated by improved soil organic matter management, or use of chemical amendments as discussed later in this manual.

Tillage

Shallow tillage can be used to disrupt both structural and depositional crusts. Where crusting problems reduce infiltration rates, a single tillage can restore infiltration rates. However, after the crop has spread into the furrows tillage is not an option. Shallow tillage using a sweep or a rolling cultivator can effectively break up the surface crust. Shallow tillage to incorporate the pesticide after application can reduce the residues available for offsite movement.

Managing Soil Organic Matter to Reduce Runoff

Soil organic matter helps stabilize soil aggregates by increasing the number of exchange sites in the soil matrix and encouraging microbial activity. Soil microbes that decompose soil organic matter produce polysaccharides and polyuronides, which act as binders to stabilize aggregates, thus improving porosity and water infiltration. Over time, continued cultivation and the use of herbicides reduces the organic matter content and aggregate stability of soils. These changes can reduce water infiltration and increase runoff potential.

It is difficult to increase and sustain soil organic matter under warm semiarid conditions that prevail in most of California, which favor rapid organic matter decomposition. Organic matter additions aimed at improving or sustaining aggregate stability and water infiltration must be incremental and continual to be effective. There are several ways for growers to achieve this as follows.

Crop Residues

After harvest remains of field crops shredded or soil incorporated, can be left to decompose adding organic matter (and some nutrients) to the soil. Crop residue biomass in California's Central Valley ranged from 9,560 pounds per acre for corn following grain harvest to 570 pounds per acre for onions. Even within a specific crop biomass can vary. In tomato, biomass varied due to harvest date but an intermediate value was 2880 pounds per acre. Wheat biomass, after grain harvest, was 4800 pounds per acre; however after baling and removal, only 670 pounds remained (Mitchell et al. 1999).

Manure and Other Organic Materials

With proper handing and management to avoid risk of crop contamination by human pathogens, animal manures or compost can help increase soil organic matter content and improve water infiltration. However, the application of manures is currently uncommon due to the limited availability of manures.

Cover Crops

Cover crops can help protect the soil surface from droplet impact under winter rainfall and provide significant organic matter biomass for decomposition and microbial stabilization of soil aggregates. In addition, cover crop residue can slow the velocity of surface water, reducing erosion and subsequent depositional crusting. A winter cover crop of triticale was planted to bed tops in a tomato field in early November and chemically controlled at about an eight-inch height in mid February. The result was a 40% reduction in stormwater runoff volume and a 70% reduction in runoff turbidity in contrast to a no cover condition (Miyao et al. , 2004). Less expensive options include using barley or oats.

Chemical Amendments Used to Improve Water Infiltration

The addition of chemical amendments to water or soil can improve water infiltration by improving the chemical makeup of the water or soil. Most chemical amendments work by increasing the total salt concentration and/or decreasing the sodium adsorption ratio (SAR) of the soil-water. Both of these actions enhance aggregate stability and reduce soil crusting and pore blockage.

Four types of materials are used to ameliorate water infiltration problems: salts, as fertilizers; calcium materials; acids or acid-forming materials; and soil conditioners, including polymers and surfactants.

Salts

Any fertilizer salt or amendment that contains salts, when applied to the soil surface or dissolved in irrigation water, increases the salinity of the irrigation water and ultimately influences the soil-water. Whether increased salinity is advantageous depends on the SAR of the irrigation water. The largest effect of a salt addition is with very low salinity (less than 0.5 EC) irrigation water. Increasing salinity above an EC of 4 dS/m has little effect on infiltration.

Calcium Materials

Adding calcium (Ca) salts to soil and water increases both the total salinity and soluble calcium. Calcium salts commonly used on alkali (high pH) soils include gypsum ($CaSO_4$), calcium chloride ($CaCl_2$), and calcium nitrate ($CaNO_3$). These are fairly soluble and can easily be applied though the irrigation water. Care should be taken if waters contain more than 2 meq/L of bicarbonate (HCO_3). Adding gypsum to such waters through a drip system significantly increases the chances of plugging the system with lime precipitate. In these cases, an acid application may provide a better solution. Lime and dolomite are used only for broadcast applications on acid soil, as they are virtually insoluble under alkali conditions.

Gypsum Injection Rates for Water

Amendment rates from 1.0 to 3.0 meq/L calcium in the irrigation water are considered low to moderate; rates that supply 3.0 to 6.0 meq/L calcium are considered moderate to high. The following example calculations show the reader how to estimate the quantity of gypsum required to improve infiltration. Table 7 lists the amount of gypsum and other products needed to increase the calcium (Ca) content of irrigation water by 1 meq/L per acre-foot. Applying 234 pounds of 100 percent pure gypsum per acre-foot of water equals 1 meq/L of Ca.

It is rarely necessary to inject gypsum constantly. Injection every other or every third irrigation may be all that is necessary to end the season with the required amount. The benefits of gypsum injection during the season in drip irrigation systems are usually superior to those of fallow season applications.

Table 7. Amounts of amendments required for calcareous soils
to increase the calcium content in the irrigation water by 1 meq/L.

Chemical Name	Trade Name and Composition	Pounds/Ac-ft of Water to Get 1 meq/L Free Ca*
Sulfur	100% S	43.6
Gypsum	$CaSO_4 \cdot 2H_2O$ 100%	234
Calcium polysulfide	Lime-sulfur 23.3% S	191
Calcium chloride	Electro-Cal 13% calcium	418
Potassium thiosulfate	KTS -- 25% K_2O, 26% S	256
Ammonium thiosulfate	Thio-sul 12% N, 26% S	110** 336***
Ammonium polysulfide	Nitro-sul 20% N, 40% S	69** 136***
Monocarbamide dihydrogen sulfate/ sulfuric acid	N-phuric, US-10 10% N, 18% S	148** 242***
Sulfuric Acid	100% H_2SO_4	133

* Salts bound to the soil are replaced on an equal ionic charge basis and not equal weight basis.

** Combined acidification potential from S and oxidation of N source to NO_3 to release free Ca from soil lime. Requires moist, biologically active soil.

*** Acidification potential from oxidation of N source to NO_3 only.

Gypsum Rates Broadcast to Soils

An alternative to water treatment is broadcasting amendments such as gypsum on the soil surface. The primary advantage of this approach is that it is often less expensive than water treatments. However, surface applications are most effective when gypsum is applied at rates equivalent to 1 to 2 tons per acre during the time of year when the infiltration problem is noticed. When applied in the non-crop season, higher rates are used.

Acids and Acid-Forming Materials

Commonly applied acid or acid-forming amendments include sulfuric acid (H_2SO_4) products, soil sulfur, ammonium polysulfide, and calcium polysulfide. The acid from these materials dissolves soil-lime to form a calcium salt (gypsum), which then dissolves in the irrigation water to provide exchangeable calcium. The acid materials react with soil-lime the instant they come in contact with the soil. The materials with elemental sulfur or sulfides must undergo microbial degradation in order to produce acid. This process may take months or years depending on the material and particle size (in the case of elemental sulfur). Since these materials form an acid via the soil reaction, they will reduce soil pH if applied at sufficiently high rates.

Acids are applied to water for two different purposes in relation to water infiltration problems. The first is to dissolve soil lime (the soil must contain lime if acids are used), increasing free calcium in the soil/water matrix and improving infiltration. The second is to prevent lime clogging in drip systems when adding gypsum to waters containing greater than 2 meq/L bicarbonate.

Table 7 indicates that it takes 133 lbs/ac-ft of 100 percent pure sulfuric acid to release 1 meq/L Ca. This assumes the acid contacts lime ($CaCO_3$) in the soil, neutralizing the carbonate molecule and releasing Ca. This is the same amount of acid required to neutralize 1 meq/L of HCO_3 in the water. If the water contains bicarbonate the acid will neutralize it, converting it to carbon dioxide which is released to the atmosphere. Acid applications must exceed the bicarbonate level of the water before the pH of the water decreases to dissolve lime in the soil.

Soil Conditioners

There are two types of amendments in this category, organic polymers and surfactants. Other amendments include synthetic and natural soil enzymes and microbial soups. Although there is a long history of soil conditioner development and testing, not enough data exists on the materials to conclude that they are uniformly effective. For an in-depth analysis of water infiltration problems and solutions see: "Water Penetration Problems in California Soils: Diagnosis and Solutions," Singer et al. 1992.

Organic Polymers

Organic polymers, mainly water-soluble polyacrylamides (PAM) and polysaccharides, are used to stabilize aggregates at the soil surface. These extremely long-chain molecules wrap around and through soil particles to bind aggregates together. This action helps resist the disruptive forces of droplet impact and decrease soil erosion and sediment load in furrow irrigation systems. They can improve infiltration into soils with illite and kaolinitic clays common in the northwest United States, but USDA researchers have found that infiltration is not improved in soils with the mostly montmorillinite clays typical of the San Joaquin Valley.

Water-soluble PAM is not to be confused with the crystal-like, cross-linked PAMs that expand when exposed to water, and does not influence water infiltration. Cross-linked PAMs enhance the water-holding capacity of soils for small-scale applications, for example in container nurseries.

Organic polymers can have different effects on infiltration. The effect depends on polymer properties—such as molecular weight, structure, and electrical charge—and salinity of the irrigation water. There are charged (ionic) and non-charged (nonionic) polymers that can behave differently depending on whether they are added to very pure water (surface waters where EC is 0.03 to 0.1 dS/m) or higher-salinity well waters (above 0.8 dS/m).

Polymers have been shown to work best when sprayed on the soil surface at a rate of about 4 pounds per acre, followed by an application of gypsum in soil or water.

Surfactants

Surfactants *or "wetting agents"* are amendments that reduce the surface tension of water. They are not effective in agricultural soils.

CAPTURING AND FILTERING SURFACE WATER AND SEDIMENTS

Reducing the volume or velocity of runoff waters can reduce offsite movement of residues whether they be in solution or sediment-attached. There are several methods of capturing and filtering surface water and sediment with the most common being the use of basins for collection and or recycling or the use of vegetation at the tail of the field or in the drainage ditch.

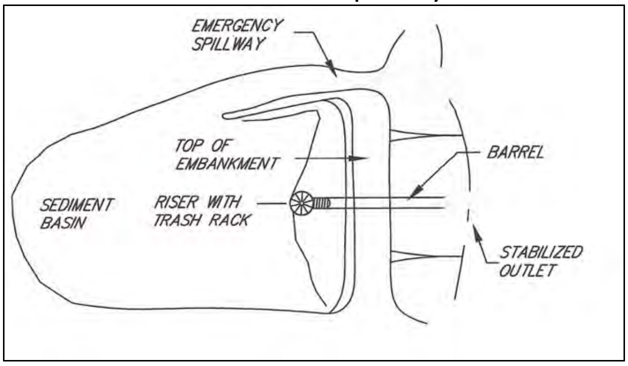
Storing Runoff

Storage of runoff waters from storm events in impoundments is often suggested as a mitigation practice. The sheer volume of runoff makes this a poor option. Storms are rated as to the frequency at which a particular amount of rainfall in a given duration is expected to return, on average. A 2-year, 24-hour storm would be the rainfall event one could expect during a 24-hour period on the average of every 2 years. For example, a 2-year, 24-hour storm in Stockton, California falling on a 40-acre parcel would produce over 1,700,000 gallons or 5.3 acre feet of water—equivalent to a one acre pond over 5 feet deep. A hundred-year storm would require three times that volume for just a single storm. Of course, some of the water would infiltrate into the field. However, if one storm came on the heels of another, most of the rainfall would run off. For more information on runoff storage and storm precipitation rates, see: "Storing Runoff from Winter Rains," Schwankl et al. 2007a, ANR Publication 8211.

Sediment Basins

A sediment basin or trap is created by constructing an embankment, a basin emergency spillway, and a perforated pipe-riser release structure. The basin may be located at the bottom of a slope where drainage enters a swale or waterway. These basins can be designed by the Natural Resources Conservation Service (NRCS) or a civil engineer on a site-specific basis and installed using proper construction and compaction for the berm and correct sizing and construction for water release structures and spillways. When runoff volumes are small, basins can be effective for reducing offsite movement of sediment containing adsorbed pesticide residues. If runoff is high enough to cause low retention times, sediment removal efficiency declines rapidly.

Diagram of a sediment basin with spillway and release structure



Effectiveness in Removing Pesticide Residues

Long et al. (2010b) found that 60- to 90-minute retention times effectively removed particles coarser than fine silts. The sediment basin was 1.4 percent of the irrigated area. Finer soil particles, which generally adsorb pyrethroid pesticide residues, were not removed from the runoff. During the first irrigation of the season, soon after cultivation, 39 percent of the sediment load entering the pond was removed. In the second measured irrigation, sediment removal was insignificant. The effectiveness of sediment traps was found to be limited by the time available for suspended sediments to settle out of the runoff. Sediment basins may be ineffective with finer soils at higher runoff rates. Long (2010a) suggests various size settling basins based on Stokes Law. Clay particles carry the bulk of the adsorbed pesticide residues. In order to provide enough holding time to settle out these small particles from a 50 gallon per minute tailwater runoff rate, a settling basin of 57 acre feet would be required.

A study was conducted in the Central Valley of California to measure pyrethroid removal by a tailwater recovery pond. The field was a border-check irrigated almond orchard to which a pyrethroid, lambda-cyhalothrin was applied at the rate of 0.04 lb ai/acre. Runoff waters were measured for volume, sediment, and pyrethroid residue concentration as inflow to a recycling pond and as outflow. About 15 percent of the irrigation onflow water exited the field as runoff. The pond was 19 feet by 16 feet by 7 feet deep. Sediment in the water was reduced by 80 percent, inflow to outflow. Pyrethroid residues were reduced by 61 percent. The difference in the removal efficiencies for sediment and pyrethroid residues was most probably due to the absorption of lambda-cyhalothrin residues to lighter weight clay particles, which did not have a chance to settle out in this trial. Removal efficiency may have been further improved with lower flow rates or longer retention times in the ponds (Markle 2009).

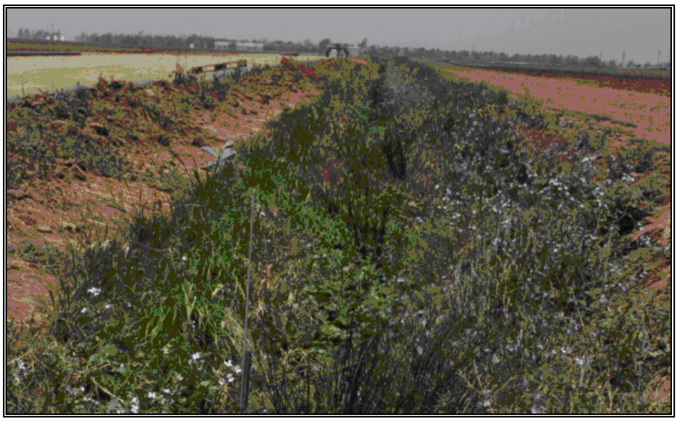
Vegetative Filter Strips

A vegetative filter strip (VFS) is any area of dense grass or other vegetation—natural or planted-between the field and a nearby waterway. Filter strips help capture and filter surface runoff from cropland to protect water quality. Tall sturdy, and hardy perennial grasses are preferred, since once established they withstand the force of runoff waters and summer drought conditions. The width of the VFS required to effectively remove sediments depends upon the slope of the area draining into the strip. For slopes of less than 1 percent, the strip should be at least 25 feet wide, increasing proportionally with the increase in slope up to 50 feet wide for 10 percent slopes

Vegetative filter strips function in three distinct layers—surface vegetation, root zone, and subsurface horizon (Grismer et al. 2006). As surface flow enters the VFS, water is infiltrated until the shallow surface and shallow subsurface is saturated. This infiltration phase is most important for reducing offsite movement of residues. The pesticide residues are trapped by soil constituents and organic matter, allowing pesticide degradation to occur. The remaining flow volume and velocity is decreased, reducing sediment transport. Sediment particles are trapped on the surface litter layer, which is high in organic matter. As the process continues, water continues to move through the subsurface horizon, further decreasing the volume of runoff.

Vegetated Drain Ditches

Drainage ditches can be vegetated with plant material that will help capture sediments and other sediment-absorbed pollutants, as well as provide for some water infiltration. The common type of a vegetated drain ditch (VDD) is a "V"-shaped ditch, 2-3 feet deep and 4 feet wide at the top. Short, sturdy, and hardy perennial grasses such as the dwarf fescues and perennial ryegrass are preferred, since once established they withstand the force of runoff waters and summer drought conditions. Vegetation in the VDD can also be resident, such as rushes and bermudagrass. Residue removal efficiency is strongly influenced by runoff flow rate per unit ditch wetted area. Higher flow rates reduce the removal efficiency.



Vegetated Ditch

Effectiveness in Removing Pesticide Residues

The chemical characteristics of different pesticides determine the type and amount of residue reduction achievable with vegetation systems. Organophosphate pesticides tend to be water-soluble, while pyrethroids are virtually non-soluble in water and are primarily adsorbed to sediments. Diazinon, an organophosphate of high solubility in water, can be expected to remain in solution for long periods (Bondarenko and Gan, 2004). Previous evaluations of the effectiveness of vegetation for removing diazinon from water have shown mixed results. Watanabe and Grismer (2001) evaluated diazinon removal by vegetated filter strips under controlled laboratory conditions and found that the majority of diazinon removal occurred via infiltration into the root zone and adsorption to vegetated matter. However, 73 percent of the applied diazinon was detected in the runoff water after the VFS. Anderson et al. (2008) found that a vegetated ditch containing aquatic vegetation removed only 4 percent of diazinon in contaminated runoff. Moore et al. (2008) used a simulated runoff event to evaluate removal of diazinon in vegetated ditches in Yolo County, California. They described reductions in diazinon runoff using a V-shaped vegetated ditch, but significant concentrations of diazinon remained in the system outflow after five hours. Essentially, runoff waters containing residues which are not infiltrated is little reduced.

Chlorpyrifos, another organophosphate, is more hydrophobic than diazinon. Gill et al. (2008) applied chlorpyrifos at 1 pt/ac and found a 40 percent reduction in the water column concentration after passage through a vegetated ditch, though the outflow water was still at 33 times the water quality standard of 15 ppt. Anderson et al. (2008) found an average 35 percent reduction of chlorpyrifos concentration in two evaluations after passage through a vegetative ditch containing aquatic vegetation. On the other end of the spectrum, Cole et al. (1997), found VFS's effective in reducing 62-99 percent of chlorpyrifos residues in runoff waters. Local conditions including runoff flow rates, size of the vegetated area, and the initial residue concentration appear to have strongly influenced the effectiveness of these studies.

Because of their hydrophobic nature, pyrethroids adsorb readily to plant surfaces and soil particles and are therefore easier to remove from runoff waters than organophosphates (Moore et al. 2001; Schulz, 2004). Moore et al. (2008), for example, found that vegetation was much more effective at removing the pyrethroid pesticide permethrin than the organophosphate diazinon. Anderson et al. (2008) found nearly 100 percent reduction of permethrin after treatment in a vegetated ditch. Additionally, Gill et al. (2008) found a 25 percent reduction of pyrethroid (lambda-cyhalothrin) residues after moving runoff waters through a vegetated ditch.

Long et al. (2010b) found that reduction in sediment load was directly related to pyrethroid residue removal in VFS. Sediment runoff was reduced by 62 percent when furrow runoff waters passed through a well-established VFS planted to either tall fescue or a perennial ryegrass and tall fescue mixture that represented 2.8 percent of the field being irrigated. They recommend 0.03 acres of vegetated filter per 100 gallons per minute of tailwater to significantly improve the water quality of field runoff (Long et al. 2010b). It should be noted that the vegetated filter strip is used once per irrigation, not for successive sets.

TAILWATER COLLECTION AND RECYCLING

Water running off the tail end of a field, part of normal irrigation, is referred to as tailwater or runoff water. Tailwater is most often associated with surface irrigation (furrow and border-check irrigation), since well-designed sprinkler and drip irrigation systems should not produce tailwater runoff. Their use is an excellent management practice to improve irrigation efficiency and minimize tailwater runoff impacts.

Tailwater collection system.

If a new tailwater return system is being planned, the planned management approach must be a key factor in its design. Tailwater generated by irrigation practices is most often pumped from the capture pond and conveyed via a pipeline system to where it will be reapplied. Such a system, well operated, maximizes irrigation efficiency and minimizes environmental impacts.

Advantages and Disadvantages of Tailwater Return Systems

Advantages:

- Offsite environmental impacts of tailwater potentially containing pesticide and fertilizer residues or sediment are minimized.
- Irrigation efficiency is improved since tailwater is beneficially re-used as irrigation water.
- Water costs may be reduced by re-using tailwater.
- Tailwater collection systems remove standing water that can cause crop loss and weed infestations from the tail end of the field.

Disadvantages:

- Cost of installation, maintenance, and operation of the tailwater return system. However, in many areas NRCS cost share programs available.
- Land must be taken out of production for the pond and other tailwater recovery system components.
- Good management, requiring timely recycling of tailwater pond contents, is necessary to prevent groundwater pollution by chemicals in the tailwater.

Tailwater Return System Management

There are numerous ways of managing tailwater return systems, and their management is often constrained by the system design. If a new tailwater return system is being planned, the planned management approach must be a key factor in the design. See ANR publication 8225, "Tailwater Return Systems" Schwankl et al. 2007b for information on design, construction, costs and operation, and National Conservation Practice Standard, Irrigation System, Tailwater Recovery, Standard 447-1, USDA Natural Resources Conservation Service, 2006.

TREATMENT OF RUNOFF WATERS

Runoff water can be chemically treated to reduce pesticide residues. This treatment can be done in the furrow, or in a holding basin. Two products are available and have been shown effective for this purpose: Polyacrylamide (PAM), for treatment of pyrethroid-laden sediments, and Landguard OP-A Enzyme®, for treatment of most soluble organophosphate pesticides. Work is underway to develop enzymes to treat pyrethroid residues, however they are unavailable at this time.

Polyacrylamide (PAM)

PAM is effective in controlling pesticide residues which are attached to soil particles (pyrethroids) that leave the field or are generated in the tailwater ditch through erosion during irrigation. Studies have shown that this erosion occurs along the field length for furrow irrigation. PAM is a solid or liquid water-soluble polymer that flocculates sediments – binding them together and causing them to drop out of the water. When added to runoff waters, PAM can mitigate transport of sediment-adsorbed pesticides from furrow irrigated fields.

Liquid PAM can be constantly injected into the irrigation water, constantly deposited in granular form into turbulent irrigation ditch water, or applied to the furrow as dry tablets (40 percent PAM) or granules (89 percent PAM), where it is slowly dissolved by irrigation water. The in-furrow methods are generally less expensive and easier to apply than liquid or granular PAM applied to the inflow ditch or piped water. However, they do not allow for equally precise control of product concentration. Table 8 shows a comparison of costs using the different forms of PAM for an 80-acre furrow-irrigated row crop planted on 5-foot beds, using data provided by a grower. The lowest cost occurred for granules placed in the furrow, while the costs were the highest using liquid PAM.

At a furrow length of 600 feet, 60-inch beds would require about one ounce or 2 tablets per furrow. It is applied in a "patch" in a 3-foot section of the furrow, far enough from the furrow head to prevent sediments from covering the PAM patch. In the Northwest, placement 5 feet from the furrow head was successful. In California, the patch was quickly covered and not effective; whereas 100 feet down furrow was successful. Once applied as a "patch," PAM seems to be effective for a few irrigations. If the soil is disturbed by cultivation, it must be reapplied. PAM is more effective in finer texture soils and in irrigation waters that contain calcium and little sodium.

Season-long control costs are difficult to estimate because effectiveness from a single application varies with the number of irrigations and the number of field cultivations. Liquid PAM that contains oil-based carrier materials is available, but the cost per acre is high and the product can be toxic to some aquatic life at recommended field application rates (Weston et al. 2009).

Table 8. Cost comparisons for different single irrigation PAM formulations for a typical 80-acre furrow-irrigated row crop planted on 5-foot beds.

Application method	Unit cost of material	Cost per acre	Comments
Granules placed in furrow	$2.79 per pound	$1.05	1 oz of granules per furrow
Tablets placed in furrow	$4.82 per pound	$6.36	Two tablets per furrow
Granules injected into irrigation water	$2.79 per pound	$5.46	Target concentration = 5 ppm; injection time = 12 hours (time needed for water advance to end of furrows)
Liquid PAM injected into irrigation water	$34 per gallon	$32.31	Target concentration = 5 ppm; injection time = 12 hours
Liquid PAM injected into irrigation water	$34 per gallon	$12.93	Target concentration = 2 ppm; injection time = 12 hours

Source: Long et al. (2010a)
Costs per acre are based on the gross acreage of the 80-acre field.

Effectiveness in Removing Pesticide Residues

PAM has been shown to be effective in reducing sediments from furrow irrigation fields when applied to irrigation furrows. Sojka et al. (2007) in their Northwest studies on furrow-irrigated soils over a three-year period, found application rates of 1 pound per acre/irrigation (about 10 ppm) eliminated 94 percent of sediment loss in field runoff. A seasonal rate of 3-7 pounds per acre was used, depending on the crop and number of cultivations. One of the mechanisms of decreased sediment loss is increased infiltration of irrigation water into the field because PAM effectively reduces runoff water volumes (Trout et al. 1995). Sojka, using the recommended 10-ppm PAM rate, found increases in infiltration of 15 to 50 percent compared to untreated controls. In California, Long et al. (2010b) found no PAM effect on infiltration into loam and clay loam soils at a lesser application rate assumed to be near 2ppm.

In a California study conducted on loam and clay loam soils, Long et al. (2010b) found an application rate of 1-2 ounces per 600-foot furrow using the “patch method” reduced sediment loss between 57 and 97 percent in numerous trials. Furrow flow rates averaged 17.5 gallons per minute. They found greater than 80 percent sediment control in 60 percent of the trials. The concentration of a pyrethroid, lambda-cyhalothrin or zeta-cypermethrin, was reduced by the same amount.

Landguard OP-A Degradation Enzyme

Runoff waters containing organophosphate insecticide residues can be treated with a degradation enzyme, Landguard OP-A, to reduce or eliminate residues in runoff water before water exits the farm. This product promotes the breakdown of most organophosphate pesticides into less toxic metabolites. The powder-like enzyme is mixed with water into a stock solution and applied to runoff water usually in the tail water ditch but can be applied to a holding basin. The enzyme treatment rate, residue concentration, and the time available before runoff discharge are all important to for ensuring degradation at a minimum material cost. Greater time available before runoff discharge allows a lower enzyme application rate.

The key factor in determining the correct dosing rate is the maximum expected runoff rate. Runoff rate is typically not constant over time. When using a single dosing rate based on the maximum estimated flow rate, over-dosing is likely at the lower flows that typically occur at the beginning and end of a runoff event. Additionally, the practice of irrigating more checks during a nighttime set can lead to different peak flows of different duration.

A comparison was made of the amount of enzyme required for single maximum rate dosing for the entire runoff period and for a variable rate dosed as required by flow rate—essentially keeping the dosing rate constant (Prichard and Antinetti 2009). A single rate setting to dose for the maximum volume during the first irrigation set resulted in a dosage that was more than double the amount actually needed. Estimating that the next set would be near the same runoff flow rate and using the same dosing rate, the second set required over 6 times that of a correctly dosed variable system do to the lower amount of runoff.

Effectiveness in Removing Pesticide Residues

A field trial in California found chlorpyrifos in runoff at a concentration near 10 ppb prior to Landguard OP-A treatment. Twelve minutes after the enzyme was added at a rate of 4.3 oz to one acre foot runoff water, the chlorpyrifos concentration declined to 0.4 ppb. At higher enzyme dosages, chlorpyrifos became undetectable. The effects of the enzyme on chlorpyrifos-related toxicity are equally dramatic. The enzyme reduces chlorpyrifos toxicity to *H. azteca* (a test organism) by at least 70 fold compared with untreated water (Weston and Jackson, 2010). Without enzyme, the concentration of chlorpyrifos required to kill half the test organisms was 141 ppb. With enzyme, they saw no ill effects to the test organisms.

A team led by Brian Anderson of the UC Davis Marine Pollution Studies Laboratory dosed Landguard OP-A at the rate of 4.3 oz/acre foot runoff water directly into a drainage ditch containing diazinon residues (Anderson et al. 2008). Samples of runoff water were collected from the ditch before dosing and 107 feet downstream from the electronic dosing unit (Figure 9).

Figure 9. Anderson trial showing vegetated ditch and electronic dosing unit 2008

In multiple trials, Anderson found that samples treated with Landguard OP-A demonstrated no detectable diazinon and all were non-toxic to *C. dubia*, another aquatic arthropod test organism.

This publication endeavors to gather into one place all the major strategies for minimizing offsite movement of pesticides in water, and to use flowcharts to help guide growers and farm managers through the process of selecting which practices may be most appropriate for their operations. However, more detailed information on implementation of many of these practices is available from sources referenced throughout the publication (or search reference list below). If you need assistance in determining which practices would be best for your operation or how to implement them, please contact your local Cooperative Extension Farm Advisor for information and advice.

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APPENDIX I

A RISK ANALYSIS CASE STUDY

Let's expand the example we introduced in the "How To Use This Manual" section to better understand how the management practices presented in this manual can be used to prevent or correct water quality problems arising from field operations.

Crop: Tomato, 40 acres—conventional tomato production-
***Topography*:** 0.15 percent slope
Soil: Hollenbeck silty clay loam soil, soil tends to crust limiting the water infiltration rate. Bed up in the fall.
***Irrigation system*:** furrow irrigation
Irrigation Runoff: Runoff is about 17% of the applied water
Drainage: Runoff moves to a drain at edge of field; then, on to a larger creek
***Irrigation water*:** pH 7.5, EC 0.2 dS/m
Pesticide mixing and loading: A pesticide mixing & loading area is located about 40 feet from the drainage ditch.
***Pest*:** Potato aphid, 60% of leaves sampled from below the highest flower are infested on July 15th, 9 weeks prior to harvest.

We begin the risk assessment with Flowchart number 1 (FC1), considering possible routes by which pesticide could move off the field and the operations or conditions that may contribute and application to near surface water sources (drift). We will determine if a risk exists for each concern, and then review management practices to mitigate the risk.

THE IRRIGATION RUNOFF RISK

<u>**We begin in flowchart 1 (FC1)** to evaluate risks associated with i**rrigation runoff** in our field using furrow irrigation.</u> In our example, furrow irrigation results in about 17% of the applied water as runoff which poses a risk of moving applied chemicals to a surface water ditch and then on to a creek. After evaluating the irrigation runoff risks and reviewing management practices we will revisit FC1 to evaluate the risks of applications near surface waters and finally the stormwater runoff risks.

<u>**Proceeding next to FC3**, the next step is to evaluate **IPM practices** used to control potato aphid.</u>

<u>**Integrated Pest Management**</u>

(The following was adapted from the UC IPM Guidelines available at:
(http://ucipm.ucdavis.edu)

<u>*The Potato Aphid Pest*</u>

The potato aphid has both a pink and green color biotype. This aphid is much bigger than the green peach aphid with a more elongate body shape and is generally found on the terminals of tomato plants later in the season than green peach aphids. It is also considered to be more damaging.

High potato aphid populations can distort leaves and stems, stunt plants, and cause necrotic spots on leaves. These aphids also secrete a large amount of honeydew that promotes development of sooty mold on foliage and fruit. Plants are particularly susceptible to yield losses from high infestations during the period from 6 to 8 weeks before harvest. Yield losses from equally high aphid populations decline substantially as harvest approaches, unless aphid densities are reducing leaf area enough to permit sunburn.

Aphid Monitoring

Monitor potato aphids from bloom to early fruit set by picking the leaf below the highest open flower on 30 plants selected at random throughout the field. Record the presence or absence of potato aphids on each leaf, while noting natural enemies. Treatment is warranted if 50 to 60% or more of the leaves are infested. If 50% of such leaves are infested during the period 6 to 8 weeks before harvest, the resulting loss is about 1 ton per acre for processing tomatoes. Yield losses from such levels of aphids decline substantially as harvest approaches, unless aphid densities are reducing foliage cover enough to permit sunburn of the fruit.

Management Options

Biological Control

Naturally occurring parasites and predators of the potato aphid are common and can provide control. Monitor the proportion of aphid mummies relative to unparasitized aphids and the numbers of predators such as lady beetles, lacewing larvae, and syrphid larvae. If the proportion of mummies is increasing or predators appear to be gaining control and aphid populations are not yet damaging, avoid sprays that will disrupt these natural enemies.

Tolerant Varieties

There is considerable difference in tomato variety susceptibility to potato aphid feeding. Varieties containing the Mi gene, which confers resistance to nematodes, have been reported to be more tolerant of potato aphid infestations. However, this resistance no longer appears to be as effective as it once was, particularly against the pink form of the potato aphid.

Organically Acceptable Methods

The use of tolerant varieties, biological control, and sprays of herbal oils, pyrethrin, or insecticidal soap are acceptable for use on an organically certified crop. Repeated applications may be necessary for control.

Chemical Control

In our example, potato aphid levels have reached the threshold level at a critical period during fruit set. A chemical control spray is warranted to avoid yield losses due to aphid feeding. After this initial spray, continued monitoring will be needed to determine if further applications are needed.

Continuing to work our way through FC3, the next step is to select an effective control pesticide that has minimum risk to water quality.

Selecting Pesticides to Reduce Water Quality Risks

Treatment options are derived from the UCIPM Pest Management Guidelines for potato aphid (Table A1.) combined with the potential for runoff risk and overall risk from Table 2 (http://www.ipm.ucdavis.edu/PMG/selectnewpest.tomatoes.html) include two organophosphates; two pyrethroids, one a carbamate, and one a neonicotinoid.

Table A1. Common treatment options for potato aphid for conventional tomato production

Chemical	Trade Name	Chemical Class	Solution Runoff potential[1]	Adsorption runoff potential[2]	Overall runoff risk[3]
acetamiprid	Assail	neonicotinoid			
methamidophos	Monitor	organophosphate	low	low	low
lambda-cyhalothrin plus acetamiprod	Warrior plus Assail	Pyrethroid plus neonicotinoid	low	intermediate	high
lambda-cyhalothrin	Warrior	pyrethroid	low	intermediate	high
methomyl plus fenopropathrin	Lannate plus Dannitol	carbamate plus pyrethroid	intermediate	low	moderate
dimethoate	Dimethoate	organophosphate	low	low	low

[1] Likelihood that the active ingredient will transport from the area of treatment as dissolved chemical in runoff.

[2] Likelihood that the active ingredient will transport from the area of treatment as attachment to soil or sediment particles in runoff.

[3] Overall likelihood to cause negative impact on surface water quality as a product of the runoff potential and the aquatic toxicity of the pesticide

Having read the sections of this manual about the water quality risks associated with various classes of chemicals, we know that many organophosphates are highly water soluble and subject to runoff risk while pyrethroids are highly hydrophobic and adsorb readily to soil sediments—also subject to offsite movement.

The next consideration in FC3 for managing potato aphid is to consider pesticide mixing and loading practices and their impact on surface water quality

Mixing and Loading

The mixing and loading site in our example field is within 50 feet of a surface water ditch. Mixing and loading practices include not over-filling the tank, triple rinsing containers and adding the rinsate to the tank, and rinsing the tank and applying the rinsate to the field. The use of a concrete pad with catchment sump is also a good solution to reduce risks from mixing and loading near surface water sources.

The next step in our assessment in FC3 is to consider changes in irrigation management.

Irrigation Management

Irrigation Scheduling

Using evapotranspiration reference (ETo) combined with the coverage of the crop canopy can potentially reduce the applied volume and therefore the amount of runoff. Scheduling using this method applies to both furrow and pressurized irrigation systems; however; the application of the desired amount is much easier with pressurized systems such as drip irrigation. Soil based moisture monitoring should be used to verify calculations and applied irrigation volumes in relation to crop water use.

Improve Irrigation Uniformity

Runoff volumes can be reduced in furrow irrigation by matching the inflow rate to the infiltration rate and optimizing the irrigation cutoff point to achieve good uniformity at a reduced runoff volume. Blocking furrows by making small dams in the length of the furrow using soil, or plastic dams can increase infiltration and help uniformity. This practice of monitoring each furrow during irrigation is labor intensive can reduce runoff volumes.

Reduce Runoff Volume

Manage Irrigation System to Reduce Runoff

Runoff volumes can be reduced in furrow irrigation fields by matching the inflow rate to the infiltration rate and optimizing the irrigation cutoff point to achieve good uniformity at a reduced runoff volume

Improve water infiltration

The irrigation water in our example field has a salinity (ECw) of 0.2 dS/m, indicating a “pure water” infiltration problem. Applying gypsum, with a “solutionizer” in the irrigation water, can help improve water infiltration potentially reducing irrigation runoff.

Runoff Water Capture and/or Recycling

Sediment Basin /Recycle Runoff

Sediment basins can be used to capture runoff and reduce sediment load. Recycling of runoff waters to the delivery system can completely eliminate the runoff.

Vegetated Strips/Drain Ditches

Vegetative strips if designed and constructed properly can infiltrate runoff waters and filter out sediments. Care should be taken to create large enough strip or ditch areas to reduce runoff velocities.

Runoff water treatment

Runoff waters containing residues of organophosphates can be treated with enzymes which rapidly degrade the material. When soil attached residues are an issue, the use of polyacrylamide (PAM) can markedly reduce sediments in the runoff waters.

PAM is a solid or liquid water-soluble polymer that flocculates sediments, binding them together and causing them to drop out of the water. When added to runoff waters, PAM can mitigate transport of sediment-adsorbed pesticides contained in runoff.

Winter applications of PAM are usually applied as dry tablets (40 percent PAM) or granules (89 percent PAM), where it is slowly dissolved by runoff water. At a furrow length of 600 feet, 60-inch beds would require about one ounce or 2 tablets per furrow. It is applied in a "patch" in a 3-foot section of the furrow, near the middle and near the end of the furrow. PAM can also be applied as a patch near the inlet to a sediment basin to help reduce the time for the clay particles to settle out.

Now that we have evaluated the irrigation runoff risks, we go back to FC1 to evaluate the drift risks. Our example field is located near a drainage ditch which contains water draining to a surface water source and therefore is significant risk, we consider ways of reducing **spray drift** that could enter the drainage ditch or creek near the example field. Go to **FC5** (Evaluating the risk of chemical applications near surface waters) and the following drift management options:

THE APPLICATION NEAR SURFACE WATER SOURCES RISK

Application Conditions

- Delay treatments near ditches and surface water bodies, until wind is blowing away from these and other sensitive areas.

Application Equipment

- Use as coarse a spray as possible (250 - 400 microns or larger) without sacrificing good canopy coverage. Droplet size is one of the most important factors affecting drift.
- Use low-drift nozzles that produce larger droplet sizes. Fitting a sprayer with air induction nozzles instead of standard nozzles will reduce spray drift up to 50 percent compared to standard nozzles.

Product Choice

- Use drift control/drift reduction spray additives agents. These materials are generally thickeners designed to minimize the formation of droplets smaller than 150 microns. They also help produce a more consistent spray pattern and aid in deposition.
- Treat buffer zones with materials that are least disruptive to aquatic life.

Buffer Zones

- Maintain adequate buffer areas or zones between the treated site and sensitive areas to ensure that pesticides don't drift from the target area. Read the label as to the size of buffer zone required as related to the rate of active ingredient.

Change application Method

- Aerial application has a larger drift potential than ground application equipment. When drift risk is present, changing to ground application equipment requires a smaller buffer zone.

Now that we have evaluated the risk of chemical applications near surface water, we go back to FC1 to evaluate the stormwater runoff risk.

THE STORMWATER RUNOFF RISK

Since in the case study the field is bedded up in the fall, there is a risk that of rainfall to cause runoff to move sediment offsite. Sediments can contain adsorbed pesticides, most likely pyrethroids. Go to **FC4** Reducing the Risk of Offsite Movement of Ag Chemicals in Stormwater Runoff. Since pesticide applications would have occurred during the last season's crop only sediment residues are of concern.

Improve Water Infiltration

Chemical Amendments Used to Improve Water Infiltration
The addition of chemical amendments to water or soil can improve water infiltration by improving the chemical makeup of the water or soil. Most chemical amendments work by increasing the total salt concentration and/or decreasing the sodium adsorption ratio (SAR) of the soil-water. Both of these actions enhance aggregate stability and reduce soil crusting and pore blockage.

Calcium Materials

Adding calcium (Ca) salts to soil and water increases both the total salinity and soluble calcium. Calcium salts commonly used on alkali (high pH) soils include gypsum ($CaSO_4$), calcium chloride ($CaCl_2$), and calcium nitrate ($CaNO_3$). Gypsum is the most common calcium material applied in the fall prior to bedding up. Surface applications are most effective when gypsum is applied at rates equivalent to 1 to 2 tons per acre.

Acids and Acid-Forming Materials

Commonly applied acid or acid-forming amendments include sulfuric acid (H_2SO_4) products, soil sulfur, ammonium polysulfide, and calcium polysulfide. The acid from these materials dissolves soil-lime to form a calcium salt (gypsum), which then dissolves in the irrigation water to provide exchangeable calcium. The acid materials react with soil-lime the instant they come in contact with the soil. The materials with elemental sulfur or sulfides must undergo microbial degradation in order to produce acid. This process may take months or years depending on the material and particle size (in the case of elemental sulfur). Since these materials form an acid via the soil reaction, they will reduce soil pH if applied at sufficiently high rates.

Managing *Soil Organic Matter to Reduce Runoff*

Soil organic matter helps stabilize soil aggregates by increasing the number of exchange sites in the soil matrix and encouraging microbial activity. Soil microbes that decompose soil organic matter produce polysaccharides and polyuronides, which act as binders to stabilize aggregates, thus improving porosity and water infiltration. Over time, continued cultivation and the use of herbicides reduces the organic matter content and aggregate stability of soils. These changes can reduce water infiltration and increase runoff potential.

It is difficult to increase and sustain soil organic matter under warm semiarid conditions that prevail in most of California, which favor rapid organic matter decomposition. Organic matter additions aimed at improving or sustaining aggregate stability and water infiltration must be incremental and continual to be effective. There are several ways for growers to achieve this.

Crop Residues

After harvest remains of field crops shredded or soil incorporated, can be left to decompose adding organic matter (and some nutrients) to the soil. Crop residue biomass in California's Central Valley ranged from 9,560 pounds per acre for corn following grain harvest to 570 pounds per acre for onions (Mitchell et al. 1999). Even within a specific crop biomass can vary. In tomato. biomass varied due to harvest date but an intermediate value was 2880 pounds per acre. Wheat biomass after grain harvest was 4800 pounds per acre; however after baling and removal, only 670 pounds remained.

Manure and Other Organic Materials

With proper handing and management to avoid risk of crop contamination by human pathogens, animal manures or compost can help increase soil organic matter content and improve water infiltration. However, the application of manures is currently uncommon due to the limited availability of manures.

Protect Soil Surface using cover crops

Cover crops can help protect the soil surface from droplet impact under winter rainfall and provide significant organic matter biomass for decomposition and microbial stabilization of soil aggregates. In addition, cover crop residue can slow the velocity of surface water, reducing erosion and subsequent depositional crusting. A winter cover crop of triticale was planted to bed tops in a tomato field in early November and chemically controlled at about an eight-inch height in mid February. The result was a 40% reduction in runoff volume and a 70% reduction in runoff turbidity in contrast to a no cover condition (Miyao et al. , 2004). Less expensive options include using barley or oats.

Runoff Water Capture

S*edi*ment Basins

A sediment basin or trap is created by constructing an embankment, a basin emergency spillway, and a perforated pipe-riser release structure. The basin may be located at the bottom of a slope where drainage enters a swale or waterway. These basins can be designed by the Natural Resources Conservation Service (NRCS) or a civil engineer on a site-specific basis, and installed using proper construction and compaction for the berm, and correct sizing and construction for release structures and spillways. When runoff volumes are small, basins can be effective for reducing offsite movement of sediment containing adsorbed pesticide residues. If runoff is high enough to cause low retention times, sediment removal efficiency declines rapidly.

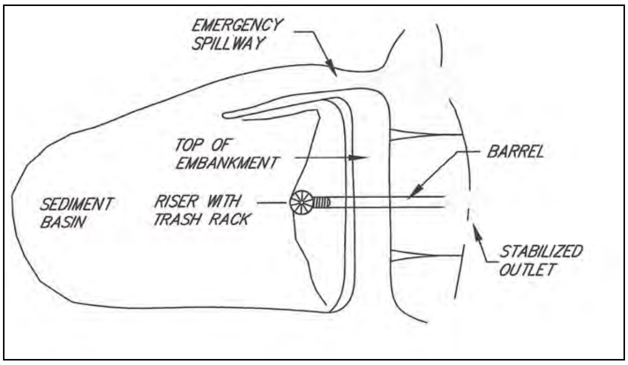

Diagram of a sediment basin with spillway and release structure

Effectiveness in Removing Pesticide Residues

To be effective settling basins must be large enough to capture the entire storm runoff volume or be large enough to provide retention time long enough to allow the clay particles to settle out. Long (2010a) suggests various size settling basins based on Stokes Law. Clay particles carry the bulk of the adsorbed pesticide residues. In order to provide enough holding time to settle out these small particles from a 50 gallon per minute tailwater runoff rate, a settling basin of 57-acre feet would be required

Vegetative Filter Strips/Drain Ditches

A vegetative filter strip (VFS) is any area of dense grass or other vegetation—natural or planted-between the field and a nearby waterway. Filter strips help capture and remove water-borne sediments before they reach the waterway. Tall, sturdy, and hardy perennial grasses are preferred, since once established they withstand the force of runoff waters and summer drought conditions. The width of the VFS required to effectively remove sediments depends upon the slope of the area draining into the strip. For slopes of less than 1 percent, the strip should be at least 25 feet wide, increasing proportionally with the increase in slope up to 50 feet wide for 10 percent slopes

Vegetative filter strips function in three distinct layers—surface vegetation, root zone, and subsurface horizon (Grismer et al. 2006). As surface flow enters the VFS, water is infiltrated until the shallow surface and shallow subsurface is saturated. This infiltration phase is most important for reducing offsite movement of residues. The pesticide residues are trapped by soil constituents and organic matter, allowing pesticide degradation to occur. The remaining flow volume and velocity is decreased, reducing sediment transport. Sediment particles are trapped on the surface litter layer, which is high in organic matter. As the process continues, water continues to move through the subsurface horizon, further decreasing the volume of runoff.

One common type of VFS is a vegetated ditch, typically a "V"-shaped ditch, 2-3 feet deep and 4 feet wide at the top. Vegetation can be resident, such as rushes and bermudagrass, or intentionally planted to species such as rushes, pennywort, creeping wild rye and red fescue. Vegetated ditches can help reduce chemical contaminants as does a VFS, by infiltration, direct adsorption of chemicals to plant surfaces, and promoting sedimentation of particle-bound contaminants. Vegetated ditches, in contrast to VFS, increase the treatment area per unit of surface land area. Residue removal efficiency is strongly influenced by runoff flow rate per unit ditch wetted area. Higher flow rates reduce the removal efficiency.

Runoff Water Treatment

Polyacrylamide (PAM)

PAM is a solid or liquid water-soluble polymer that flocculates sediments, binding them together and causing them to drop out of the water. When added to runoff waters, PAM can mitigate transport of sediment-adsorbed pesticides contained in runoff.

Winter applications of PAM are usually applied as dry tablets (40 percent PAM) or granules (89 percent PAM), where it is slowly dissolved by runoff water. At a furrow length of 600 feet, 60-inch beds would require about one ounce or 2 tablets per furrow. It is applied in a "patch" in a 3-foot section of the furrow, near the middle and near the end of the furrow. PAM can also be applied as a patch near the inlet to a sediment basin to help reduce the time for the clay particles to settle out.

Landguard

Tomato runoff water can be chemically treated to reduce pesticide residues. This treatment can be done in a tailwater ditch, or in a holding basin. Landguard OP-A Enzyme® has been shown to be effective for treatment of most soluble organophosphate pesticides. Work is underway to develop enzymes to treat pyrethroid residues; however they are unavailable at this time.

Controlling Offsite Movement of Agricultural Chemical Residues -- Walnuts

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Prepared as a Component of:
California Department of Pesticide Regulation-- Pesticide Management Alliance Grant in Cooperation with the San Joaquin County and Delta Water Quality Coalition. 2010

Table of Contents

Controlling Offsite Movement of Agricultural Chemical Residues -- Walnut

INTRODUCTION

WHAT'S IN THIS PUBLICATION?

The goal of this publication is to provide walnut growers with information on farming practices to help reduce the occurrence of organophosphate and synthetic pyrethroid pesticides in surface waters, which include streams, lakes, ponds, rivers, and drainage ditches. An assessment of the potential risk of offsite movement of an insecticide is made before a field application is performed using a flowchart for specific management practices and field conditions in orchards. This risk self-assessment focuses on issues that affect either the number of pesticide applications containing these active ingredients, or the offsite movement of pesticides as drift, attached to sediment, or in water that carries pesticide active ingredients.

If a significant risk that pesticide residues will leave the site of application and enter surface waters exists, a grower is able to consult the information in this manual about an array of science-based management practices to mitigate that risk.

WHY IS THIS PUBLICATION NEEDED?

The Central Valley occupies about 40 percent of the land area in California and provides much of the State's agricultural production. Maintaining this productivity has required the use of about 132 million pounds of pesticides annually. Water quality in the Central Valley's rivers and streams has been impacted in part due to pesticide movement from agricultural lands into these waters. The list of impaired water bodies recently proposed for listing under the Clean Water Act Section 303(d) includes nearly a hundred water body segments in which impairment is due to agriculture. Agriculture is identified more often than any other source in the State as the likely cause of impairment.

Agricultural pesticides reach surface water bodies directly as spray drift or indirectly through irrigation or stormwater runoff from treated fields, vineyards, and orchards. Runoff waters may transport pesticides as dissolved or soil particle-adhering residues. Among the pollutants often attributable to agriculture is the organophosphate insecticide chlorpyrifos. California agriculture uses 1,425,000 pounds of chlorpyrifos annually, more than any other insecticide. Approximately half of the hundred 303(d) listed water body segments impaired due to agriculture in the Central Valley are impaired in whole or in part by chlorpyrifos. Total Maximum Daily Load is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards. The presence of chlorpyrifos in surface water and its toxicity to aquatic life has been responsible for multiple Total Maximum Daily Load (TMDL) projects in California, including one for the San Joaquin River, another for the Sacramento-San Joaquin Delta, and many other TMDLs elsewhere in the State where the process is less developed. In one study, chlorpyrifos was

responsible for mortality to the test organism, *Ceriodaphnia dubia*, in seven of ten toxic samples (de Vlaming et al. 2004).

Synthetic pyrethroids are another group of pesticides emerging as a concern. Pyrethroids are a cause for 303(d) listing of about 10 percent of agriculture-impaired water bodies in California. In a study of toxicity of sediments collected from agricultural waterways, 54 out of 200 sediment samples caused acute toxicity to the test organism, *Hyalella azteca*, and pyrethroids were responsible for the toxicity in 61 percent of those cases (Weston et al. 2009). Chlorpyrifos was the second most common contributor to toxicity, responsible for toxicity in 20 percent of the samples. Recent data also indicate that pyrethroids are present at toxic levels in the water column of irrigation tailwater samples. In a study just completed, the pyrethroid lambda-cyhalothrin was responsible for toxicity to *H. azteca* in three out of six toxic samples collected at California agricultural pump stations where tailwater was being returned to nearby rivers. Chlorpyrifos was responsible for toxicity in the remaining three samples (Weston and Lydy 2010). As analyses of environmental samples for pyrethroids become more frequent, it is likely that the water quality effects of pyrethroids will be even more broadly recognized in future years.

The continued use of these effective agricultural pesticides is dependent on measures to prevent offsite movement of residues into surface waters. A listing of the active ingredients and trade names for pesticides used in walnut production can be found in Table 1. The table is restricted to those materials with reported use in California during 2008 with use over 50 pounds annually. Organophosphates and pyrethroids represent 96% of this list. Even though organophosphate, pesticides are declining in use each year, they still represent 93% of the list total with chlorpyrifos the highest use product based on pounds applied per year.

Table 1. Walnut pesticides used in California in 2008 that are registered for use in 2011 (CDPR, California Department of Pesticide Regulation).

Active Ingredient Common Name	Trade Name	Lbs/Year	Chemical Class
chlorpyrifos	Lorsban	180,026	organophosphate
phosmet	Imidan	33,221	organophosphate
methyl parathion	Penn-Cap	31,994	organophosphate
malathion	Malathion	18,761	organophosphate
methyoxfenozide	Intrepid	9,439	diacylhydrazine
diazinon	Diazinon	4,404	organophosphate
permethrin	Pounce	2,888	pyrethroid
bifenthrin	Brigade	2,404	pyrethroid
esfenvalerate	Asana XL	2,335	pyrethroid
methidathion	Supracide	773	organochlorine
diflubenzuron	Dimilin	790	benzoylurea
azinphos-methyl	Guthion	679	organophosphate
lamda-cyhalothrin	Warrior	659	pyrethroid
spinetoram	Delegate	423	spinosyn
pyriproxyfen	Esteem	311	pyridine
carbaryl	Sevin	264	carbamate
spinosad	Entrust	51	spinosyn

CURRENT REGULATORY APPROACH TO SURFACE WATER PROTECTION

All growers farm under the requirement not to pollute surface and groundwater. Water leaving agricultural lands, as irrigation or stormwater runoff, can contain pesticide residues, sediment, or nutrients. These discharges are regulated by California's Central Valley Regional Water Quality Control Board (Water Board) under a program called the Irrigated Lands Regulatory Program. Essentially, the Board is enforcing the California Water Code of 1969 and the Federal Clean Water Act of 1972. To this end the Water Board has:

- Established surface water quality standards in each watershed basin plan
- Enforced waste discharge requirements

THE AG WAIVER

In 1982 the Board adopted a resolution "*Waiving Waste Discharge Requirements for Specific Types of Discharge.*" The resolution contained 23 categories of waste discharges, including *irrigation return flows and stormwater runoff* from agricultural lands. The resolution also listed the conditions required to comply with the waiver, hence the term '**Conditional Ag Waiver**.' However, due to a shortage of resources at the time, the Water Board did not impose measures to verify compliance with these conditions.

The waiver, set to sunset in 2003, was amended by adopting two conditional waivers for discharges from irrigated lands. **One** was for *coalition groups* of individual dischargers that comply with the California Water Code and Water Board regulations. **The other** was for growers to comply as individual entities. To be covered by the waivers, the coalition or individual must have filed with the Water Board by November 1, 2003 a Notice of Intent and General Report that contained specific information about their farm and then must have adhered to a plan and timeline that includes, among other things, a farm management plan and surface water monitoring plan.

WATER QUALITY COALITIONS

Water quality coalitions are generally formed by growers on a sub-watershed basis, although some are based on a specific commodity. The San Joaquin County and Delta Water Quality Coalition, for example, encompasses all of San Joaquin County and portions of Contra Costa and Calaveras Counties. The Coalition includes about 500,000 acres of irrigated lands and 4500 individual members. The Coalition monitors and analyzes the water quality of sub-watersheds in surface waters and facilitates the implementation of management plans. Coalitions provide outreach and support to growers in response to water quality exceedances at sub-watershed monitoring sites, in order to enhance the water quality of those water bodies affected.

Water Quality Monitoring

The Coalition currently monitors water quality at numerous sites in both large and small sub-watersheds within the coalition watershed. Water samples are collected monthly, while sediment samples are collected twice per year. During 2008, water quality standards were exceeded many times. At some locations, as many as 40 percent of the samples exceeded water quality standards for pesticide residues (Management Plan, San Joaquin County Delta Water Quality Coalition, Karkoski 2008). When more than one exceedance of water quality limits occurs for any contaminant, a management plan must be developed by the Coalition to address it. In addition, any single exceedance of either chlorpyrifos or diazinon triggers the requirement for a management plan.

Management Plans

The overall goal of water quality management plans, whether developed by individuals or coalition groups, is to reduce agricultural impacts on water quality in the plan area. Management plans evaluate the frequency and magnitude of exceedances and prioritizes locations for outreach.

To achieve the goal of improving water quality, a management plan must include:

- Source identification of constituents causing water quality impairments
- Outreach to growers about irrigation and dormant season management practices to protect water quality
- Evaluation of water quality improvements achieved by monitoring and implementation of management practices

Under the management plan landowners/growers must:

- Help the Coalition succeed by participating in efforts to solve water quality impairments identified through water monitoring
- Staying informed – read mailings and updates, respond as necessary
- Attending grower water-quality information meetings
- Implementing management practices that mitigate the identified water quality concerns

HOW TO USE THIS MANUAL

This manual is designed to be used in a two-step process. The first step is to make a "risk assessment" of orchard conditions or operations to identify those farming practices that may influence the risk of offsite pesticide movement. To aid in doing this, a series of "flowcharts" are presented. The first will help identify avenues of possible offsite pesticide movement from a particular orchard. Succeeding flowcharts help "zero in" on specific conditions to consider in making changes to reduce pesticide movement out of the orchard.

The second step is to understand and implement management practices to address the problem areas that were identified. These management practices, presented beginning on page 17 of this publication, are divided into three broad categories:

USE INTEGRATED PEST MANAGEMENT (IPM) APPROACHES, HANDLE, APPLY, AND STORE PESTICIDES CORRECTLY

Integrated Pest Management (IPM) is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used **only** after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Coupling use of IPM techniques with proper pesticide selection, handling, application, and storage can go a long way towards preventing offsite movement and protecting water quality.

These practices should be the foundation of any water quality protection program. Implementing at least some of them can also reduce risks to human health, beneficial and non-target organisms, and the environment.

USE SOIL AND WATER MANAGEMENT PRACTICES

Use soil and water management practices that reduce runoff potential. Runoff occurs when using surface irrigation or when rainfall occurs faster than it can enter the soil. Runoff water can carry pesticides in the water itself or adsorbed to eroding soil particles. Proper irrigation method selection, design, and operation, coupled with orchard floor management and water treatments that maximize water infiltration, help ensure that the water needs will be met and runoff kept at a minimum.

CAPTURE, FILTER, RECYCLE OR TREAT RUNOFF WATERS

When IPM and soil and water management do not adequately address a water quality problem, techniques for physically intercepting, recycling, or chemically treating runoff water can be used to reduce offsite transport of water pesticides in water.

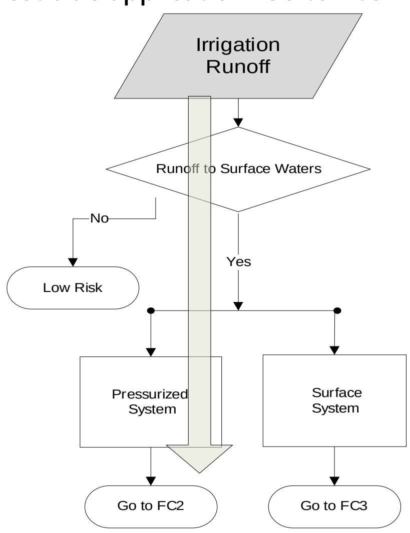
QUICK OVERVIEW OF THE RISK EVALUATION PROCESS

For a quick overview of the process, let's consider an example of a northern San Joaquin Valley walnut orchard to illustrate how the flowcharts and management information in this manual could be used to identify and correct an offsite insecticide movement problem. We'll return to a more detailed discussion of this scenario in the case study presented in Appendix I located at the end of this manual. The opaque arrows in these flowcharts indicate the logical progression in considering the most cost effective management practices.

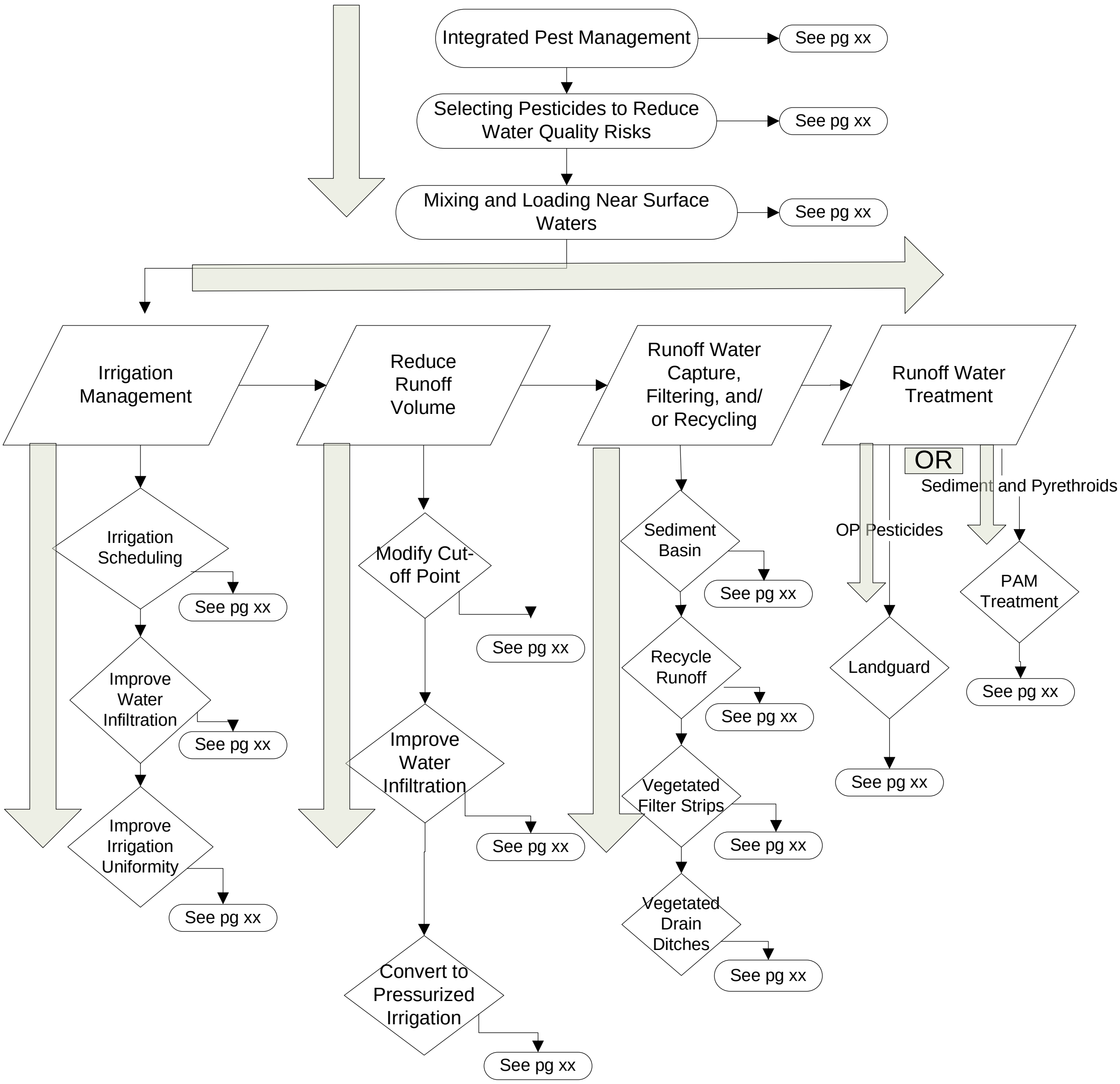
Orchard: Mature walnuts, 32 acres-- not organic
Topography**:** 0-2 percent slope
Soil: Hollenbeck silty clay loam soil, soil tends to crust limiting the water infiltration rate causing some runoff in mid – late season.
Irrigation Runoff: runoff is relatively small in volume –carrying little or no sediment
Irrigation system**:** Full coverage sprinklers, application rate 0.10 in/hr
Irrigation water**:** pH 7.5, EC 0.2 dS/m
Irrigation operation**:** 50 hr per 14 day period at mid season
Drainage: mid-late summer runoff moves to a drain at edge of field; then, on to a larger creek
Proximity to surface waters: During the spring and summer, a drainage ditch along one edge of the orchard often contains irrigation runoff water from adjacent lands.
Pesticide mixing and loading: A pesticide mixing & loading area is located about 40 feet from the drainage ditch.

We begin the risk assessment with Flowchart number 1 (FC1), considering possible routes by which pesticide could move off the field and the operations or conditions that may contribute to the movement. The two possible areas of concern are:

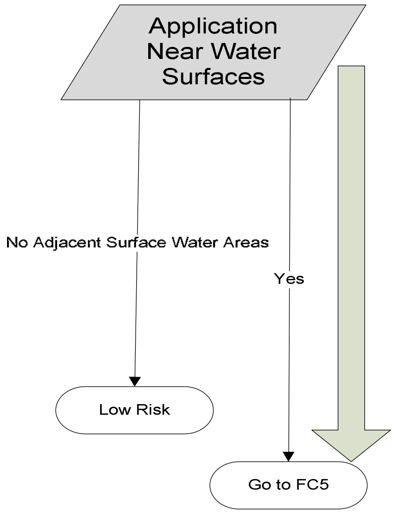
1) **FC1. Irrigation runoff risk.** Pesticides may be carried in the runoff that occurs during surface irrigation after the pesticide application. Go to FC3.



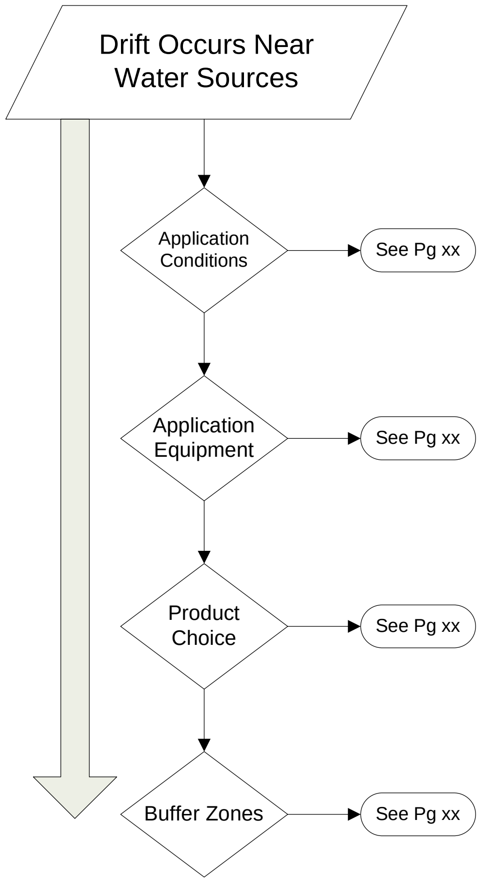
Flowchart 3 (FC3). Pressurized Irrigation Runoff Risk. If runoff occurs, this leads us first to an assessment of IPM practices, pesticide selection, mixing and loading practices and, in the management section, ways these can be improved. Following this, the flowchart leads us to consider irrigation management, methods to reduce runoff volume, capturing, filtering, and recycling and, finally, ways that runoff water–if it still occurs, could be treated to reduce any pesticide residues it may contain.



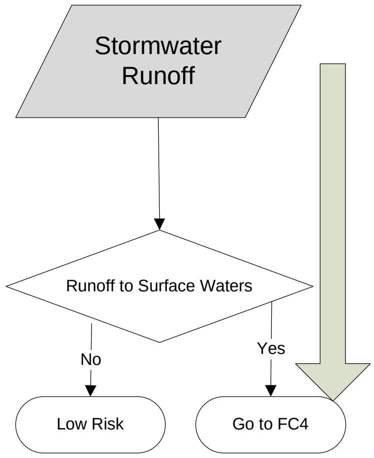
1) **Beginning again at FC1. Spray Drift to Open Water Risk.** During spray applications, pesticides may drift into the drainage ditch along the edge of the field; Go to FC5.



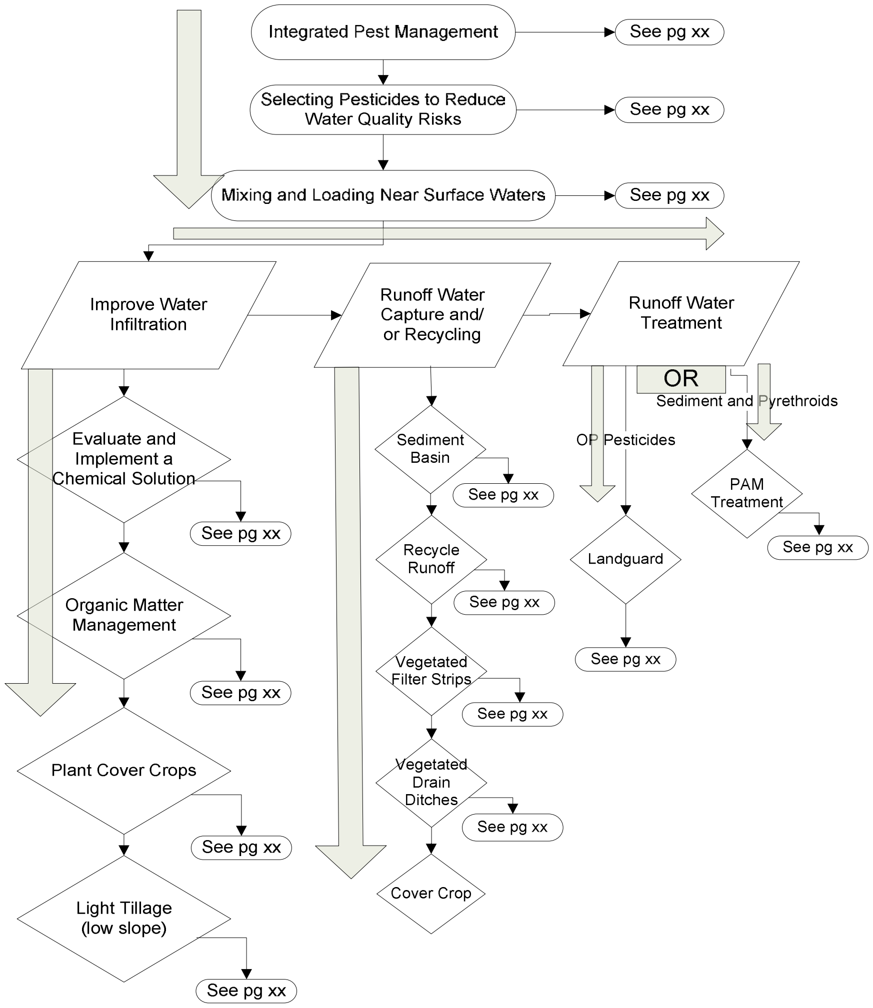
Flowchart 5 (FC5) Spray Drift to Open Water Risk presents various factors related to drift control. Each factor leads to a portion in the management information section of the manual where drift management practices are discussed.



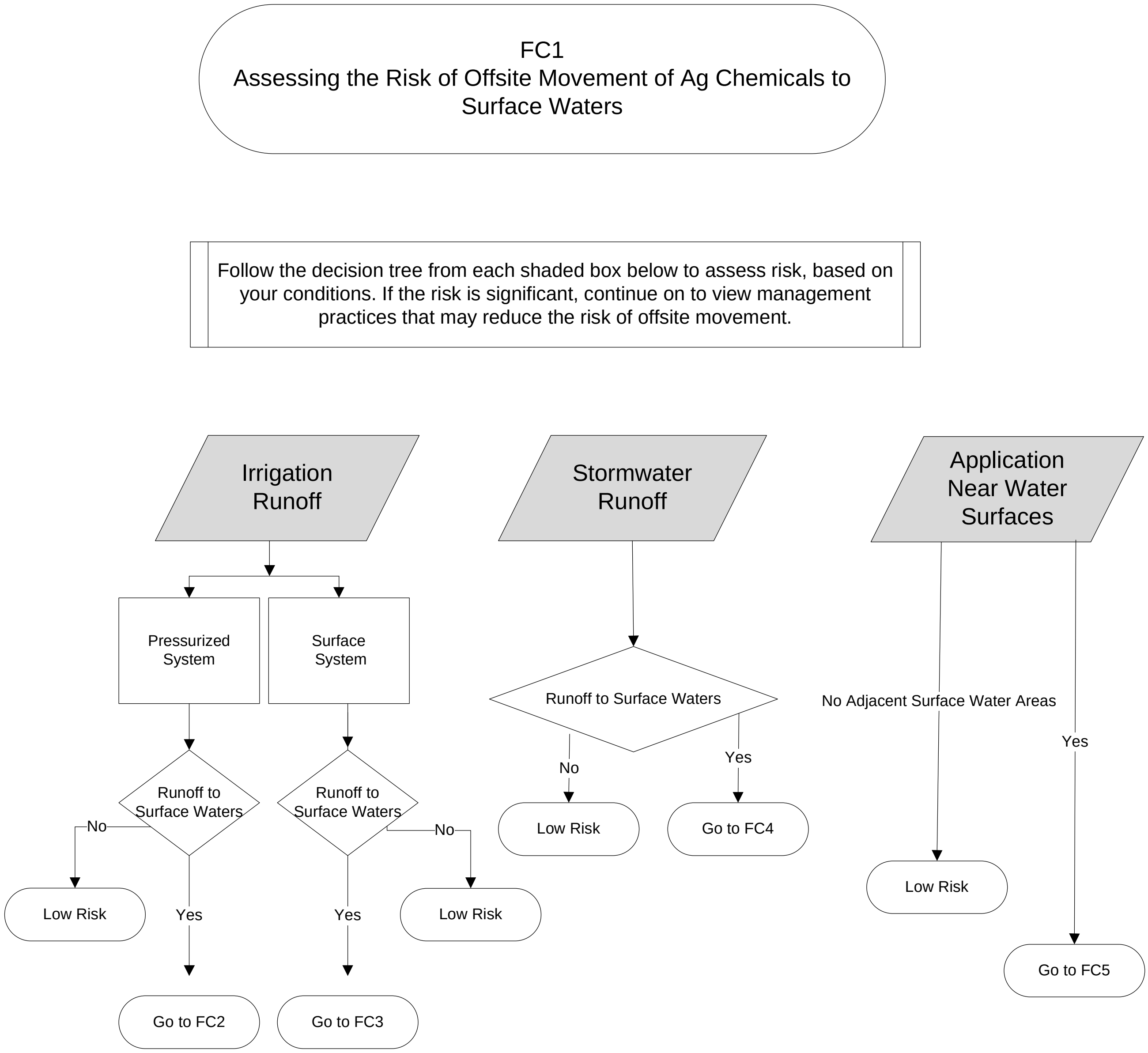
3) Beginning again at FC1. Stormwater Runoff Risk. Pesticides may be carried in the stormwater runoff as dissolved and sediment adsorbed residues. Since applications occur during the crop season, the risk is generally low; however persistent insecticides can still contribute to surface water degradation during stormwater runoff. Go to FC4.

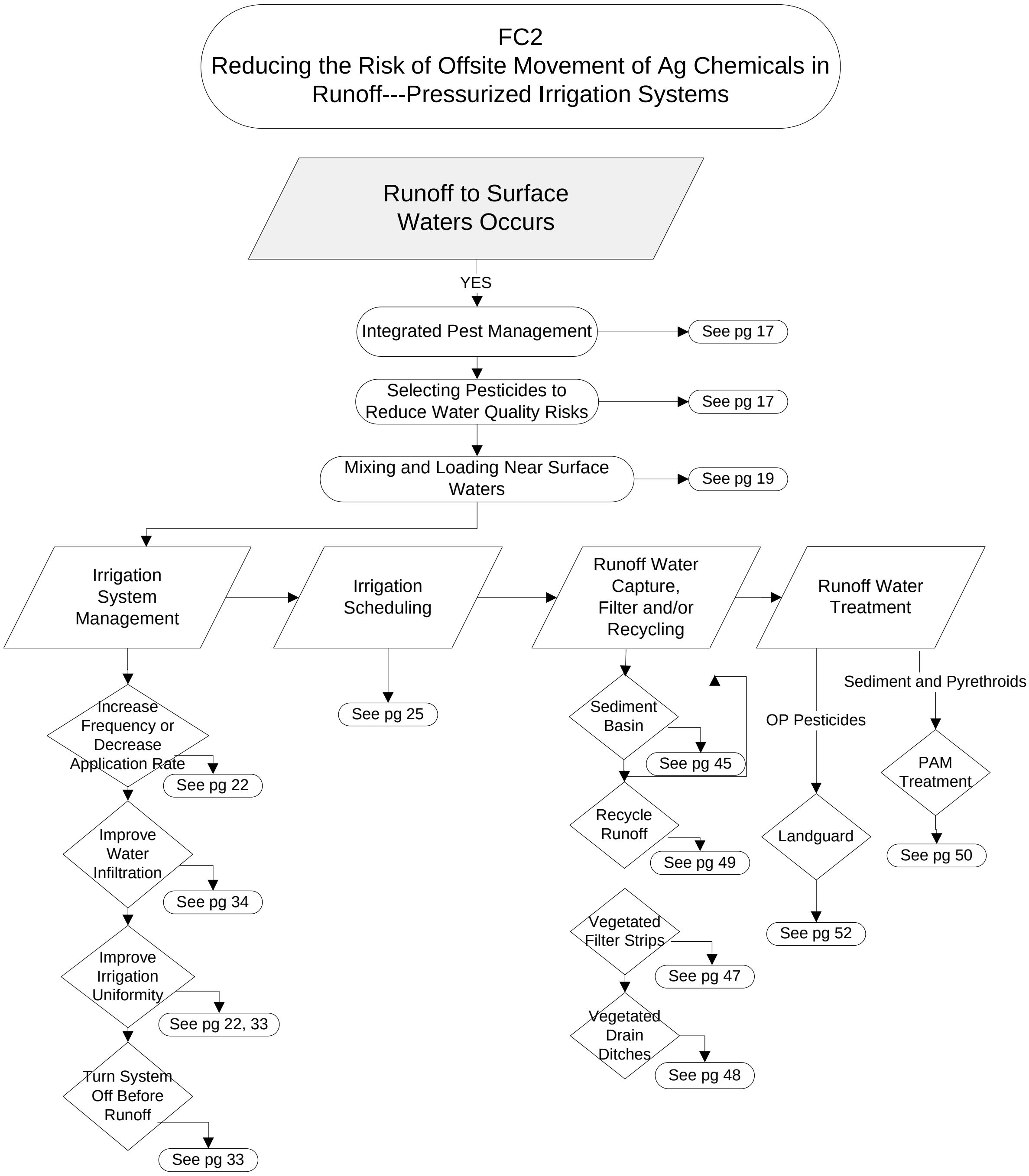


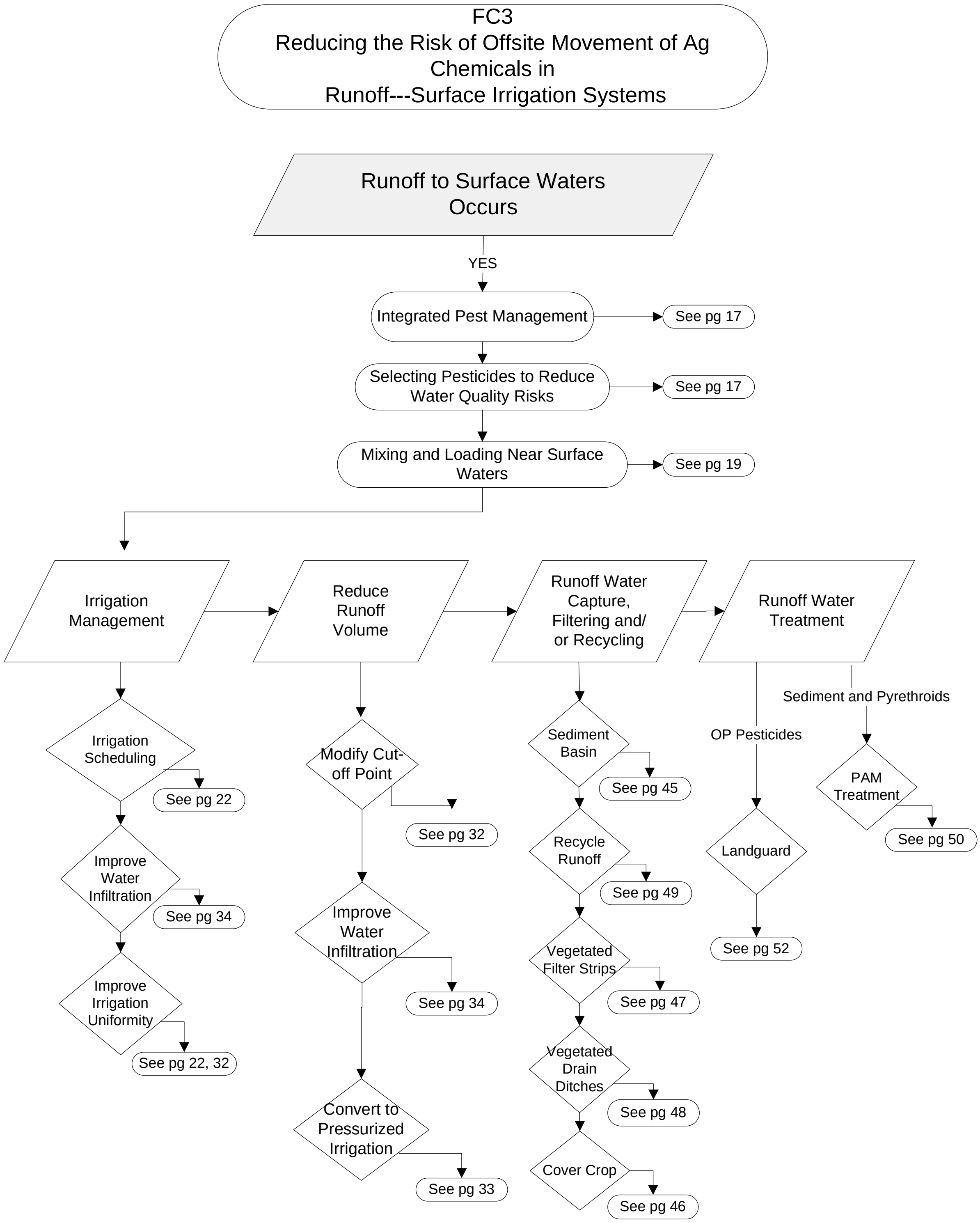
Flowchart 4 (FC4) Stormwater Runoff Risk presents various factors related to stormwater runoff risks. Each factor leads to a portion in the management information section of the manual where management practices are discussed to reduce pesticide residues in stormwater runoff.

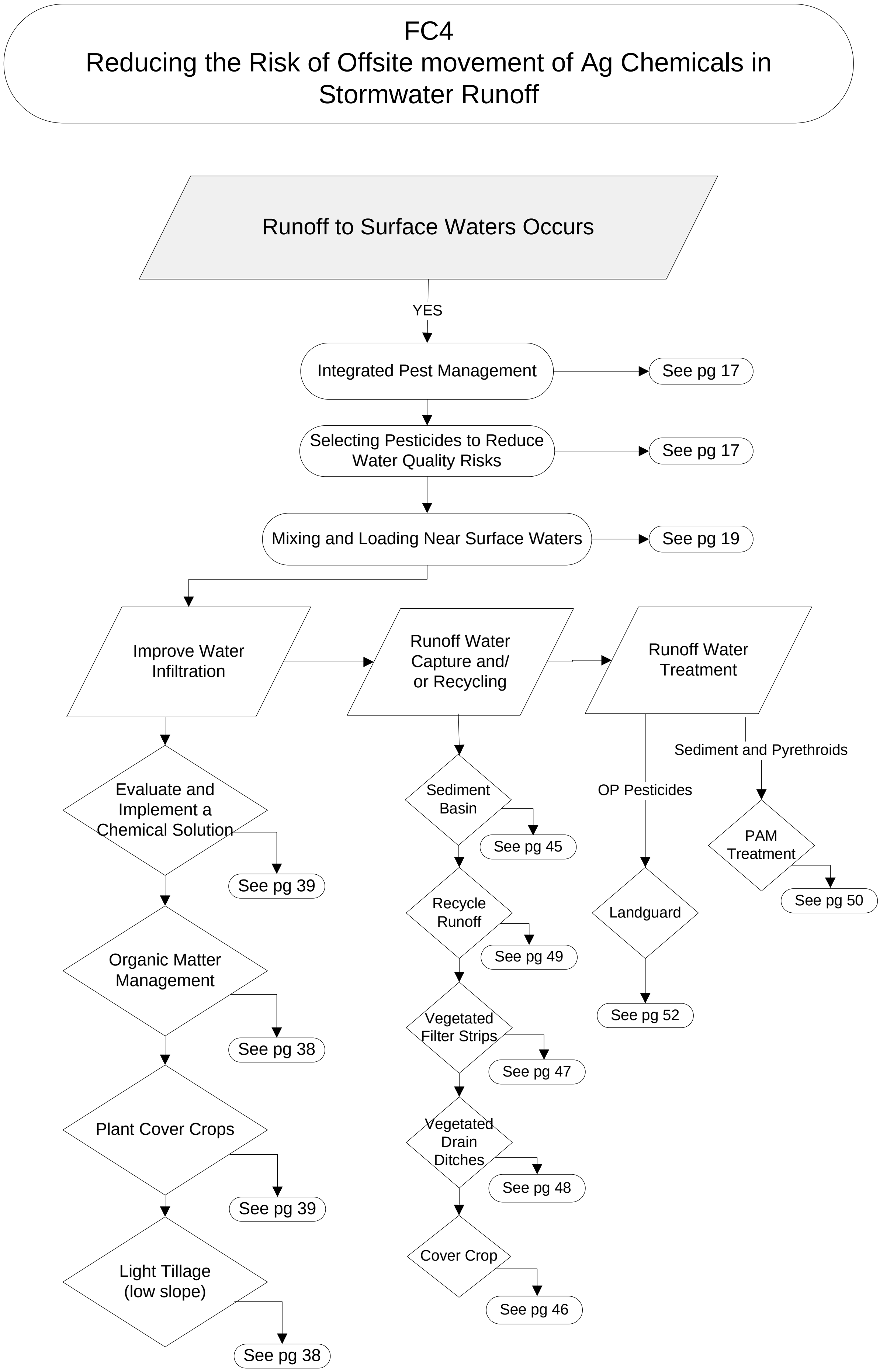


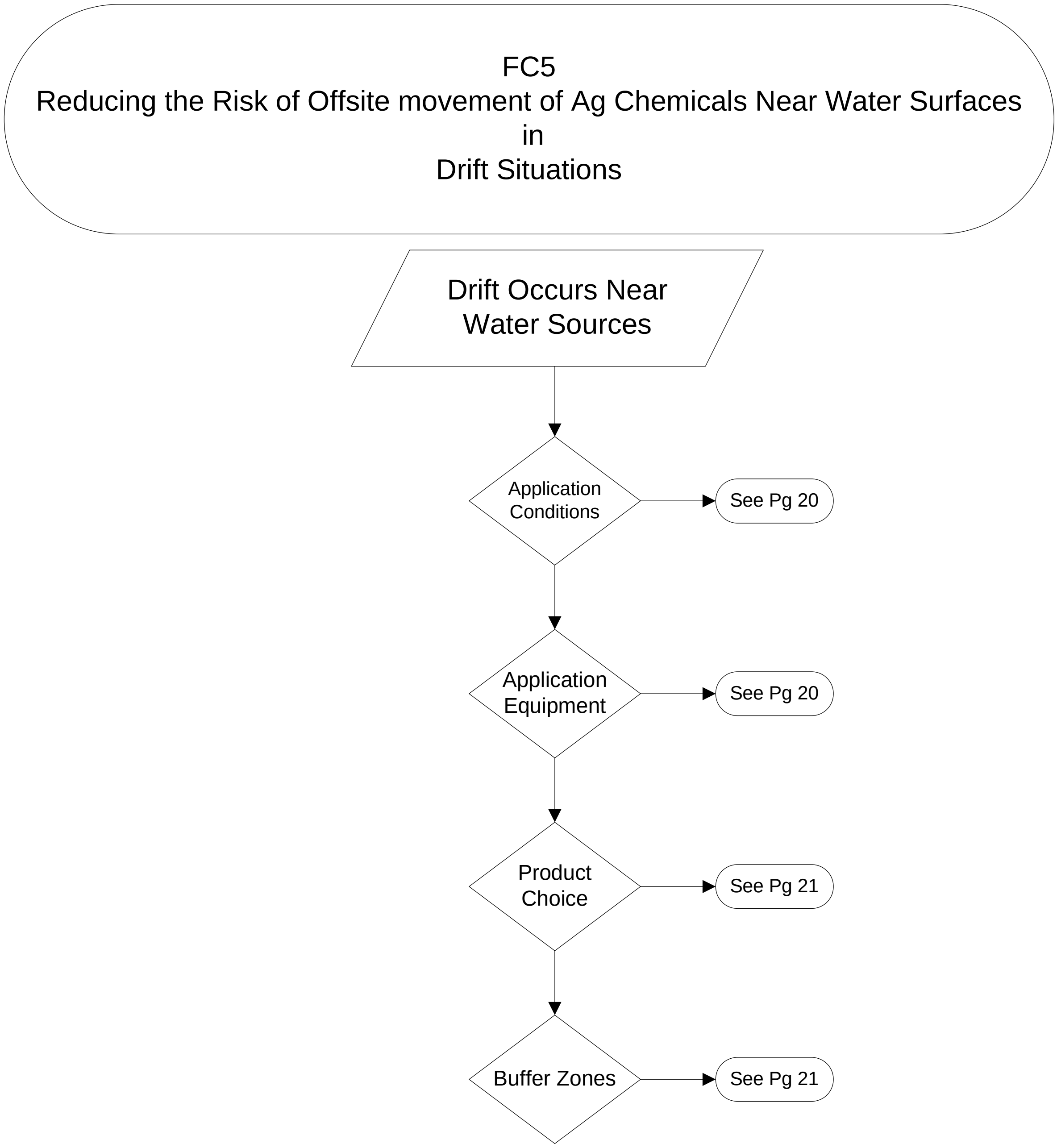
RISK EVALUATION FLOWCHARTS




FC2
Reducing the Risk of Offsite Movement of Ag Chemicals in Runoff---Pressurized Irrigation Systems
Runoff to Surface Waters Occurs
YES
Integrated Pest Management
See pg 17
Selecting Pesticides to Reduce Water Quality Risks
See pg 17
Mixing and Loading Near Surface Waters
See pg 19
Irrigation System Management
Irrigation Scheduling
Runoff Water Capture, Filter and/or Recycling
Runoff Water Treatment
Increase Frequency or Decrease Application Rate
See pg 22
Improve Water Infiltration
See pg 34
Improve Irrigation Uniformity
See pg 22, 33
Turn System Off Before Runoff
See pg 33
See pg 25
Sediment Basin
See pg 45
Recycle Runoff
See pg 49
Vegetated Filter Strips
See pg 47
Vegetated Drain Ditches
See pg 48
OP Pesticides
Landguard
See pg 52
Sediment and Pyrethroids
PAM Treatment
See pg 50


FC3
Reducing the Risk of Offsite Movement of Ag Chemicals in
Runoff---Surface Irrigation Systems
Runoff to Surface Waters Occurs
YES
Integrated Pest Management
See pg 17
Selecting Pesticides to Reduce Water Quality Risks
See pg 17
Mixing and Loading Near Surface Waters
See pg 19
Irrigation Management
Reduce Runoff Volume
Runoff Water Capture, Filtering and/ or Recycling
Runoff Water Treatment
Irrigation Scheduling
See pg 22
Improve Water Infiltration
See pg 34
Improve Irrigation Uniformity
See pg 22, 32
Modify Cut-off Point
See pg 32
Improve Water Infiltration
See pg 34
Convert to Pressurized Irrigation
See pg 33
Sediment Basin
See pg 45
Recycle Runoff
See pg 49
Vegetated Filter Strips
See pg 47
Vegetated Drain Ditches
See pg 48
Cover Crop
See pg 46
OP Pesticides
Landguard
See pg 52
Sediment and Pyrethroids
PAM Treatment
See pg 50


FC4
Reducing the Risk of Offsite movement of Ag Chemicals in Stormwater Runoff
Runoff to Surface Waters Occurs
YES
Integrated Pest Management
See pg 17
Selecting Pesticides to Reduce Water Quality Risks
See pg 17
Mixing and Loading Near Surface Waters
See pg 19
Improve Water Infiltration
Runoff Water Capture and/ or Recycling
Runoff Water Treatment
Evaluate and Implement a Chemical Solution
See pg 39
Organic Matter Management
See pg 38
Plant Cover Crops
See pg 39
Light Tillage (low slope)
See pg 38
Sediment Basin
See pg 45
Recycle Runoff
See pg 49
Vegetated Filter Strips
See pg 47
Vegetated Drain Ditches
See pg 48
Cover Crop
See pg 46
OP Pesticides
Landguard
See pg 52
Sediment and Pyrethroids
PAM Treatment
See pg 50


FC5
Reducing the Risk of Offsite movement of Ag Chemicals Near Water Surfaces
in
Drift Situations
Drift Occurs Near Water Sources
Application Conditions
See Pg 20
Application Equipment
See Pg 20
Product Choice
See Pg 21
Buffer Zones
See Pg 21

MANAGEMENT PRACTICES TO REDUCE SURFACE WATER PESTICIDE CONTAMINATION

INTEGRATED PEST MANAGEMENT

The University of California Integrated Pest Management Programs defines IPM as:

> "…an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and non-target organisms, and the environment." http://ucipm.ucdavis.edu

IPM is a systematic approach to pest management. The decision process includes:

- proper pest identification;
- understanding pest life cycles and conditions conducive to infestation;
- monitoring for the presence, locations and abundance of pests and their natural enemies;
- treat when established action thresholds (economic, aesthetic, tolerance) are reached;
- consideration of multiple tactics for pest suppression – biological, cultural, and chemical—and selection of the lowest-risk practical and effective approach; and
- evaluate results.

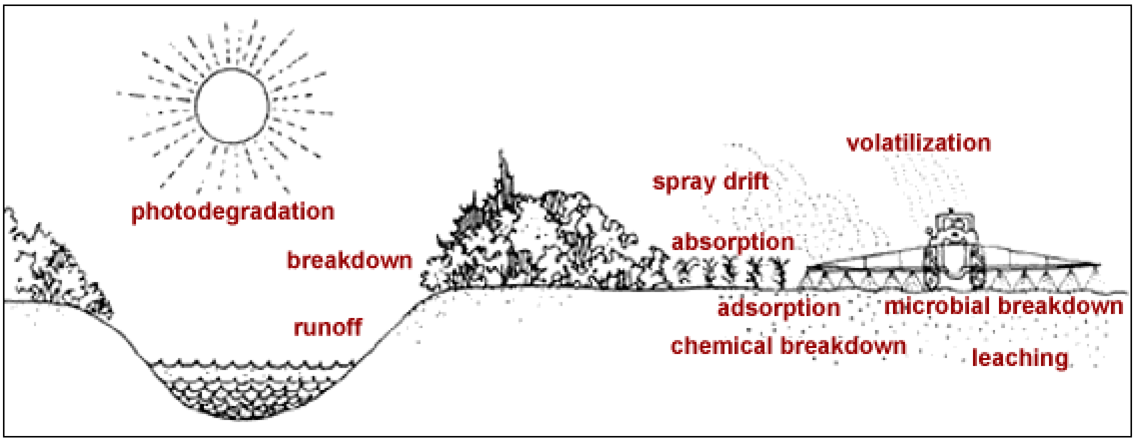
Because many print and on-line publications are available to help walnut growers use IPM in their orchards, they are not discussed in detail here. Walnut pest and disease biology, monitoring, management, as well as water quality considerations in selecting and using walnut pesticides, may be found in and from:

- The online UC IPM Guidelines for walnuts http://www.ipm.ucdavis.edu/PMG/selectnewpest.walnuts.html,
- The UC IPM Year Round Program for walnuts, with annual checklist http://www.ipm.ucdavis.edu/PMG/C881/m881yi01.html,
- Integrated Pest Management for Walnut Publication 3270,
- UC Walnut Production Manual Publication3373,
- Licensed Pest Control and Crop Advisers, and
- UC IPM Advisors and Farm Advisors.

SELECTING PESTICIDES TO REDUCE WATER QUALITY RISKS

Knowledge of how pesticides move and degrade in the environment is useful for product selection. Pesticides and pesticide residues can move along several different pathways, depending on properties of the pesticide, the application method, and conditions at the application site (Figure 1). This movement is a complex process and, combined with several other factors, influences a pesticide's fate and potential water quality impacts. From a surface water management perspective, keeping the pesticide on or in the soil by preventing runoff is the most desirable option.

Figure 1. Pesticide fate processes



Walnut pesticide active ingredients vary in water solubility, soil adsorption and half-life. Pesticides with high water solubility can move directly in runoff waters while those adsorbed to soil sediments (and generally with low water solubility) move with the sediment. Half-life is an indication of the persistence in the environment, usually the number of days it takes for the pesticide for one-half the amount in soil to degrade. The soil adsorption coefficient (Koc) can be considered an index for pesticide mobility. USDA-NRCS has a model that takes these characteristics into consideration in determining a pesticide's tendency to move in dissolved form with water or move with adsorbed to the sediments. The potential to move offsite, either in solution or with the soil, was categorized as high, intermediate, and low (Table 2.)

Aquatic toxicity rankings were extracted from the U.S. E.P.A. ECOTOX database (2007). The toxicity for EPA indicator species was then used to rank the overall aquatic risk (Long et al. 2005). The overall likelihood to cause negative impact (risk) on surface water quality is a product of the runoff potential and the aquatic toxicity of the pesticide. Table 2 indicates this relationship for commonly used insecticides in walnut production; products without a risk category listed here are new and/or not yet categorized in this system. The table can be used to select pesticides based on the risk of offsite movement to surface waters. A change in pesticide within a same class or to a different class can significantly reduce the environmental risk.

Table 2. California-registered walnut insecticides and their potential to move in solution or as adsorbed particles and overall pesticide runoff risk.

Insecticide active ingredient (common name)	Trade name	Chemical Class	Solution runoff potential[1]	Adsorption runoff potential[2]	Overall runoff risk[3]
diazinon	Diazinon	organophosphate	high	high	very high
chlorpyrifos	Lorsban	organophosphate	high	intermediate	very high
phosmet	Imidan	organophosphate	intermediate	low	moderate
malathion	Malathion	organophosphate	intermediate	low	moderate
Methyl parathion	Penn-Cap	organophosphate	intermediate	intermediate	moderate
permethrin	Pounce	pyrethroid	low	high	high
bifenthrin	Brigade	pyrethroid	low	high	high
esfenvalerate	Asana XL	pyrethroid	low	high	high
Lamda-cyhalothrin	Warrior	pyrethroid	low	intermediate	high
imidacloprid	Provado	neonicotinoid	high	intermediate	low
carbaryl	Sevin	carbamate	intermediate	low	moderate
hexythiazox	Savy	thiazolidine	high	intermediate	moderate
dicofol	Kelthane	organochlorine	high	high	high
propargite	Omite	organosulfur	high	high	high
methidathion	Supracide	organochlorine	Intermediate	low	moderate
pyriproxyfen	Esteem	pyridine	unlisted		
methyoxfenozoide	Intrepid	diacylhydrazine			
spinetoram	Delegate	spinosyn			
spinosad	Entrust	spinosyn	intermediate	intermediate	low
diflubenzuron	Dimilin	benzoylurea			
spirodiclofen	Endivor	keto-enol			
spirotetramat	Movento	keto-enol	intermediate	intermediate	low

[1] Likelihood that the active ingredient will transport from the area of treatment as dissolved chemical in runoff.

[2] Likelihood that the active ingredient will transport from the area of treatment as attachment to soil or sediment particles in runoff.

[3] Overall likelihood to cause negative impact on surface water quality as a product of the runoff potential and the aquatic toxicity of the pesticide

Source: Pesticide Choice: Best Management Practice for Protecting Surface Water Quality in Agriculture, Long et al. 2005, UCANR Publication 8161, http://anrcatalog.ucdavis.edu/pdf/8161.pdf

HANDLING PESTICIDES TO REDUCE WATER QUALITY RISKS

The risk of offsite pesticide movement is great during mixing and loading due to the possible spillage of undiluted pesticides. Care should be taken to ensure all of the pesticide goes in the tank. Partially fill the tank with water prior to adding the pesticide to prevent high strength materials entering spray lines. Agitation and the use of a bypass can assist good mixing. Avoid over filling the tank, because spillage can move offsite aided by cleanup waters. Mix and load at a distance of greater than 50 feet from sensitive areas (open surface water)—more if there is a potential for movement in the direction of the sensitive area. Triple rinse pesticide containers and pour the rinsate into the sprayer tank for use on the field. Also apply tank rinse water to the field. The use of a concrete pad with a catchment sump is a good way to reduce risks from mixing and loading near surface water sources.

PESTICIDE APPLICATION PRACTICES TO REDUCE OFFSITE PESTICIDE MOVEMENT

Minimizing Spray Drift

Drift is the physical movement of pesticide droplets or particles through the air at the time of pesticide application or soon thereafter, from the target site to any non- or off-target site. All applications produce some drift. How much drift occurs depends on such factors as the formulation of the material applied, how the material is applied, the volume used, and prevailing weather conditions at the time of application, and the size of the application job. Drift can impact surface water quality through direct contact with open ditches or surface water adjacent to the treated field.

Spray drift can be mitigated by management practices to reduce off-target drift. Application practices that take weather and other site conditions into consideration, appropriately equipped delivery systems (low-drift nozzles), appropriate product choice (low vapor pressure, low water solubility), and the use of buffer zones can significantly reduce the risk of offsite movement of pesticides.

Application Conditions

- Don't apply pesticides under dead calm or windy/gusty conditions; don't apply at wind speeds greater than 10 mph, ideally not over 5 mph. Read the label for specific instructions.
- Apply pesticides early in the morning or late in the evening; the air is often more still than during the day.
- Determine wind direction and take it into account when deciding whether or not or how to make an application.
- Calibrate and adjust sprayers to accurately direct the spray into the canopy "target."
- Delay treatments near ditches and surface water bodies until wind is blowing away from these and other sensitive areas.
- Don't spray during thermal inversions, when air closest to the ground is warmer than the air above it.

Application Equipment

- Use as coarse a spray as possible (250 - 400 microns or larger) while still obtaining good coverage and control. Droplet size is one of the most important factors affecting drift.

- Use low drift nozzles that produce larger droplet sizes. Fitting a sprayer with air induction nozzles instead of standard nozzles will reduce spray drift up to 50 percent compared to standard nozzles.
- Use a directed spray to minimize the contact with soil.
- Check to verify the spray deposition pattern expected.
- Service and calibrate spray equipment regularly.
- Check the system for leaks. Small leaks under pressure can produce very fine droplets. Large leaks contaminate soil which can be moved offsite by water.
- Use low pressure and spray volumes appropriate for canopy size.

Product Choice

- Choose an application method and a formulation that are less likely to cause drift. After considering the drift potential of a product/formulation/application method, it may become necessary to use a different product to reduce the chance of drift.
- Use drift control/drift reduction spray additives/agents. These materials are generally thickeners designed to minimize the formation of droplets smaller than 150 microns. They also help produce a more consistent spray pattern and deposition.
- Use spray adjuvants, which can greatly reduce application volumes without compromising pesticide efficacy.
- Use maximum spray volume per acre and low pressure.
- Treat buffer zones with materials that are the least risk to aquatic life.

Buffer Zones

- Maintain adequate buffer zones around the treated site to ensure that pesticides don't drift onto sensitive areas. Read the label to determine the size of buffer zone required as related to the rate of active ingredient.
- Wolf et al. (2003) documented 75 to 95 percent reductions in drift deposits up to 98 feet downwind when setback distances were vegetated with grass or shrubs.

IRRIGATION WATER MANAGEMENT TO REDUCE RUNOFF

Irrigation management entails assessing the orchard's water needs and applying irrigation water to supplement stored winter moisture. Irrigation frequency and duration should ensure that all water infiltrates such that plant water use is met while preventing water loss through runoff and deep percolation. The extent of runoff depends on several factors, including: 1) the slope or grade of an area; 2) the texture and moisture content of the soil; 3) how well the soil surface supports water infiltration; 4) the amount and timing of irrigation or rainfall. Runoff containing pesticides can cause direct injury to non-target species, harm aquatic organisms in streams and ponds, and lead to groundwater contamination.

Walnut Orchard Irrigation Systems

Two basic types of irrigation systems are used in walnut production: surface systems (furrow, or border-check), and pressurized systems (sprinklers and microirrigation). Each has distinct cultural, cost, and offsite movement advantages and disadvantages. Some disadvantages can be overcome using specific management practices.

In *pressurized irrigation systems,* water should be applied at a slower rate than it is absorbed by the soil, to prevent runoff. However, as irrigation progresses the infiltration rate declines, making runoff more likely. In order to prevent runoff, the system should be turned off before significant runoff occurs. When properly managed, pressurized irrigation systems cause no irrigation water runoff, effectively reducing the risk of pesticide residue moving offsite.

In *surface systems,* soil characteristics control the amount of water infiltrated and its distribution across the field as it travels down slope. Runoff is necessary to maximize distribution uniformity (how even the water is applied across the field) within the field. Limiting runoff after a reasonable uniformity has been achieved is a good practice to reduce the continued movement of residues offsite. Closed-end furrows used on relatively flat ground can also eliminate runoff. The successful use of this practice relies on a high infiltration rate and precise irrigation cutoff. Lastly, an irrigation recycling system can capture runoff and return it to the irrigation inflow, to be applied to adjacent sets or another field. At sites with runoff risks, changing from surface irrigation to pressurized irrigation is recommended when possible.

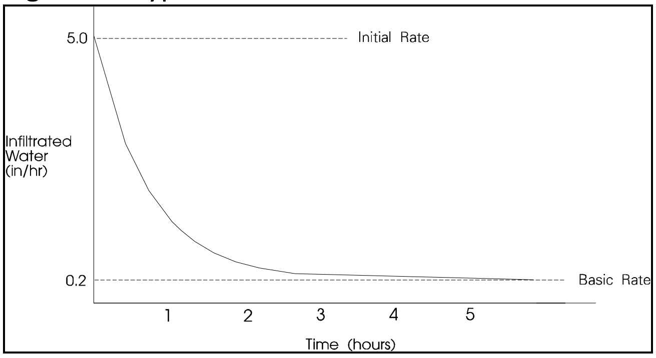
Growers must determine the amount of irrigation water to apply, when to apply it, and the **most efficient** method of irrigation for a given set of conditions. That avoids problems associated with over- or under-irrigating. The goal is to maintain root zone moisture content at a level that will encourage vegetative growth and not reduce yield or quality in the current or subsequent years.

Surface Irrigation Systems

Surface irrigation systems (flood, border-check, and furrow irrigation), while being the simplest irrigation systems with regard to hardware, are the most difficult ones to manage properly. Control of runoff water is essential for controlling offsite movement of pesticides, sediments, and nutrients.

With surface methods, water is applied to the soil surface and gravity moves the water across the field. Soil characteristics control both the rate at which water enters the soil and its distribution across the irrigated area. As irrigation begins, the rate at which water enters the soil is high, primarily because of soil dryness and easy access to the soil pores. As irrigation proceeds, the infiltration rate declines rapidly to a basic or sustained rate. Figure 2 shows the typical relationship between the amount of water infiltrated into the soil and hours of irrigation.

Figure 2. Typical water infiltration characteristics.



A soil's water intake characteristics depend on both its physical and chemical composition as well as the chemical composition of the water. Irrigation water containing very low salt content or higher sodium and/or bicarbonate levels can reduce infiltration rates. For more information, see the section: “Reducing Runoff by Improving Water Infiltration.”

In general, the objective of any irrigation system is to have water infiltrating for the same length of time in all parts of the field. This is difficult to accomplish with furrow systems because it takes time for water to flow, starting from the head of field, down the furrow to the end of the field (called “advance time”) resulting in a variable time for infiltration. This shorter time that water is in contact with the soil means less water is infiltrated.

For surface irrigation, the head of the orchard irrigation run almost always has more water applied to it than the tail of the run. The exception is if water is allowed to pond at the end of the row. The part of the field which gets the least water applied to it is frequently at approximately 2/3 to 3/4 of the distance down the row. Often, water onflow rate to the furrow or check is increased to get water down the row more quickly and improve irrigation uniformity. Unfortunately, this practice will increase runoff volume.

In general, it is advantageous to keep furrows or checks as short as practical, which keeps irrigation uniformity high. The tradeoffs with short furrows or checks are increased labor, pipeline costs and increased runoff volumes. Tailwater return systems can be used with these irrigation systems to increase their efficiency and eliminate discharges.

One difficulty with managing surface irrigation systems is measuring the water going onto the field. If water supplies are from a pump, a flow meter such as a propeller meter can be installed in the outlet pipe. Following the manufacturer's recommended installation criteria is important for accurate measurements. If water supplies are from an open ditch, etc., water measurement is difficult. Consulting the irrigation district may help in getting a good estimate of the flow rate to the field.

The following formula may be used to determine the average amount of water applied to a field using a meter that indicated cubic feet per second (cfs).

$$D = Q \times T / A$$

Where D = depth of applied water (inches), Q = flow rate into the field (cubic feet per second), T = time required to irrigate the field (hours), and A = acres irrigated

Note: If the flow meter reads in gallons per minute (gpm) rather than in cubic feet per second (cfs), the conversion is as follows:

1cfs = 449 gpm

An example:

Flow = 2.67 cfs (1200 gpm)
Irrigation on time = 24.7 hours
Area = 8 acres

$$\frac{2.67\text{cfs} \times 27.7 \text{ hours}}{8 \text{ acres}} = 3.3 \text{ inches (Depth of water applied)}$$

Depth of water applied in the above formula should match the amount of water used by the crop since the last irrigation and is roughly equivalent to evapotranspiration (ET) (see section: "Irrigation Scheduling to Meet Crop Requirements"). Remember that some additional water should be applied because no irrigation system is 100 percent efficient. The efficiencies of furrow-irrigated fields are generally lower than with pressurized irrigation systems.

Measuring distribution of infiltrated water under surface systems is difficult at best. The overall goal is to provide near equal opportunity time along the length of the furrow.

<u>Pressurized Irrigation Systems</u>

Pressurized orchard irrigation systems include full coverage sprinkler and microirrigation systems. Microirrigation systems encompasses smaller volume less than full coverage sprinklers called micro or minisprinklers and drip systems. Drip systems allow small amounts of water to be applied slowly and frequently through emitters spaced along polyethylene tubing. When properly designed and operated, pressurized systems apply water uniformly than surface systems.

Unlike surface irrigation systems or full coverage sprinklers where soil water is recharged on an infrequent basis and then drawn down by tree use, microirrigation, by virtue of frequent applications, can be operated to replace water used by the tree. The process occurs on a time scale a few days.

Irrigation Scheduling to Meet Orchard Water Requirements

Walnuts orchards use soil-stored winter rainfall and irrigation water to meet their demands for water. Water use begins at a low level as trees leaf out in spring when climatic conditions are mild; it increases as the canopy develops and the climatic demand increases, maximizing in July – August time period. Water use declines after this period, through leaf drop.

Crop water use or evapotranspiration (ET) is the sum of plant water use (transpiration) and evaporation from the soil surface. Climate factors affecting the crop evapotranspiration include solar radiation, temperature, wind, and humidity. Plant and soil factors affecting evapotranspiration include plant type, canopy size, health of the plant, and available soil moisture.

Irrigations should be applied to: (1) meet the variable crop requirements over the season, (2) be distributed evenly to maximize irrigation efficiency and facilitate the uptake of nutrients, and (3) minimize saturated soil conditions that encourage diseases and result in excess runoff. Some water in excess of the crop requirement may be needed to maintain a favorable salt balance in the root zone.

Estimating Orchard Water Requirements

The best way to determine the irrigation requirement is using climatic data and a specific orchard's characteristics to estimate the volume of water consumed by the orchard.

Walnut orchard ET can be estimated using the following formula:

$$ETc = ETo \times Kc$$

Where ETc is the crop water use, ETo is the reference evapotranspiration for a given area, and Kc is a crop coefficient.

ETc in inches of water can be time-framed to the day, week, month or season in order to assess the orchard's water requirements for irrigation scheduling purposes.

The reference ET information is available from a network of over 100 CIMIS (California Irrigation Management System) weather stations that provide daily reference evapotranspiration values. Two good web-based sources are the UC Statewide Integrated Pest Management website (www.ipm.ucdavis.edu) and the California Department of Water Resources CIMIS website (http://www.cimis.water.ca.gov). Some newspapers and irrigation districts also provide CIMIS ETo data. The CIMIS program provides real time, current values. Historical or long-term average ETo can be more convenient than real-time ETo information and can be used to prepare an irrigation plan well ahead of the irrigation season. Table 3 lists historical daily values for ETo for selected Central Valley locations.

Table 3. Historical crop evapotranspiration reference (inches/day)
for various California Central Valley locations

		Hanford	Manteca	Davis	Durham
Jan	1-15	0.04	0.04	0.03	0.03
	16-31	0.05	0.05	0.05	0.05
Feb	1-15	0.06	0.07	0.06	0.06
	16-28	0.09	0.09	0.09	0.09
Mar	1-15	0.11	0.11	0.09	0.09
	16-31	0.15	0.14	0.14	0.12
Apr	1-15	0.20	0.17	0.18	0.16
	16-30	0.22	0.19	0.28	0.17
May	1-15	0.23	0.22	0.23	0.21
	16-31	0.27	0.23	0.24	0.22
Jun	1-15	0.29	0.26	0.28	0.25
	16-30	0.30	0.27	0.29	0.26
Jul	1-15	0.30	0.27	0.29	0.27
	16-31	0.28	0.25	0.27	0.25
Aug	1-15	0.28	0.24	0.26	0.24
	16-31	0.25	0.22	0.24	0.21
Sep	1-15	0.23	0.19	0.21	0.19
	16-30	0.20	0.16	0.18	0.16
Oct	1-15	0.17	0.13	0.16	0.14
	16-31	0.13	0.10	0.12	0.10
Nov	1-15	0.10	0.07	0.09	0.07
	16-30	0.07	0.05	0.06	0.05
Dec	1-15	0.05	0.04	0.05	0.04
	16-31	0.03	0.04	0.04	0.03

The Crop Coefficient (Kc) is a factor that is used with reference evapotranspiration values (ETo) to estimate water use (ETc) in a mature non-water stressed orchard. An orchard is considered to be mature when about 62% or more of the orchard floor is shaded at midday. Kc's have been experimentally determined for various times through the growing season. Table 4 shows the calculations for determining mature walnut orchard water use, in two-week periods, from leaf out to leaf drop using the reference ETo from the CIMIS station #70 located near Manteca, California. Historical ETo daily and summed values for different time scales are available for the Manteca (#70 and Lodi #166) CIMIS stations based on the past 20 years of data:
http://ucanr.org/sites/CE_San_Joaquin/Custom_Program/Publications_Available_for_Download/

Monthly averages from all CIMIS stations are available from the CIMIS Web site: www.cimis.water.ca.gov.

Generally, cover crops in orchards are using water in the winter and before leaf-out. Their water use during this time, if in excess of rainfall, will decrease the amount of water in storage at leaf-out. Cover crops growing during the tree growing season, if extensive in coverage, can increase water use about 25 percent over the values in Table 4.

Table 4. Irrigation Scheduling Using ETo Values Based on a 20-year Average.
Manteca, CIMIS Station 70
Leaf out: 3/15; Leaf drop: 11/15
No cover crop

Date	Evapotranspiration Reference ETo	Crop Coefficient KC	Water Use (inches) ETc	Cumulative Inches ETc
Mar 16-31	2.3	0.12	0.28	0.3
Apr 1-15	2.5	0.53	1.34	1.6
Apr 16-30	2.9	0.68	1.96	3.6
May 1-15	3.3	0.79	2.59	6.2
May 16-31	3.6	0.86	3.14	9.3
Jun 1-15	3.8	0.93	3.53	12.8
Jun 16-30	4.0	1.00	3.98	16.8
Jul 1-15	4.1	1.14	4.66	21.5
Jul 16-31	3.9	1.14	4.49	26.0
Aug 1-15	3.7	1.14	4.16	30.1
Aug 16-31	3.5	1.14	3.98	34.1
Sep 1-15	2.9	1.08	3.12	37.2
Sep 16-30	2.4	0.97	2.30	39.5
Oct 1-15	2.0	0.88	1.73	41.3
Oct 16-31	1.6	0.51	0.79	42.1
Nov 1-15	1.1	0.28	0.30	42.4

Young trees (those with less than 62% shaded orchard floor measured at midday) are generally better irrigated using soil based monitoring. Monitoring soil moisture can often be more critical in young trees than a mature orchard due to the greater potential for excessive soil water saturation leading to root disorders.

Determining Irrigation Amount.

Once the crop water requirement is determined for some period of time (bi-weekly in Table 5), the demand can be met by different sources of water. Water can be available from stored soil moisture, effective in-season rainfall or applied as irrigation.

If rainfall occurs that increases the soil water content (called effective rainfall) during these periods, it must be subtracted from the ETc, effectively reducing the irrigation requirement. Most feel that, for rainfall to be effective, it must occur in a quantity that exceeds the daily reference ETo by a factor of three. As an example, a rainstorm on April 25 would have to be 0.6 inch to exceed the 0.2-inch ETo average for that date. The method used to approximate the effective in-season rainfall in this case is: inches of rainfall -0.6 = inches of effective rainfall.

Soil storage plays an important role in the seasonal irrigation requirement. Soils hold stored water at leaf-out for subsequent tree use. The amount of winter rainfall stored for subsequent tree use is generally about one half the total winter rainfall if the water holding capacity of the rootzone is large enough to hold that amount. When soil storage is full, the amount varies primarily by soil texture and rootzone depth. Table 6 shows the available soil moisture in inches of water per foot of soil for various soil textures. This amount of water (inches per foot of soil) is multiplied times the rootzone depth in feet to estimate the available soil water. About one half of this value is easily available before tree stress begins. This value (one half the available moisture content) can be subtracted out of the seasonal use when calculating the net irrigation amount for the season. The importance of amount of soil moisture in irrigation scheduling diminishes as midsummer is reached since a substantial portion has been consumed, allowing scheduling to occur based on ETc alone.

Table 6. Available Soil Moisture Content in Inches of Water per Foot of Soil for Various Soil Textures

Soil Texture	Available Moisture Content
Sand	0.7
Loamy Sand	1.1
Sandy Loam	1.4
Loam	1.8
Silt Loam	1.8
Sandy Clay Loam	1.3
Sandy Clay	1.6
Clay Loam	1.6
Silty Clay Loam	1.9
Silty Clay	2.4
Clay	2.2

Once the orchard net irrigation requirement has been determined, the irrigator must account for losses such as evaporation, runoff, or deep percolation. These losses depend on both the irrigation system type and management. Surface irrigation (border check and furrow) can have substantial runoff losses and has larger variability in infiltration than pressurized systems. This variability in infiltration requires additional water be applied to achieve a minimum amount of water to all parts of the orchard. Sprinkler irrigation systems have greater application uniformity, less deep percolative losses and little if any runoff when compared to surface systems. Drip and microsprinkler systems have the advantages of sprinkler systems and additionally have less evaporative losses. To account for these differences between systems, we use a term irrigation efficiency to adjust the applied irrigation water amount to meet the orchard water requirement.

Table 5. Estimated application efficiency (percent)of irrigation systems (Hanson 1995)

System Type	Estimated Efficiency
Surface Irrigation	70-85*
Sprinkler	70-80
Microirrigation	80-90

**Efficiency reflects the use of a tailwater capture and return system. If not available, reduce by 15%*

To adjust the application amount for system efficiency, divide the net amount to be applied by the system efficiency factor. For example, to supply 2.7 inches of water to a sprinkler-irrigated orchard would require that 2.7 x 0.75 = 3.6 inches of water be applied to the orchard. This amount is called the gross irrigation application which ensures adequate water is applied to the areas of the orchard receiving the least water.

Determine Irrigation Application Time (duration)

The irrigation application time for a surface irrigation system is determined by simply dividing the amount of water applied by the land area it is applied to. For example, the duration of irrigation can be calculated by:

$$T= (A \times D) / Q$$

Where T = time required to irrigate the field (hours), A = acres irrigated, D = depth of applied water (inches), and Q = flow rate into the field (cfs). 1cfs = 449 gallons per minute

Furrow and border-check irrigation. Using an example of 4.0 inches ETc for two week period in June (Table 6.), and an efficiency of 75% using a tailwater recovery system, and a 20-acre field with a 1200 gallon per minute supply the on time would be:

$$T= (20 \times 3.6) / 2.67 = 27 \text{ hrs}$$

Once the irrigation amount and timing of irrigation is determined to meet the crop water use, the application can be problematic and site-specific. When using surface irrigation on high infiltration soils, it may be difficult to apply the relatively small amount of water (3.6 inches in our example) due to the large amount of water required to move water down the furrow or check and the time to advance the water to the end of the field. Excess infiltrated water would percolate below the rootzone. The selection of appropriate onflow volumes and cutoff times discussed below can minimize over application of water.

Sprinkler and drip irrigation. To determine the irrigation time for hand-move sprinklers:

$$T = D / AR$$

Where = T = time of irrigation (hours), D = depth of water (inches), and AR = application rate (inches/hour).

Using our example for a one week net irrigation in the last half of June, the gross applied water is 2.7 inches. The application rate is 0.10 inch per hour. The on time would be:

$$T = 2.7 / 0.10 = 27 \text{ hrs}$$

Check Up on the Calculations and Applications

The climate-based method described above for determining orchard water needs gives an estimate of demand which should be verified and fine-tuned by soil or plant-based monitoring of actual orchard water status.

There are many soil moisture-monitoring devices which measure soil moisture content and soil tension (Schwankl and Prichard 2009). If decreasing soil water occurs over the season or an increase in soil water tension is evident, too little irrigation was applied. If soil water content increases or tension is reduced progressively after each irrigation, too much applied water is indicated.

In contrast to soil-based methods, which assess how soil moisture responds to irrigation applications and tree water use, plant-based monitoring, performed using a pressure chamber to measure actual tree water status, allows for direct and timely assessments of tree water status - referred to as stem water potential (SWP) - as it changes in relation to water applications and use. Research has shown that SWP readings are an accurate and reliable indicator of tree water status and, as such, can be used very effectively to “fine-tune” irrigation scheduling decisions and evaluate impacts of those decisions on orchard status. Table 7 summarizes tentative guidelines developed for interpreting pressure chamber readings in walnuts based on research trials.

Table 7. tentative guidelines for interpreting pressure chamber readings (midday stem water potential-SWP) in walnut
Allan Fulton and Richard Buchner, UCCE Farm Advisors, Tehama County,
Joe Grant, Farm Advisor, San Joaquin County,
Terry Prichard, Bruce Lampinen, Larry Schwankl, Extension Specialists, UC Davis,
and Ken Shackel, Professor UC Davis

Pressure Chamber Reading (- bars)	**Crop: Walnut**
0 to –2.0	Not commonly observed
-2.0 to –4.0	Fully irrigated, low stress, commonly observed when orchards are irrigated according to estimates of real time evapotranspiration (ETc), long term root and tree health may be a concern
-4.0 to –6.0	Low to mild stress, high rate of shoot growth visible, suggested level from leaf-out until mid June when nut sizing is completed
-6.0 to –8.0	Mild to moderate stress, shoot growth in non-bearing and bearing trees has been observed to decline especially with Black Walnut Rootstock. These levels do not appear to affect kernel development and may be appropriate during kernel development
-8.0 to –10.0	Moderate to high stress, shoot growth in non-bearing trees may stop, nut sizing may be reduced in bearing trees
-10.0 to –12.0	High stress, temporary wilting of leaves has been observed. New shoot growth may be sparse or absent and some defoliation may be evident. Nut size likely to be reduced.
-12.0 to –14.0	Relative high levels of stress, moderate to severe defoliation, should be avoided
-14.0 to –18.0	Severe defoliation, trees are likely dying

More information on using SWP for irrigation scheduling in walnut orchards can be found in Schwankl and Prichard 2009b. and http://fruitsandnuts.ucdavis.edu/crops/Almond_MiddayStemWaterPotential.pdf

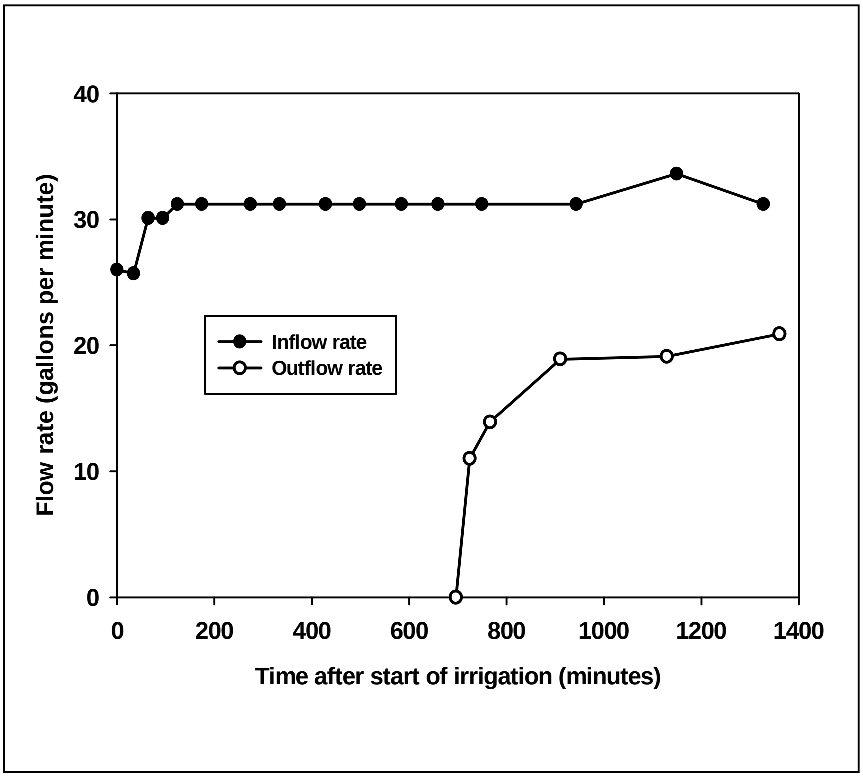
Managing Irrigation Systems to Reduce Runoff

Surface Irrigation Systems.

Irrigation runoff that enters surface waters can carry both dissolved and sediment-adsorbed pesticide residues. Soluble residue concentrations in runoff waters are fairly consistent for the entire runoff period. Therefore any reduction in the total runoff volume will reduce the amount of residues discharged. The degree to which soils erode during irrigation will depend on a number of factors, with soil aggregate stability, the ability of soil particles to cling together and resist the forces of flowing water, being the most important. Aggregate stability can be enhanced by chemical and physical amendments and management practices discussed in the section: "Reducing Runoff by Improving Water Infiltration." Soil erosion rates will depend on the soil conditions, including the amount, size, and density of loose particles on the soil surface. For example, erosion increases after cultivation. The degree of soil erosion depends on the velocity of the water and the duration of runoff. Therefore, reducing the peak volume and duration of runoff will reduce sediment loss.

The cutoff time is the time that an irrigation set is ended and no more water is applied to the furrow. Decreasing the cutoff time of the irrigation water (shortening the amount of time a field is irrigated) can reduce the amount of surface runoff from furrow-irrigated fields. The cutoff time for a given field depends on the time needed to infiltrate sufficient water along the lower part of the field. It may need to be determined on a trial-and-error basis. In cracking clay soils, infiltration times of only two to three hours may be adequate because water flow into the cracks results in a very high initial infiltration rate. After the cracks close, infiltration rates become very small. Thus, in cracked soils the cutoff time should occur about two to three hours after water reaches the end of the field (Hanson and Schwankl 1995). Figure 3 illustrates inflow and outflow rates in a field using furrow irrigation. Note the 700 minutes of water advancing to field end (before runoff begins) and the nearly equal time the irrigation is allowed to continue in order to have equal intake opportunity time at the tail end of the field. The result is significant – about 2/3 of the inflow water running off for 500 minutes. A shorter cutoff time would have reduced runoff volume but may also slightly reduce the distribution uniformity across the field.

Figure 3. Furrow irrigation inflow and outflow rates over the term of irrigation.



Source: Hanson and Schwankl 1995

Blocking furrows by making small dams in the length of the furrow using soil, or plastic dams can increase infiltration and help uniformity. This practice of monitoring each furrow during irrigation is labor intensive can reduce runoff volumes.

Converting to pressurized irrigation can reduce runoff. This option significantly reduces the chance of runoff, but requires a significant investment. See the Pressurized Irrigation Systems section.

Capturing and recycling runoff by using a tailwater collection system can mitigate runoff and therefore offsite residue problems, and make irrigation more efficient. For more information see the Tailwater Runoff Collection and Recycling section.

Pressurized Irrigation Systems

Pressurized systems should be operated to meet the orchard's water requirement while eliminating any surface runoff. Uniformity is designed into pressurized irrigation systems, with management left to ensure not only efficiency but the elimination of runoff losses by turning off the system before runoff occurs. In orchards with some slope, a small amount of runoff tends to accumulate from each emitter or sprinkler, potentially causing offsite movement. Improving uniformity of water application can avoid runoff. Sprinkler nozzle wear can increase application rates exceeding the soils infiltration rate at the end of the irrigation when infiltration rate declines. All nozzles should be the same size to minimize pressure differential application rates. Unfortunately, most of these highly engineered irrigation systems are not managed to their full potential because they need constant monitoring and maintenance. Problems such as clogged emitters decrease uniformity leading to under application is some areas and over application in others.

REDUCING RUNOFF BY IMPROVING WATER INFILTRATION IN ORCHARDS

Poor water infiltration can increase runoff from irrigation or winter rains. Irrigation runoff is typically associated with surface irrigation, but can occur with pressurized systems on soils with poor infiltration or sloping land.

The first step in determining how to mitigate a water infiltration problem is to understand the soil and water factors that influence it.

At the onset of irrigation, water infiltrates at a high rate. Initially the soil is dry and may have cracks through which water can infiltrate rapidly. After the soil near the surface wets for a few hours, these factors become less important in sustaining infiltration rates. The clay particles swell, closing cracks and limiting access to soil pores and decreasing infiltration rates. As the wetting process continues, the salinity and salt composition of the soil-water (water contained between soil particles) begins to more closely reflect that of the irrigation water, which is generally less saline. This reduction in soil water salinity retards water infiltration.

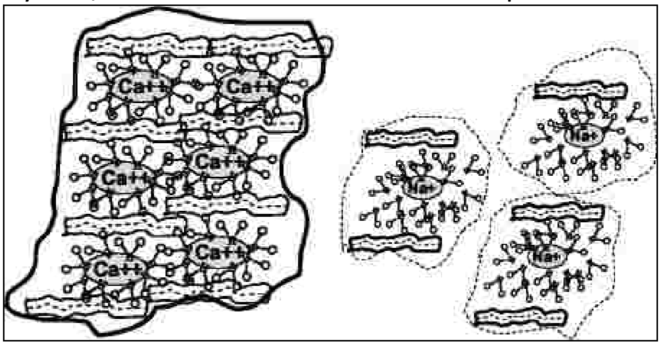
Water infiltration can only be improved by increasing soil total pore volume and/or individual pore size, and providing easy access to surface pores. Physical soil disruption practices and chemical and organic amendments are all attempts to influence one or more of these factors.

Soil Structure and its Impact on Water Infiltration

Pores are the spaces between mineral and organic particles in soils through which water and air move. Soils with a predominance of sands (larger spherical particles) tend to have larger pores, while clay-dominated soils (clays are plate-like particles) tend to be smaller. With some exceptions, soils with larger pores generally have higher infiltration rates. Water usually moves more slowly through small-pored soils because the smaller pores provide more surface area for water to adhere to. On the other hand, clay soils which form cracks as the soil dries and shrinks can help increase water infiltration.

Individual soil particles can clump together, forming larger structures called aggregates. The small pores between particles remain, and larger pores formed between the aggregates significantly enhance water infiltration and gas exchange (Figure 4). Soil water salinity and individual mineral constituents as well as organic matter content play a significant role in stabilizing soil aggregates and increasing pore size.

Figure 4. Conceptual illustration of soil aggregate stability: forming stable aggregates with plentiful calcium on clay exchange sites (left), compared to weak soil aggregates due to low salinity and/or excessive sodium in the soil pore water.



Soil Crusting

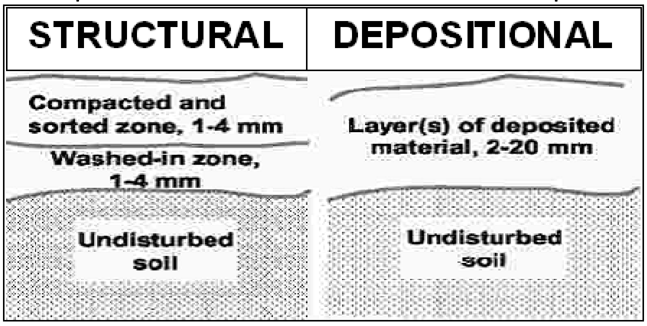
Soil crusts or surface seals reduce infiltration by impeding water access to soil pores beneath the crust layer. Crusts form at the soil surface when the soil aggregates become dispersed, causing a loss of porosity at the soil surface. Weak cementation of the crust often follows when the soil dries, slowing water penetration during succeeding irrigations.

Soil surface crusts can be divided into either structural crusts or depositional crusts, as defined below.

> Structural crusts form when surface soil aggregates are destroyed by the impact of rain or sprinkler droplets. The mechanical breakdown of soil aggregates tends to sort soil particles, leaving a film of finer particles on top (sealing layer) that blocks the entry of water into the larger intact pores beneath. Another type of structural crust forms under furrow irrigation, through a process is called "slaking." As the soil is wetted, a combination of mechanical and chemical dispersion of soil aggregates occurs, causing the structure to collapse. Upon drying the crust becomes hard.
>
> Depositional crusts form when small (usually clay- and silt-sized) soil particles, suspended and transported in flowing water, settle out of suspension and form a thin low-porosity surface layer. In agricultural settings, this type of soil crust is most often the result of high-velocity water in the head end of the furrow or check eroding fine particles that settle out when the water slows.

Both structural and depositional crusts are thin, characterized by higher density, greater strength and smaller pores than the underlying soil. These crusts are usually less than one tenth of an inch thick but often limit infiltration for the entire root zone (Figure 5). Structural crusts are a far more common cause of poor water infiltration problems in California orchards than depositional crusts.

Figure 5. Conceptual illustration of structural and depositional crusts.



In fine-textured silty soils, soil crusts are often the result of sodic conditions caused by excess exchangeable sodium in the soil or irrigation water, and/or too little total salinity. In coarse- to medium-textured, nonsaline and nonsodic soils, continued cultivation can reduce pore size and number to the point where water infiltration is affected. This problem can be made worse where very low salinity irrigation water is used, such as from irrigation districts on the east side of the San Joaquin Valley. Additionally, wells that contain high bicarbonates and relatively low calcium levels encourage crusting. The increased use of herbicides for no-till management can also decrease soil organic matter and soil microbial activity. This also results in decreased soil aggregation and reduced pore size.

Irrigation Water Quality

Irrigation water quality influences water infiltration rates through affecting whether soil particles tend to absorb water, stay together, or become separated by swelling. Swelling of soil particles causes aggregate breakdown and soil particle dispersion, resulting in surface crust formation.

Salinity

The higher the salinity of the irrigation water, the more likely the aggregates will remain stable, preserving infiltration rates. Salinity is measured by determining the electrical conductivity (EC) of the irrigation water (ECw) or soil water extracted from a saturated soil paste (ECe).

Sodicity

The index for sodicity is the sodium adsorption ratio (SAR), which depends on the relative amounts of sodium, calcium, and magnesium content of the irrigation water. SAR of a soil sample can also be used to estimate exchangeable sodium levels in the soil. With increasing levels of exchangeable sodium, the affinity of soil particles for water increases and aggregate stability decreases reducing water infiltration rates.

Combined Effect of Salinity and Sodicity

Since both salinity and sodicity of the irrigation water effect aggregate stability and water infiltration rate, both must be assessed when diagnosing an infiltration problem. In the top three inches of soil, salinity and sodicity of the irrigation water and soil are closely linked.

Consequently both surface soil samples and water samples are necessary to diagnose the problem and evaluate the success of mediation practices. In general, aggregate stability increases as EC increases and the SAR decreases (Table 7). As a general guideline, the SAR should be less than 5 times the EC (Figure 6). The exception is low salt waters with EC values of less than 0.5 dS/m. They are corrosive and deplete surface soils of readily soluble minerals and all soluble salts. They often have a strong tendency to dissolve all sources of calcium rapidly from surface soils. The soils then break down, disperse, and seal, resulting in poor water infiltration.

The EC and SAR-based guidelines discussed above may not necessarily work for all California soils. Some soils contain a large amount of serpentine clays rich in magnesium (Mg) and low in calcium (Ca). In these soils, Mg may have the same soil-dispersing effect as sodium. Soils with a predominance of montmorillonite and illite clays are also easily dispersed by excess magnesium. Although the diagnostic criteria for such conditions have not been extensively tested, some studies suggest that when the Mg to Ca ratio of these soils exceeds 1:1, they may be prone to water infiltration problems. Some reports report that high soil potassium levels can also promote aggregate dispersion and soil crusting.

Table 7. Potential for a water infiltration problem

SAR*	Problem Likely ECe[1] or ECw[2] dS/m	Problem Unlikely ECe or ECw dS/m
0.0 – 3.0	< 0.3	> 0.7
3.1 – 6.0	< 0.4	> 1.0
6.1 – 12.0	< 0.5	> 2.0

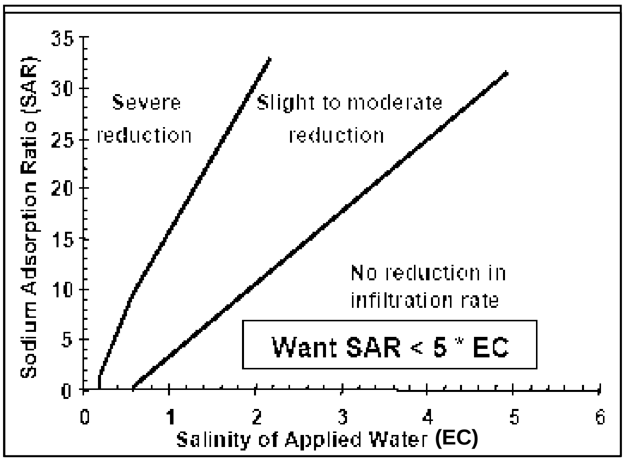
Source: Ayers and Westcot (1985).

* Sodium Adsorption Ratio.

[1] Electrical conductivity of soil extract (soil is saturated paste soil salinity).

[2] Electrical conductivity of water (irrigation water salinity).

Figure 6. Interaction of total salinity as EC with the sodium adsorption ratio of applied water for causing potential infiltration problems. (Ayers and Westcott, 1985)



High carbonate (CO_3^-) and bicarbonate (HCO_3^-) levels in water increase the sodium hazard of the water to a level greater than that indicated by the SAR. In alkaline soils, high CO_3^- and

HCO_3^- tend to precipitate calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) when the soil solution concentrates during soil drying. The concentrations of calcium and magnesium in soil solution are reduced relative to sodium, and the SAR of the soil solution tends to increase.

An adjusted SAR value may be calculated for water high in carbonate and bicarbonate if the soil being irrigated contains free lime (calcareous soil). The adjusted SAR and knowledge of soil properties help determine management practices when using high bicarbonate water.

Mitigating Water Infiltration Difficulties

Solving an infiltration problem by modifying irrigation practices (as discussed in other sections of this manual) should always be the starting point and will generally be less costly than the soil and water modifying treatments discussed below. Water infiltration problems not amenable to improvement by optimizing irrigation system design and operation may be mitigated by improved soil organic matter management, or use of chemical amendments as discussed later in this manual.

Tillage

Shallow tillage can be used to disrupt both structural and depositional crusts. Where crusting problems reduce infiltration rates, a single tillage can restore infiltration rates. However, in soils with severely reduced infiltration, tillage before each irrigation is common. Shallow tillage using shallow disking or harrowing can break up the surface crust. Shallow tillage to incorporate the pesticide after application can effectively reduce the residues available for offsite. Some orchards have been planted to non-uniform layered soils without any deep tillage prior to planting, and examination of backhoe pits reveals significant hardpan and other layers that limit root development. Tillage of orchard middles is limited to a single pass with depth related to the draft force required and traction of the tractor.

> **CAUTION:** Ripping will damage existing roots, especially in orchards where water infiltration has been limiting root zone depth. However, the improved soil characteristics and root pruning will help to encourage new root growth. Roots take time to begin growing and re-growth varies with the season and the carbohydrate status of the tree. In any event, do not till all the middles at once. Modifying alternate middles each year produces the best results. Ripping is most be most effective in the fall, after harvest when water use is low and soils are dry and easy to shatter and mix. .

Managing Soil Organic Matter to Reduce Runoff

Soil organic matter helps stabilize soil aggregates by increasing the number of exchange sites in the soil matrix and encouraging microbial activity. Soil microbes that decompose soil organic matter produce polysaccharides and polyuronides, which act as binders to stabilize aggregates, thus improving porosity and water infiltration. Over time, continued cultivation and the use of herbicides reduces the organic matter content and aggregate stability of soils. These changes can reduce water infiltration and increase runoff potential.

It is difficult to increase and sustain soil organic matter under warm semiarid conditions that prevail in most of California, which favor rapid organic matter decomposition. Organic matter additions aimed at improving or sustaining aggregate stability and water infiltration must be incremental and continual to be effective. There are several ways for growers to achieve this as follows.

Crop Residues

Tree leaves and prunings, shreaded or soil incorporated, can be left to decompose adding organic matter (and some nutrients) to the soil.

Manure and Other Organic Materials

With proper handing and management to avoid risk of crop contamination by human pathogens, animal manures or compost can help increase soil organic matter content and improve water infiltration. However, the application of manures is currently uncommon due to the limited availability of manures

Cover Crops

Cover crops can help protect the soil surface from droplet impact under winter rainfall or sprinkler irrigation and provide significant organic matter biomass for decomposition and microbial stabilization of soil aggregates. In addition, cover crop residue can slow the velocity of surface water; reducing erosion and subsequent depositional crusting. Winter annual cover crops are most often planted in orchards because they grow during the wet season, reducing the competition for water and nutrients that is a disadvantage of perennial covers. They are sown or allowed to reseed in the fall and mowed or disked in the spring. A winter annual cover crop - planted in fall, grown during the winter and early spring, and mowed or disked to remove it in spring - for example, can produce as much as 3 tons of dry matter (above and below ground) per planted acre. A comprehensive review of this topic is available in: Cover crops for walnut orchards. ANR Publication 21627 (Grant et al. 2006)

Chemical Amendments Used to Improve Water Infiltration

The addition of chemical amendments to water or soil can improve water infiltration by improving the chemical makeup of the water or soil. Most chemical amendments work by increasing the total salt concentration and/or decreasing the sodium adsorption ratio (SAR) of the soil-water. Both of these actions enhance aggregate stability and reduce soil crusting and pore blockage.

Four types of materials are used to ameliorate water infiltration problems: salts, as fertilizers; calcium materials; acids or acid-forming materials; and soil conditioners, including polymers and surfactants.

Salts

Any fertilizer salt or amendment that contains salts, when applied to the soil surface or dissolved in irrigation water, increases the salinity of the irrigation water and ultimately influences the soil-water. Whether increased salinity is advantageous depends on the SAR of the irrigation water. The largest effect of a salt addition is with very low salinity (less than 0.5 EC) irrigation water. Increasing salinity above an EC of 4 dS/m has little effect on infiltration.

Calcium Materials

Adding calcium (Ca) salts to soil and water increases both the total salinity and soluble calcium. Calcium salts commonly used on alkali (high pH) soils include gypsum ($CaSO_4$), calcium chloride ($CaCl_2$), and calcium nitrate ($CaNO_3$). These are fairly soluble and can easily be applied though the irrigation water. Care should be taken if waters contain more than 2 meq/L of bicarbonate (HCO_3). Adding gypsum to such waters through a drip system significantly increases the chances of plugging the system with lime precipitate. In these cases, an acid application to decrease bicarbonate concentrations may be necessary. Lime and dolomite are used only for broadcast applications on acid soil, as they are virtually insoluble under alkali conditions.

Gypsum Injection Rates for Water

Amendment rates from 1.0 to 3.0 meq/L calcium in the irrigation water are considered low to moderate; rates that supply 3.0 to 6.0 meq/L calcium are considered moderate to high. The following example calculations show the reader how to estimate the quantity of gypsum required to improve infiltration. Table 8 lists the amount of gypsum and other products needed to increase the calcium (Ca) content of irrigation water by 1 meq/L per acre-foot. Applying 234 pounds of 100 percent pure gypsum per acre-foot of water equals 1 meq/L of Ca.

It is rarely necessary to inject gypsum constantly. Injection every other or every third irrigation may be all that is necessary to end the season with the required amount. The benefits of gypsum injection during the season in drip irrigation systems are usually superior to those of dormant season applications.

Table 8. Amounts of amendments required for calcareous soils to increase the calcium content in the irrigation water by 1 meq/L.

Chemical Name	**Trade Name and Composition**	**Pounds/Ac-ft of Water to Get 1 meq/L Free Ca***
Sulfur	100% S	43.6
Gypsum	$CaSO_4 \cdot 2H_2O$ 100%	234
Calcium polysulfide	Lime-sulfur 23.3% S	191
Calcium chloride	Electro-Cal 13% calcium	418
Potassium thiosulfate	KTS -- 25% K_2O, 26% S	256
Ammonium thiosulfate	Thio-sul 12% N, 26% S	110** 336***
Ammonium polysulfide	Nitro-sul 20% N, 40% S	69** 136***
Monocarbamide dihydrogen sulfate/ sulfuric acid	N-phuric, US-10 10% N, 18% S	148** 242***
Sulfuric Acid	100% H_2SO_4	133

* Salts bound to the soil are replaced on an equal ionic charge basis and not equal weight basis.

** Combined acidification potential from S and oxidation of N source to NO_3 to release free Ca from soil lime. Requires moist, biologically active soil.

*** Acidification potential from oxidation of N source to NO_3 only.

Gypsum Rates Broadcast to Soils

An alternative to water treatment is broadcasting amendments such as gypsum on the soil surface and irrigating the amendment into the soil. The primary advantage of this approach is that it is often less expensive than water treatments. However, for surface application to be nearly as effective as water treatment, it must be properly timed. If infiltration is a problem in the summer months, then apply the amendment at the onset of those months—not in the preceding fall or winter. If the application is made too early, the amendment will percolate with post harvest irrigations and winter rainfall to depths below that where the crust forms. Surface applications are most effective when gypsum is applied at rates equivalent to 500 to 1,000 pounds of gypsum per acre, prior to the onset of irrigation. Use finely and consistently ground gypsum products in surface applications. Applications that are limited to the berm have been successful at decreased field rates (same rate per unit area but applied to the berm only) when using drip irrigation. For maximum effect on surface crusting, do not till the soil after the gypsum is applied.

Acids and Acid-Forming Materials

Commonly applied acid or acid-forming amendments include sulfuric acid (H_2SO_4) products, soil sulfur, ammonium polysulfide, and calcium polysulfide. The acid from these materials dissolves soil-lime to form a calcium salt (gypsum), which then dissolves in the irrigation water to provide exchangeable calcium. The acid materials react with soil-lime the instant they come in contact with the soil. The materials with elemental sulfur or sulfides must undergo microbial degradation in order to produce acid. This process may take months or years depending on the material and particle size (in the case of elemental sulfur). Since these materials form an acid via the soil reaction, they will reduce soil pH if applied at sufficiently high rates.

Acids are applied to water for two different purposes in relation to water infiltration problems. The first is to dissolve soil lime (the soil must contain lime if acids are used), increasing free calcium in the soil/water matrix and improving infiltration. The second is to prevent lime clogging in drip systems when adding gypsum to waters containing greater than 2 meq/L bicarbonate.

Table 8 indicates that it takes 133 lbs/ac-ft of 100 percent pure sulfuric acid to release 1 meq/L Ca. This assumes the acid contacts lime ($CaCO_3$) in the soil, neutralizing the carbonate molecule and releasing Ca. This is the same amount of acid required to neutralize 1 meq/L of HCO_3 in the water. If the water contains bicarbonate the acid will neutralize it, converting it to carbon dioxide which is released to the atmosphere. Acid applications must exceed the bicarbonate level of the water before the pH of the water decreases to dissolve lime in the soil.

Soil Conditioners

There are two types of amendments in this category, organic polymers and surfactants. Other amendments include synthetic and natural soil enzymes and microbial soups. Although there is a long history of soil conditioner development and testing, not enough data exists on the materials to conclude that they are uniformly effective. For an in-depth analysis of water infiltration problems and solutions see: "Water Penetration Problems in California Soils: Diagnosis and Solutions," Singer et al. 1992.

Organic Polymers

Organic polymers, mainly water-soluble polyacrylamides (PAM) and polysaccharides, are used to stabilize aggregates at the soil surface. These extremely long-chain molecules wrap around and through soil particles to bind aggregates together. This action helps resist the disruptive forces of droplet impact and decrease soil erosion and sediment load in furrow irrigation systems. They can improve infiltration into soils with illite and kaolinitic clays common in the northwest United States, but USDA researchers have found that infiltration is not improved in soils with the mostly montmorillinite clays typical of the San Joaquin Valley.

Water-soluble PAM is not to be confused with the crystal-like, cross-linked PAMs that expand when exposed to water, and does not influence water infiltration. Cross-linked PAMs enhance the water-holding capacity of soils for small-scale applications, for example in container nurseries.

Organic polymers can have different effects on infiltration. The effect depends on polymer properties—such as molecular weight, structure, and electrical charge—and salinity of the irrigation water. There are charged (ionic) and non-charged (nonionic) polymers that can behave differently depending on whether they are added to very pure water (surface waters where EC is 0.03 to 0.1 dS/m) or higher-salinity well waters (above 0.8 dS/m).

Polymers have been shown to work best when sprayed on the soil surface at a rate of about 4 pounds per acre, followed by an application of gypsum in soil or water.

Surfactants

Surfactants *or "wetting agents"* are amendments that reduce the surface tension of water. They are not effective in agricultural soils.

Other Amendments

Other amendments include synthetic and natural soil enzymes, and microbial soups. Although there is a long history of soil conditioner development and testing, not enough data exists on the materials to conclude that they are uniformly effective.

CAPTURING AND FILTERING SURFACE WATER AND SEDIMENTS

Reducing the volume or velocity of runoff waters can reduce offsite movement of residues whether they be in solution or sediment-attached. There are several methods of capturing and filtering surface water and sediment. Some are temporary and used with a new orchards or in emergency situations where the need for runoff control is short lived, and some are permanent. Hillside orchards should have several types of permanent erosion control measures in place, such as permanent cover crops, adequately sized filter strips between the orchard and any waterways, and permanent sediment basins for collection and or recycling or the use of vegetation at the tail of the field or in the drainage ditch.

Storing Runoff

Storage of runoff waters from storm events in impoundments is often suggested as a mitigation practice. The sheer volume of runoff makes this a poor option. Storms are rated as to the frequency at which a particular amount of rainfall in a given duration is expected to return, on average. A 2-year, 24-hour storm would be the rainfall event one could expect during a 24-hour period on the average of every 2 years. For example, a 2-year, 24-hour storm in Stockton, California falling on a 40-acre parcel would produce over 1,700,000 gallons or 5.3 acre feet of water—equivalent to a one acre pond over 5 feet deep. A hundred-year storm would require three times that volume for just a single storm. Of course, some of the water would infiltrate into the field. However, if one storm came on the heels of another, most of the rainfall would run off. For more information on runoff storage and storm precipitation rates, see: "Storing Runoff from Winter Rains," Schwankl et al. 2007a, ANR Publication 8211.

Temporary Measures

Filter Fabric Fencing

A barrier of filter cloth with woven wire stretched between temporary fence posts across a slope to reduce soil movement. Make sure the posts are on the downslope side of the fencing.

Straw Bale Check Dam

To construct a check dam, place bales of clean straw bound with wire or plastic twine across an area of surface sheet flow or gully erosion, and anchor them into the soil surface with rebar or stakes.

Straw Bale Water Bars

Straw bales used to create a temporary water bar across a road or a temporary sediment barrier. A series of straw bale water bars may be needed for long slopes.

Straw Wattles

Straw wattles or fiber rolls are designed to slow down runoff, reducing erosion and filtering and trapping sediment before the runoff gets into watercourses. Straw wattles must be installed on contour.

Straw wattles used for erosion control

Temporary Drainage Structure

Constructed at the tail of a field, the temporary drainage structures are designed to slow and trap runoff for short periods of time. The water eventually infiltrates the soil.

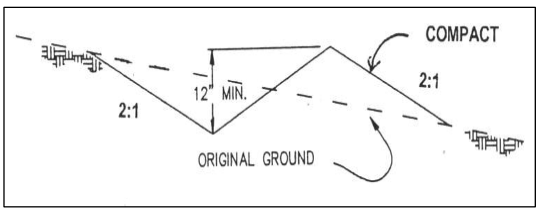


Diagram and photo of a temporary drainage structure

Temporary Sediment Basin

Temporary sediment basins are used to catch and settle out sediment before it can enter a waterway. They are usually placed at the base of a slope or drainage area. A small basin can be created from compacted soil and rocks or straw bales. The embankment should not exceed 4 feet in height, and a drain or outlet should restrict flow from the basin to allow sediment to be trapped.

Permanent Measures

Sediment Basins

A sediment basin or trap is created by constructing an embankment, a basin emergency spillway, and a perforated pipe-riser release structure. The basin may be located at the bottom of a slope where drainage enters a swale or waterway. These basins can be designed by the Natural Resources Conservation Service (NRCS) or a civil engineer on a site-specific basis and installed using proper construction and compaction for the berm and correct sizing and construction for water release structures and spillways. When runoff volumes are small, basins can be effective for reducing offsite movement of sediment containing adsorbed pesticide residues. If runoff is high enough to cause low retention times, sediment removal efficiency declines rapidly.

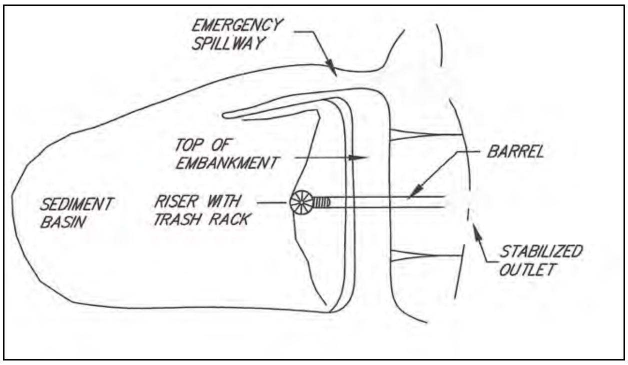


Diagram of a sediment basin with spillway and release structure

Effectiveness in Removing Pesticide Residues

Long et al. (2010b) found that 60- to 90-minute retention times effectively removed particles coarser than fine silts. The sediment basin was 1.4 percent of the irrigated area. Finer soil particles, which generally adsorb pyrethroid pesticide residues, were not removed from the runoff. During the first irrigation of the season, soon after cultivation, 39 percent of the sediment load entering the pond was removed. In the second measured irrigation, sediment removal was insignificant. The effectiveness of sediment traps was found to be limited by the time available for suspended sediments to settle out of the runoff. Sediment basins may be ineffective with finer soils at higher runoff rates. Long (2010a) suggests various size settling basins based on Stokes Law. Clay particles carry the bulk of the adsorbed pesticide residues. In order to provide enough holding time to settle out these small particles from a 50 gallon per minute tailwater runoff rate, a settling basin of 57 acre feet would be required.

A study was conducted in the Central Valley of California to measure pyrethroid removal by a tailwater recovery pond. The field was a border-check irrigated almond orchard to which a pyrethroid, lambda-cyhalothrin was applied at the rate of 0.04 lb ai/acre. Runoff waters were measured for volume, sediment, and pyrethroid residue concentration as inflow to a recycling pond and as outflow. About 15 percent of the irrigation onflow water exited the field as runoff. The pond was 19 feet by 16 feet by 7 feet deep. Sediment in the water was reduced by 80 percent, inflow to outflow. Pyrethroid residues were reduced by 61 percent. The difference in the removal efficiencies for sediment and pyrethroid residues was most probably due to the absorption of lambda-cyhalothrin residues to lighter weight clay particles, which did not have a chance to settle out in this trial. Removal efficiency may have been further improved with lower flow rates or longer retention times in the ponds (Markle 2009).

Permanent Cover Crops

Cover crops are usually grown in orchard middles with rows kept free of vegetation. Plant species used for cover crops may be annuals (planted, grown and removed each season) or perennials, which generally live three or more years. Annual cover crops can be composed of species that reseed themselves naturally each year (for example, annual clovers and medics) or others that are generally removed before they form seeds and must be intentionally replanted each year. Perennials such as ryegrass, orchard grass, and fescues are not often used because they will compete with the trees for water and nutrients during the summer.

Cover crops can help reduce offsite movement of water-borne pesticide residues in several ways. By shielding the soil from the impact of rain droplets, a winter-grown cover crop can help reduce the likelihood that soil particles will be eroded from the soil surface. Cover crop vegetation may also help slow sedimentation by directly “filtering” soil particles out of moving water and by slowing the speed of water moving over the soil surface. As the weather warms in late winter and spring, cover crops can help deplete excessive soil moisture and increase water storage potential (thus reducing runoff) from storm events at this time of year. Also see: "Cover crops for Walnut Orchards." ANR Publication 21627 (Grant et al. 2006).

For further reading see: "Erodibility of Agricultural Soils with Examples in Lake and Mendocino Counties," O’Geen, et al. 2006a, ANR Pub 8194, and "Orchard Floor Management Practices to Reduce Erosion and Protect Water Quality," O’Geen, et al. 2006b, ANR Publication 8202.

Effectiveness in Removing Pesticide Residues

Early fall establishment of cover crops is critical to their effectiveness in capturing runoff waters and sediments containing pesticide residues. Among the best cover crops are perennial sods which have dense foliage and root systems. Reseeding winter annual grasses such as ‘Blando’ brome or ‘Zorro’ fescue work well after establishment (Ingels et al.

1998). Cover crops are often mentioned as being related to reducing the runoff of pesticide residues; however, research measuring such reductions is limited or nonexistent. However, numerous works measuring reduced runoff volumes and sediments when using cover crops have been published. In a Central Coast vineyard 'Trios 102' triticale and 'Merced' rye cover crops planted in vineyard middles reduced runoff volumes from 46 to 78 percent respectively, when compared to bare soil (Smith et al. 2008). The comparisons, made over a three year period, also found a significant reduction in suspended sediment and turbidity.

Vegetative Filter Strips

A vegetative filter strip (VFS) is any area of dense grass or other vegetation—natural or planted- between the orchard and a nearby waterway. Filter strips help capture and filter surface runoff from cropland to protect water quality. Tall, sturdy, and hardy perennial grasses are preferred, since once established they withstand the force of runoff waters and summer drought conditions. The width of the VFS required to effectively remove sediments depends upon the slope of the area draining into the strip. For slopes of less than 1 percent, the strip should be at least 25 feet wide, increasing proportionally with the increase in slope up to 50 feet wide for 10 percent slopes. Filter strips can also be used to reduce sediment flow between orchard blocks.

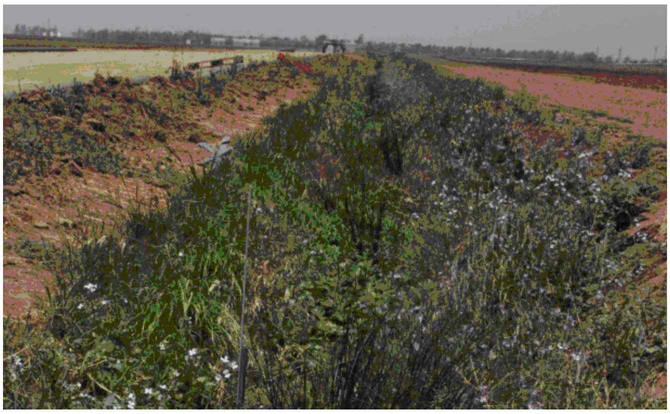
Vegetative filter strips function in three distinct layers—surface vegetation, root zone, and subsurface horizon (Grismer et al. 2006). As surface flow enters the VFS, water is infiltrated until the shallow surface and shallow subsurface is saturated. This infiltration phase is most important for reducing offsite movement of residues. The pesticide residues are trapped by soil constituents and organic matter, allowing pesticide degradation to occur. The remaining flow volume and velocity is decreased, reducing sediment transport. Sediment particles are trapped on the surface litter layer, which is high in organic matter. As the process continues, water continues to move through the subsurface horizon, further decreasing the volume of runoff.

Effectiveness in Removing Pesticide Residues

The chemical characteristics of different pesticides determine the type and amount of residue reduction achievable with vegetation systems. Organophosphate pesticides tend to be water-soluble, while pyrethroids are virtually non-soluble in water and are primarily adsorbed to sediments. Diazinon, an organophosphate of high solubility in water, can be expected to remain in solution for long periods (Bondarenko and Gan, 2004). Previous evaluations of the effectiveness of vegetation for removing diazinon from water have shown mixed results. Watanabe and Grismer (2001) evaluated diazinon removal by vegetated filter strips under controlled laboratory conditions and found that the majority of diazinon removal occurred via infiltration into the root zone and adsorption to vegetated matter. However, 73 percent of the applied diazinon was detected in the runoff water after the VFS. Long et al. (2010b) found that reduction in sediment load was directly related to pyrethroid residue removal in VFS. Sediment runoff was reduced by 62 percent when furrow runoff waters passed through a well-established VFS planted to either tall fescue or a perennial ryegrass and tall fescue mixture that represented 2.8 percent of the field being irrigated. They recommend 0.03 acres of vegetated filter per 100 gallons per minute of tailwater to significantly improve the water quality of field runoff (Long et al. 2010b). It should be noted that the vegetated filter strip is used once per irrigation, not for successive sets.

Vegetated Drain Ditches

Drainage ditches can be vegetated with plant material that will help capture sediments and other sediment-absorbed pollutants, as well as provide for some water infiltration. The common type of a vegetated drain ditch (VDD) is a "V"-shaped ditch, 2-3 feet deep and 4 feet wide at the top. Short, sturdy, and hardy perennial grasses such as the dwarf fescues and perennial ryegrass are preferred, since once established they withstand the force of runoff waters and summer drought conditions. Vegetation in the VDD can also be resident, such as rushes and bermudagrass. Residue removal efficiency is strongly influenced by runoff flow rate per unit ditch wetted area. Higher flow rates reduce the removal efficiency.



Vegetated Ditch

Effectiveness in Removing Pesticide Residues

Anderson et al. (2008) found that a vegetated ditch containing aquatic vegetation removed only 4 percent of diazinon in contaminated runoff. Moore et al. (2008) used a simulated runoff event to evaluate removal of diazinon in vegetated ditches in Yolo County, California. They described reductions in diazinon runoff using a V-shaped vegetated ditch, but significant concentrations of diazinon remained in the system outflow after five hours. Essentially, runoff waters containing residues which are not infiltrated were little reduced.

Chlorpyrifos, another organophosphate, is more hydrophobic than diazinon. Gill et al. (2008) applied chlorpyrifos at 1 pt/ac and found a 40 percent reduction in the water column concentration after passage through a vegetated ditch, though the outflow water was still at 33 times the water quality standard of 15 ppt. Anderson et al. (2008) found an average 35 percent reduction of chlorpyrifos concentration in two evaluations after passage through a vegetative ditch containing aquatic vegetation. On the other end of the spectrum, Cole et al. (1997), found VFS's effective in reducing 62-99 percent of chlorpyrifos residues in runoff waters. Local conditions including runoff flow rates, size of the vegetated area, and the initial residue concentration appear to have strongly influenced the effectiveness of these studies.

Because of their hydrophobic nature, pyrethroids adsorb readily to plant surfaces and soil particles and are therefore easier to remove from runoff waters than organophosphates (Moore et al. 2001; Schulz, 2004). Moore et al. (2008), for example, found that vegetation was much more effective at removing the pyrethroid pesticide permethrin than the organophosphate diazinon. Anderson et al. (2008) found nearly 100 percent reduction of permethrin after treatment in a vegetated ditch. Additionally, Gill et al. (2008) found a 25 percent reduction of pyrethroid (lambda-cyhalothrin) residues after moving runoff waters through a vegetated ditch.

TAILWATER COLLECTION AND RECYCLING

Water running off the tail end of a field, part of normal irrigation, is referred to as tailwater or runoff water. Tailwater is most often associated with surface irrigation (furrow and border-check irrigation), since well-designed sprinkler and drip irrigation systems should not produce tailwater runoff. Their use is an excellent management practice to improve irrigation efficiency and minimize tailwater runoff impacts.

Tailwater collection systems have most frequently been used in row and field crops and are not as common in surface irrigated tree and vine crops. There is no reason tailwater collection and recycling systems cannot be used in permanent crops using furrow or border-check irrigation. Their use is an excellent management practice to improve irrigation efficiency and minimize tailwater runoff impacts.

Tailwater collection system.

If a new tailwater return system is being planned, the planned management approach must be a key factor in its design. Tailwater generated by irrigation practices is most often pumped from the capture pond and conveyed via a pipeline system to where it will be reapplied. Such a system, well operated, maximizes irrigation efficiency and minimizes environmental impacts.

Advantages and Disadvantages of Tailwater Return Systems

Advantages:

- Offsite environmental impacts of tailwater potentially containing pesticide and fertilizer residues or sediment are minimized.
- Irrigation efficiency is improved since tailwater is beneficially re-used as irrigation water.
- Water costs may be reduced by re-using tailwater.
- Tailwater collection systems remove standing water that can cause crop loss and weed infestations from the tail end of the field.

Disadvantages:

- Cost of installation, maintenance, and operation of the tailwater return system. However, in many areas NRCS cost share programs available.
- Land must be taken out of production for the pond and other tailwater recovery system components.
- Good management, requiring timely recycling of tailwater pond contents, is necessary to prevent groundwater pollution by chemicals in the tailwater.

Tailwater Return System Management

There are numerous ways of managing tailwater return systems, and their management is often constrained by the system design. If a new tailwater return system is being planned, the planned management approach must be a key factor in the design. See ANR publication 8225, "Tailwater Return Systems," Schwankl et al. 2007b for information on design, construction, costs and operation, and National Conservation Practice Standard, Irrigation System, Tailwater Recovery, Standard 447-1, USDA Natural Resources Conservation Service, 2006.

TREATMENT OF RUNOFF WATERS

Runoff water can be chemically treated to reduce pesticide residues. This treatment can be done in the furrow or check, in a tailwater ditch, or in a holding basin. Two products are available and have been shown effective for this purpose: Polyacrylamide (PAM), for treatment of pyrethroid-laden sediments, and Landguard OP-A Enzyme®, for treatment of most soluble organophosphate pesticides. Work is underway to develop enzymes to treat pyrethroid residues, however they are unavailable at this time.

Polyacrylamide (PAM)

PAM is effective in controlling pesticide residues which are attached to soil particles (pyrethroids) that leave the field or are generated in the tailwater ditch through erosion during irrigation. Studies have shown that this erosion occurs along the field length for furrow irrigation. PAM is a solid or liquid water-soluble polymer that flocculates sediments, binding them together and causing them to drop out of the water. When added to runoff waters, PAM can mitigate transport of sediment-adsorbed pesticides from furrow and border-check irrigated fields.

Liquid PAM can be constantly injected into the irrigation water, constantly deposited in granular form into turbulent irrigation ditch water, or applied to the furrow as dry tablets (40 percent PAM) or granules (89 percent PAM), where it is slowly dissolved by irrigation water. The in-furrow methods are generally less expensive and easier to apply than liquid or granular PAM applied to the inflow ditch or piped water. However, they do not allow for equally precise control of product concentration. Table 9 shows a comparison of costs using the different forms of PAM for an 80-acre furrow-irrigated row crop planted on 5-foot beds, using data provided by a grower. The lowest cost occurred for granules placed in the furrow, while the costs were the highest using liquid PAM.

At a furrow length of 600 feet, 60-inch beds would require about one ounce or 2 tablets per furrow. It is applied in a "patch" in a 3-foot section of the furrow, far enough from the furrow head to prevent sediments from covering the PAM patch. In the Northwest, placement 5 feet from the furrow head was successful. In California, the patch was quickly covered and not effective; whereas 100 feet down furrow was successful. Once applied as a "patch," PAM seems to be effective for a few irrigations. If the soil is disturbed by cultivation, it must be reapplied. PAM is more effective in finer texture soils and in irrigation waters that contain calcium and little sodium.

Season-long control costs are difficult to estimate because effectiveness from a single application varies with the number of irrigations and the number of field cultivations. Liquid PAM that contains oil-based carrier materials is available, but the cost per acre is high and the product can be toxic to some aquatic life at recommended field application rates (Weston et al. 2009).

Table 9. Cost comparisons for different single irrigation PAM formulations for a typical 80-acre furrow-irrigated row crop planted on 5-foot beds.

Application method	Unit cost of material	Cost per acre	Comments
Granules placed in furrow	$2.79 per pound	$1.05	1 oz of granules per furrow
Tablets placed in furrow	$4.82 per pound	$6.36	Two tablets per furrow
Granules injected into irrigation water	$2.79 per pound	$5.46	Target concentration = 5 ppm; injection time = 12 hours (time needed for water advance to end of furrows)
Liquid PAM injected into irrigation water	$34 per gallon	$32.31	Target concentration = 5 ppm; injection time = 12 hours
Liquid PAM injected into irrigation water	$34 per gallon	$12.93	Target concentration = 2 ppm; injection time = 12 hours

Source: Long et al. (2010a)

Costs per acre are based on the gross acreage of the 80-acre field.

Effectiveness in Removing Pesticide Residues

PAM has been shown to be effective in reducing sediments from furrow irrigation fields when applied to irrigation furrows. Sojka et al. (2007) in their Northwest studies on furrow-irrigated soils over a three-year period, found application rates of 1 pound per acre/irrigation (about 10 ppm) eliminated 94 percent of sediment loss in field runoff. A seasonal rate of 3-7 pounds per acre was used, depending on the crop and number of cultivations. One of the mechanisms of decreased sediment loss is increased infiltration of irrigation water into the field because PAM effectively reduces runoff water volumes (Trout et al. 1995). Sojka, using the recommended 10-ppm PAM rate, found increases in infiltration of 15 to 50 percent compared to untreated controls. In California, Long et al. (2010b) found no PAM effect on infiltration into loam and clay loam soils at a lesser application rate assumed to be near 2ppm.

In a California study conducted on loam and clay loam soils, Long et al. (2010b) found an application rate of 1-2 ounces per 600-foot furrow using the "patch method" reduced sediment loss between 57 and 97 percent in numerous trials. Furrow flow rates averaged 17.5 gallons per minute. They found greater than 80 percent sediment control in 60 percent of the trials. The concentration of a pyrethroid, lambda-cyhalothrin or zeta-cypermethrin was reduced by the same amount.

Landguard OP-A Degradation Enzyme

Runoff waters containing organophosphate insecticide residues can be treated with a degradation enzyme, Landguard OP-A, to reduce or eliminate residues in runoff water before water exits the farm. This product promotes the breakdown of most organophosphate pesticides into less toxic metabolites. The powder-like enzyme is mixed with water into a stock solution and applied to runoff water usually in the tail water ditch but can be applied to a holding basin. The enzyme treatment rate, residue concentration, and the time available before runoff discharge are all important to for ensuring degradation at a minimum material cost. Greater time available before runoff discharge allows a lower enzyme application rate.

The key factor in determining the correct dosing rate is the maximum expected runoff rate. Runoff rate is typically not constant over time. When using a single dosing rate based on the maximum estimated flow rate, over-dosing is likely at the lower flows that typically occur at the beginning and end of a runoff event. Additionally, the practice of irrigating more checks during a nighttime set can lead to different peak flows of different duration.

A comparison was made of the amount of enzyme required for single maximum rate dosing for the entire runoff period and for a variable rate dosed as required by flow rate—essentially keeping the dosing rate constant (Prichard and Antinetti 2009). A single rate setting to dose for the maximum volume during the first irrigation set resulted in a dosage that was more than double the amount actually needed. Estimating that the next set would be near the same runoff flow rate and using the same dosing rate, the second set required over 6 times that of a correctly dosed variable system do to the lower amount of runoff.

Effectiveness in Removing Pesticide Residues

A field trial in California found chlorpyrifos in runoff at a concentration near 10 ppb prior to Landguard OP-A treatment. Twelve minutes after the enzyme was added at a rate of 4.3 oz to one acre foot runoff water, the chlorpyrifos concentration declined to 0.4 ppb. At higher enzyme dosages, chlorpyrifos became undetectable. The effects of the enzyme on chlorpyrifos-related toxicity are equally dramatic. The enzyme reduces chlorpyrifos toxicity to *H. azteca* (a test organism) by at least 70 fold compared with untreated water (Weston and Jackson, 2010). Without enzyme, the concentration of chlorpyrifos required to kill half the test organisms was 141 ppb. With enzyme, they saw no ill effects to the test organisms.

A team led by Brian Anderson of the UC Davis Marine Pollution Studies Laboratory dosed Landguard OP-A at the rate of 4.3 oz/acre foot runoff water directly into a drainage ditch containing diazinon residues (Anderson et al. 2008). Samples of runoff water were collected from the ditch before dosing and 107 feet downstream from the electronic dosing unit (Figure 7).

In multiple trials, Anderson found that samples treated with Landguard OP-A demonstrated no detectable diazinon and all were non-toxic to *C. dubia*, another aquatic arthropod test organism.

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APPENDIX I

ORCHARD ANALYSIS CASE STUDY – Codling Moth

The management practices presented in this manual have been proven effective in reducing pesticide related water quality problems arising from orchard operations. The following case study expands upon the walnut orchard example introduced earlier in this manual and illustrates how specific changes could be made in orchard operations to reduce pesticide movement out of the orchard.

Crop: Mature, conventionally managed (not organic) walnuts, 32 acres
Site:
Topography**:** 0-2 percent slope
Soil: Hollenbeck silty clay loam soil, soil tends to crust limiting the water infiltration rate causing some runoff in mid – late season.
Irrigation Runoff: runoff is relatively small in volume –carrying little or no sediment.
Irrigation system**:** solid full coverage sprinklers, application rate 0.10 in/hr
Irrigation water**:** pH 7.5, EC 0.2 dS/m
Irrigation system operation**:** 50 hr per 14 day period at mid season
Drainage: mid-late summer runoff moves to a drain at edge of field; then, on to a larger creek
Proximity to surface waters: During the spring and summer, a drainage ditch along one edge of the orchard often contains orchard irrigation runoff water
Pesticide mixing and loading: A pesticide mixing & loading area is located about 40 feet from the drainage ditch
Pest**:** codling moth, damage was 4% last season and first flight trap catches this year average 1.5 moths/trap/night in 1 mg pheromone traps

We begin the risk assessment with Flowchart number 1 *(FC1), by considering possible routes by which pesticide could move off the field and the operations or conditions that may contribute or mitigate the risk. We will determine if a risk exists for each concern, "Irrigation Runoff," "Stormwater Runoff," and "Application Near Water Surfaces" and then review management practices to mitigate the risk.*

THE IRRIGATION RUNOFF RISK

The first step in flowchart 1 (FC1) is to evaluate risks associated with i**rrigation runoff** in our orchard using pressurized irrigation. Although runoff from irrigation is unlikely with the use a of solid set sprinkler irrigation, some runoff does occur in this orchard. Essentially, the poor water infiltration characteristics of this soil, combined with the need to meet the mid-season peak water demand, result on runoff to a surface water ditch and then on to a creek. After evaluating the irrigation runoff risks and reviewing management practices, we will revisit FC1 to evaluate the risks of applications near surface waters and finally the stormwater runoff risks.

Proceeding to FC2*, the next step is to consider orchard* ***IPM practices*** *for codling moth that might help reduce pesticide runoff risks. These, are presented in detail in the publication,* *"UC IPM Guidelines for Walnuts" and the UC Pest Management Guidelines available at (http://ucipm.ucdavis.edu).*

Integrated Pest Management

The Codling Moth Pest

Codling moths overwinter as full-grown larvae which pupate and begin emerging as the "first flight" of adult moths from early March to early April. Depending on climate, codling moth may have two to three generations per year, with a partial fourth generation in the warmest years and locations. Eggs laid by first flight moths hatch into larvae that bore into nutlets through the blossom end. Most of these nuts drop to the ground before the nuts mature, reducing yield. Larvae of subsequent generations bore into walnuts anywhere on their surfaces but often enter where two nuts touch each other. If the shell has hardened, it may take them up to a week to enter the nut. These nuts usually remain on the tree but are unmarketable because of the damage to the kernel.

Codling Moth Monitoring

Pheromone (or pheromone + DA kairomone) baited sticky traps and daily temperature records *-days* are used to track the seasonal development of codling moth and time spray applications. Codling moth development in each generation - from eggs to larvae to adults – depends on temperature: warmer temperatures promote faster development. The need for treatment and the timing of sprays is slightly different for each generation of codling moth and depends on the population. The development of each generation can be predicted very accurately by determining the start of the flight – called the *biofix* – and measuring daily high and low temperatures and calculating each day's incremental heat accumulation, expressed in units called *degree-days.* Pesticides that kill by contact or ingestion are generally applied to kill larvae after they emerge from eggs. Insect growth regulators are generally applied earlier – either before egg laying or egg hatch, depending on the product and its specific mode of action.

Management Options

Biological Control

While some natural enemies present in walnut orchards may help control codling moth, they do provide enough suppression to eliminate the need for chemical treatments.

Chemical Control

In our example orchard, codling moth pressure would be considered "moderate" based on last season's damage of 4%. Pheromone mating disruption could be an effective tool for reducing codling moth population and damage in the orchard over time but, according to our case study conditions, our first flight trap catches of 1.5/trap/night indicate the need for a late first generation (1B) treatment at 600-700 degree-days. Treatments for subsequent generations will depend on the results of monitoring nut drop, trap catches, and canopy damage. . In orchards treated with contact or ingested insecticides (e.g., spinosad and oil, organophosphates, pyrethroids, and carbamates), treatments are timed to kill larvae as they emerge from eggs. If insect growth regulators are used, treatments are applied before egg laying or egg hatch, depending on the product being used.

Continuing to work our way through FC2, the next step is to select an effective control pesticide that has minimum risk to water quality.

Selecting Pesticides to Reduce Water Quality Risks

To illustrate how pesticides might be selected based upon water quality considerations, let's assume that a second codling moth treatment is needed later in the season to control the second codling moth generation. Treatment options, derived from the UCIPM Pest Management Guidelines for Walnuts. A variety of chemicals of different classes are available for treatment. Consideration should be given to efficacy, costs and surface water protection when a sensitive area is nearby or if runoff reaches water sources. Table A1 lists the chemicals available for use within the different pest pressure population groups. Combined into table A1 is the potential for solution and adsorption runoff potential as well as an overall runoff risk which considers the aquatic toxicity of the pesticide.

Table A1. Common treatment options for codling moth in walnut production

Population	Trade Name	Chemical Class	Solution Runoff potential[1]	Adsorption runoff potential[2]	Overall runoff risk[3]
High Population					
azinphos-methyl	Guthion	organophosphate	intermediate	intermediate	moderate
methyl parathion	Penn-Cap	organophosphate	intermediate	intermediate	moderate
Moderate to High Population					
lambda-cyhalothrin	Warrior	pyrethroid	low	intermediate	high
cyfluthrin	Baythroid	pyrethroid	low	intermediate	high
bifenthrin	Brigade	pyrethroid	low	high	high
Moderate Population					
phosmet	Imidan	organophosphate	intermediate	low	moderate
chlorpyrifos	Lorsban	organophosphate	high	intermediate	v high
methoxyfenozide	Intrepid	diacylhydrazine			
esfenvalerate	Asana XL	pyrethroid	low	high	high
permethrin	Pounce	pyrethroid	Low	high	high
carbaryl	Sevin	carbamate	intermediate	low	moderate
spinetoram	Delegate	spinosyn			
Low Population					
diflubenzuron	Dimilin	benzoylurea	high	intermediate	low
spinosad	Entrust	spinosyn	intermediate	intermediate	low

[1] Likelihood that the active ingredient will transport from the area of treatment as dissolved chemical in runoff.
[2] Likelihood that the active ingredient will transport from the area of treatment as attachment to soil or sediment particles in runoff.
[3] Overall likelihood to cause negative impact on surface water quality as a product of the runoff potential and the aquatic toxicity of the pesticide

Our example orchard has a moderate population, and the table includes ten insecticides considered appropriate in for moderate or moderate to high populations. Two are organophosphates; five are pyrethroids, one spinosyn, one a carbamate, and one diacylhydrazine. Having read the sections of this manual about the water quality risks associated with various classes of chemicals, we know that organophosphates are highly water soluble while pyrethroids are much less soluble but and adsorb readily to soil sediments and therefore each move offsite using different pathways. Selection should be made based on pesticide efficacy, costs and the risk of offsite movement from the orchard. In our example orchard, there is a risk of a small volume of irrigation runoff which should encourage the use of pesticides in the lower solution runoff risk category.

The next consideration in FC2 for managing codling moth is to consider pesticide mixing and loading practices and their impact on surface water quality

Mixing and Loading Pesticides Near Surface Waters

The mixing and loading site in our example field is within 50 feet of a surface water ditch. Mixing and loading practices include not over-filling the tank, triple rinsing containers and adding the rinsate to the tank, and rinsing the tank and applying the rinsate to the field. The use of a concrete pad with catchment sump is also a good solution to reduce risks from mixing and loading near surface water sources.

The next step in our assessment in FC2 is to consider changes in irrigation management.

In our example orchard, runoff to a drainage ditch and nearby creek occurs during mid and late summer irrigations. Potential solutions related to orchard irrigation might include:

Irrigation System Management

Change Irrigation Frequency or Application Rate

In addition to making changes that improve water infiltration, it may be possible to modify the example orchard's irrigation schedule being used in ways that will help reduce runoff. With the current schedule, 5 acre-inches of water are applied every 14 days in mid-summer. The 14-day mid-summer ETc for mature walnuts is 4.5 inches. Meeting this demand requires the application of 6 inches of water, because the irrigation efficiency of our sprinkler system is roughly 75%. Thus, the current irrigation of 5 inches every 2 weeks is 1 inch below the requirement. Any new schedule must correct this deficiency AND reduce runoff. One possible solution is to change the irrigation interval to 7 days and the duration to 30 hours. This schedule would meet the orchard's demand while reducing the likelihood of runoff by reducing irrigation duration –avoiding the lowest intake rate part of the irrigation. Another possible solution is to reduce the application rate by 20 percent in an attempt to not exceed the infiltration capacity. However a longer irrigation time would be necessary to meet the irrigation requirement.

<u>Improve Water Infiltration</u>

The soil is our example orchard prone to crusting. Winter annual cover crops may help protect the soil surface from the dispersive effects of winter and spring rainfall and improve water infiltration during the summer by increasing soil organic matter content. Light tillage in the spring and summer can also be used to break up surface crusts. If done after a pesticide application, tillage may also help incorporate pesticide residues into the soil, thus reducing runoff potential.

The irrigation water in our example orchard has a salinity (ECw) of 0.2 dS/m, indicating a "pure water" infiltration problem. Applying gypsum – with a "solutionizer" in the irrigation water or broadcast and left on the surface to be dissolved by the sprinkler irrigation water - would help improve water infiltration rates.

<u>Improve Irrigation Uniformity</u>

Uniformity must be "designed into" pressurized irrigation systems during the orchard planning process. Sprinkler nozzle wear can increase application rates exceeding the infiltration rate at the end of the irrigation when infiltration rate declines. All nozzles should be the same size to minimize pressure differential application rates.

<u>Manage Irrigation System to Avoid Runoff</u>

The simplest way to avoid irrigation runoff is to turn the system off before runoff occurs at the end of each irrigation. Irrigation <u>frequency</u> may need to be to be increased to compensate for shorter irrigation duration.

The next step in our assessment in FC2 is to consider changes in irrigation scheduling.

<u>Irrigation Scheduling</u>

Irrigation scheduling entails estimating the amount of crop water use, then applying this amount plus an amount of irrigation to overcome system efficiencies ensuring most parts of the orchard which receive the minimum water required. Irrigations should be scheduled before significant water stress is experienced at durations that do not cause runoff. Soil based or plant based monitoring methods should be used to check up the irrigation calculations and applications.

The next step in our assessment in FC2 is to consider runoff water capture, filtering and/or recycling of runoff.

<u>Runoff Water Capture, Filter and/or Recycling</u>

<u>Sediment Basin /Recycle Runoff</u>

Sediment basins can be used to capture runoff and reduce sediment load. Recycling of runoff waters to the delivery system can completely eliminate the offsite runoff. Installing a sediment basin upstream of the drainage ditch or creek could prevent runoff, but its capacity would need to be great enough to hold the runoff water long enough for it to infiltrate before the next runoff event. Another option is to construct install a berm at the lower end of the orchard to trap and hold runoff water long enough for it to infiltrate the soil.

<u>Vegetated Strips/Drain Ditches</u>

Vegetative strips if designed and constructed properly can infiltrate runoff waters and filter out sediments. Take care to create large enough strip or ditch areas to reduce runoff velocities.

The last step in our assessment in FC2 is to consider runoff water treatment.

<u>Runoff Water Treatment</u>

Runoff waters from our example orchard are low in volume which generally does not carry sediments, confining the offsite movement to water soluble organophosphate pesticides. Runoff waters containing organophosphate insecticide residues can be treated with the degradation enzyme Landguard OP-A to reduce or eliminate residues in runoff water before water exits the farm. This product promotes the breakdown of most organophosphate pesticides into less toxic metabolites.

<u>Now that we have evaluated the risk of chemical applications near surface water, we go back to FC1</u> *to evaluate the "Stormwater Runoff" risk.*

THE STORMWATER RUNOFF RISK

In our example orchard, all codling moth application are in season, allowing for residue degradation prior to the stormwater runoff season. Therefore, there is little risk of offsite movement.

<u>Now that we have evaluated the "Stormwater" risks, we go back to FC1</u> *to evaluate the "Application Near Surface Water" risks. Our example orchard is located near a drainage ditch which contains water draining to a surface water source and therefore is significant risk, we consider ways of reducing* ***spray drift*** *that could enter the drainage ditch or creek near the example orchard. Go to* ***FC5*** *(Evaluating the risk of chemical applications near surface waters) and the following drift management options:*

THE APPLICATION NEAR SURFACE WATER RISK (Drift)

Application Conditions

- Don't apply pesticides under dead calm or windy/gusty conditions; don't apply at wind speeds greater than 10 mph, ideally not over 5 mph. Read the label for specific instructions.
- Apply pesticides early in the morning or late in the evening; the air is often more still than during the day.
- Determine wind direction and take it into account when deciding whether or not or how to make an application.
- Calibrate and adjust sprayers to accurately direct the spray into the canopy “target.”
- Delay treatments near ditches and surface water bodies until wind is blowing away from these and other sensitive areas.
- Don't spray during thermal inversions, when air closest to the ground is warmer than the air above it.

Application Equipment

- Use as coarse a spray as possible (250 - 400 microns or larger) while still obtaining good coverage and control. Droplet size is one of the most important factors affecting drift.
- Use low drift nozzles that produce larger droplet sizes. Fitting a sprayer with air induction nozzles instead of standard nozzles will reduce spray drift up to 50 percent compared to standard nozzles.
- Use a directed spray to minimize the contact with soil.
- Check to verify the spray deposition pattern expected.
- Service and calibrate spray equipment regularly.
- Check the system for leaks. Small leaks under pressure can produce very fine droplets. Large leaks contaminate soil which can be moved offsite by water.
- Use low pressure and spray volumes appropriate for canopy size.

Product Choice

- Choose an application method and a formulation that are less likely to cause drift. After considering the drift potential of a product/formulation/application method, it may become necessary to use a different product to reduce the chance of drift.
- Use drift control/drift reduction spray additives/agents. These materials are generally thickeners designed to minimize the formation of droplets smaller than 150 microns. They also help produce a more consistent spray pattern and deposition.
- Use spray adjuvants, which can greatly reduce application volumes without compromising pesticide efficacy.
- Use maximum spray volume per acre and low pressure.
- Treat buffer zones with materials that are the least risk to aquatic life.

Buffer Zones

- Maintain adequate buffer zones around the treated site to ensure that pesticides don't drift onto sensitive areas. Read the label to determine the size of buffer zone required as related to the rate of active ingredient.
- Wolf et al. (2003) documented 75 to 95 percent reductions in drift deposits up to 98 feet downwind when setback distances were vegetated with grass or shrubs.

Controlling Offsite Movement of Agricultural Chemical Residues -- Winegrapes

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Prepared as a Component of:
California Department of Pesticide Regulation-- Pesticide Management Alliance Grant in Cooperation with the San Joaquin County and Delta Water Quality Coalition. 2010

Table of Contents

Controlling Offsite Movement of Agricultural Chemical Residues -- Winegrapes

INTRODUCTION

WHAT'S IN THIS PUBLICATION?

The goal of this publication is to provide winegrape growers with information on farming practices to help reduce the occurrence of organophosphate and synthetic pyrethroid pesticides in surface waters, which include streams, lakes, ponds, rivers, and drainage ditches. An assessment of the potential risk of offsite movement of an insecticide is made before a field application is performed using a flowchart for specific management practices and field conditions in winegrapes. This risk self-assessment focuses on issues that affect either the number of pesticide applications containing these active ingredients, or the offsite movement of pesticides as drift, attached to sediment, or in water that carries pesticide active ingredients.

If a significant risk that pesticide residues will leave the site of application and enter surface waters exists, a grower is able to consult the information in this manual about an array of science-based management practices to mitigate that risk.

WHY IS THIS PUBLICATION NEEDED?

The Central Valley occupies about 40 percent of the land area in California and provides much of the State's agricultural production. Maintaining this productivity has required the use of about 132 million pounds of pesticides annually. Water quality in the Central Valley's rivers and streams has been impacted in part due to pesticide movement from agricultural lands into these waters. The list of impaired water bodies recently proposed for listing under the Clean Water Act Section 303(d) includes nearly a hundred water body segments in which impairment is due to agriculture. Agriculture is identified more often than any other source in the State as the likely cause of impairment.

Agricultural pesticides reach surface water bodies directly as spray drift or indirectly through irrigation or stormwater runoff from treated fields, vineyards, and orchards. Runoff waters may transport pesticides as dissolved or soil particle-adhering residues. Among the pollutants often attributable to agriculture is the organophosphate insecticide chlorpyrifos. California agriculture uses 1,425,000 pounds of chlorpyrifos annually, more than any other insecticide. Approximately half of the hundred 303(d) listed water body segments impaired due to agriculture in the Central Valley are impaired in whole or in part by chlorpyrifos. Total Maximum Daily Load is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards. The presence of chlorpyrifos in surface water and its toxicity to aquatic life has been responsible for multiple Total Maximum Daily Load (TMDL) projects in California, including one for the San Joaquin River, another for the Sacramento-San Joaquin Delta, and many other TMDLs elsewhere in the state where the process is less developed. In one study, chlorpyrifos was

responsible for mortality to the test organism, *Ceriodaphnia dubia*, in seven of ten toxic samples (de Vlaming et al. 2004).

Synthetic pyrethroids are another group of pesticides emerging as a concern. Pyrethroids are a cause for 303(d) listing of about 10 percent of agriculture-impaired water bodies in California. In a study of toxicity of sediments collected from agricultural waterways, 54 out of 200 sediment samples caused acute toxicity to the test organism, *Hyalella azteca*, and pyrethroids were responsible for the toxicity in 61 percent of those cases (Weston et al. 2009). Chlorpyrifos was the second most common contributor to toxicity, responsible for toxicity in 20 percent of the samples. Recent data also indicate that pyrethroids are present at toxic levels in the water column of irrigation tailwater samples. In a study just completed, the pyrethroid lambda-cyhalothrin was responsible for toxicity to *H. azteca* in three out of six toxic samples collected at California agricultural pump stations where tailwater was being returned to nearby rivers. Chlorpyrifos was responsible for toxicity in the remaining three samples (Weston and Lydy 2010). As analyses of environmental samples for pyrethroids become more frequent, it is likely that the water quality effects of pyrethroids will be even more broadly recognized in future years.

The continued use of these effective agricultural pesticides is dependent on measures to prevent offsite movement of residues into surface waters. A listing of the active ingredients and trade names for pesticides used in winegrape production can be found in Table 1. The table is restricted to those materials with reported use in California during 2008 with use over 100 pounds annually. Organophosphates and pyrethroids represent 60% of this list. Even though organophosphate, pesticides are declining in use each year, they still represent 57% of the list total with chlorpyrifos the highest use product based on pounds applied per year.

Table 1. Winegrape pesticides used in California in 2008 that are registered for use in 2011 (CDPR, California Department of Pesticide Regulation).

Active Ingredient Common Name	Trade Name	Lbs/Year	Chemical Class
chlorpyrifos	Lorsban	100,895	organophosphate
imidacloprid	Admire	21,919	neonicotinoid
methyoxfenozide	Intrepid	16,986	diacylhydrazine
cryolite	Cryolite	16,160	inroganic
buprofezin	Applaud	16,395	unclassified
fenpropathrin	Danitol	6,552	pyrethroid
dinotefuran	Venom	5,472	neonicotinoid
phosmet	Imidan	5,348	organophosphate
malathion	Malathion	5,113	organophosphate
methomyl	Lannate	3,310	carbamate
fenamiphos	Nemacur	2,632	organophosphate
diazinon	Diazinon	1,046	organophosphate
clothianidin	Clutch	542	neonicotinoid
spinosad	Success	238	spinosyn
thiamethoxam	Platinum	154	neonicotinoid
spinosad	Success	238	spinosyn
dimethoate	Cygon	113	organophosphate

CURRENT REGULATORY APPROACH TO SURFACE WATER PROTECTION

All growers farm under the requirement not to pollute surface and groundwater. Water leaving agricultural lands, as irrigation or stormwater runoff, can contain pesticide residues, sediment, or nutrients. These discharges are regulated by California's Central Valley Regional Water Quality Control Board (Water Board) under a program called the Irrigated Lands Regulatory Program. Essentially, the Board is enforcing the California Water Code of 1969 and the Federal Clean Water Act of 1972. To this end the Water Board has:

- Established surface water quality standards in each watershed basin plan
- Enforced waste discharge requirements

THE AG WAIVER

In 1982 the Board adopted a resolution "*Waiving Waste Discharge Requirements for Specific Types of Discharge.*" The resolution contained 23 categories of waste discharges, including *irrigation return flows and stormwater runoff* from agricultural lands. The resolution also listed the conditions required to comply with the waiver, hence the term '**Conditional Ag Waiver**.' However, due to a shortage of resources at the time, the Water Board did not impose measures to verify compliance with these conditions.

The waiver, set to sunset in 2003, was amended by adopting two conditional waivers for discharges from irrigated lands. **One** was for *coalition groups* of individual dischargers that comply with the California Water Code and Water Board regulations. **The other** was for growers to comply as individual entities. To be covered by the waivers, the coalition or individual must have filed with the Water Board by November 1, 2003 a Notice of Intent and General Report that contained specific information about their farm and then must have adhered to a plan and timeline that includes, among other things, a farm management plan and surface water monitoring plan.

WATER QUALITY COALITIONS

Water quality coalitions are generally formed by growers on a sub-watershed basis, although some are based on a specific commodity. The San Joaquin County and Delta Water Quality Coalition, for example, encompasses all of San Joaquin County and portions of Contra Costa and Calaveras Counties. The Coalition includes about 500,000 acres of irrigated lands and 4500 individual members. The Coalition monitors and analyzes the water quality of sub-watersheds in surface waters and facilitates the implementation of management plans. Coalitions provide outreach and support to growers in response to water quality exceedances at sub-watershed monitoring sites, in order to enhance the water quality of those water bodies affected.

Water Quality Monitoring

The Coalition currently monitors water quality at numerous sites in both large and small sub-watersheds within the coalition watershed. Water samples are collected monthly, while sediment samples are collected twice per year. During 2008, water quality standards were exceeded many times. At some locations, as many as 40 percent of the samples exceeded water quality standards for pesticide residues (Management Plan, San Joaquin County Delta Water Quality Coalition, Karkoski 2008). When more than one exceedance of water quality limits occurs for any contaminant, a management plan must be developed by the Coalition to address it. In addition, any single exceedance of either chlorpyrifos or diazinon triggers the requirement for a management plan.

Management Plans

The overall goal of water quality management plans, whether developed by individuals or coalition groups, is to reduce agricultural impacts on water quality in the plan area. Management plans evaluate the frequency and magnitude of exceedances and prioritizes locations for outreach.

To achieve the goal of improving water quality, a management plan must include:

- Source identification of constituents causing water quality impairments
- Outreach to growers about irrigation and dormant season management practices to protect water quality
- Evaluation of water quality improvements achieved by monitoring and implementation of management practices

Under the management plan landowners/growers must:

- Help the Coalition succeed by participating in efforts to solve water quality impairments identified through water monitoring
- Staying informed – read mailings and updates, respond as necessary
- Attending grower water-quality information meetings
- Implementing management practices that mitigate the identified water quality concerns

HOW TO USE THIS MANUAL

This manual is designed to be used in a two-step process. The first step is to make a "risk assessment" of field conditions or operations to identify those farming practices that may influence the risk of offsite pesticide movement. To aid in doing this, a series of "flowcharts" are presented. Once avenues of possible pesticide movement from a particular field are identified in the first flowchart, succeeding flowcharts help "zero in" on specific conditions and operations that can be used to reduce offsite movement. When followed systematically from beginning to end, the flowcharts will guide one through a stepwise evaluation of a farming operation to identify potential problem areas.

The second step is to understand and implement management practices to address the problem areas that were identified. These management practices, presented beginning on page 17 of this publication, are divided into three broad categories:

USE INTEGRATED PEST MANAGEMENT (IPM) APPROACHES, HANDLE, APPLY, AND STORE PESTICIDES CORRECTLY

Integrated Pest Management (IPM) is an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used **only** after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Coupling use of IPM techniques with proper pesticide selection, handling, application, and storage can go a long way towards preventing offsite movement and protecting water quality.

These practices should be the foundation of any water quality protection program. Implementing at least some of them can also reduce risks to human health, beneficial and non-target organisms, and the environment.

USE SOIL AND WATER MANAGEMENT PRACTICES

Use soil and water management practices that reduce runoff potential. Runoff occurs when using surface irrigation or when rainfall occurs faster than it can enter the soil. Runoff water can carry pesticides in the water itself or adsorbed to eroding soil particles. Proper irrigation method selection, design, and operation, coupled with vineyard floor management and water treatments that maximize water infiltration, help ensure that the water needs will be met and runoff kept at a minimum.

CAPTURE, FILTER, RECYCLE OR TREAT RUNOFF WATERS

When IPM and soil and water management do not adequately address a water quality problem, techniques for physically intercepting, recycling, or chemically treating runoff water can be used to reduce offsite transport of water pesticides in water.

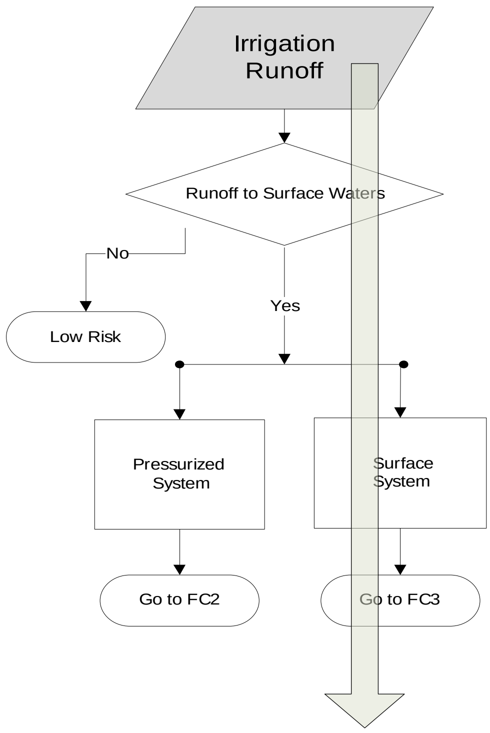
QUICK OVERVIEW OF THE RISK EVALUATION PROCESS

For a quick overview of the process, let's consider an example vineyard to illustrate how the flowcharts and management information in this manual could be used to identify and correct an offsite insecticide movement problem. We'll return to a more detailed discussion of this scenario in the case study presented in Appendix I located at the end of this manual. The opaque arrows in these flowcharts indicate the logical progression in considering the most cost effective management practices.

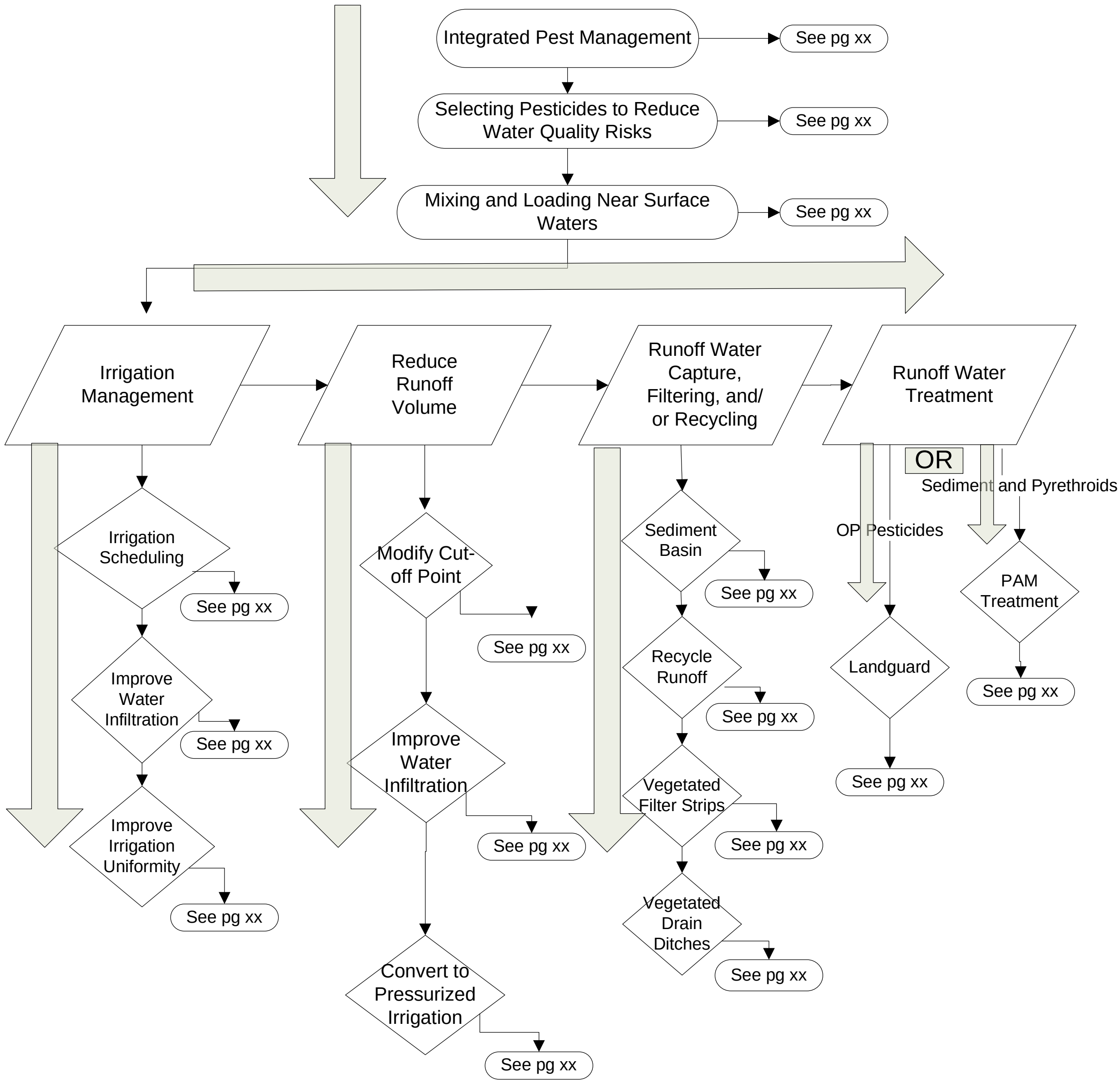
Vineyard: Mature Cabernet Sauvignon
Topography: Undulating topography 0- 4 percent slope
Soil: San Joaquin Sandy Loam, prone to soil surface crusting—limiting water infiltration
Irrigation system: Drip
Drainage: Runoff moves to a drain at edge of field; then, on to a larger creek
Proximity to surface water sources: Edge of field drain contains irrigation runoff from neighboring lands.
Pesticide mixing and loading: A pesticide mixing and loading area is located about 40 feet from the drainage ditch.

We begin the risk assessment with Flowchart number 1 (FC1), considering possible routes by which pesticide could move off the field and the operations or conditions that may contribute to the movement. The two possible areas of concern are:

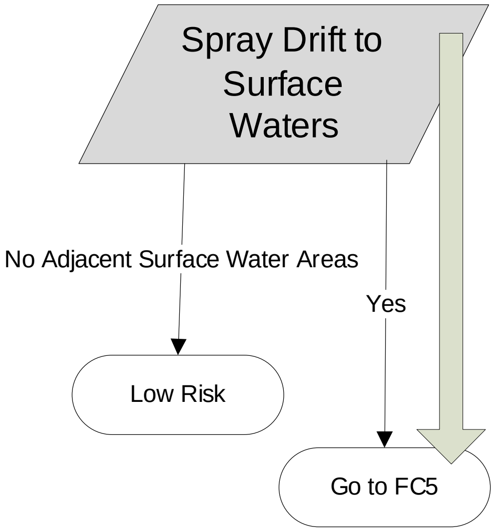
1) **FC1. Irrigation runoff risk.** Pesticides may be carried in the runoff that occurs during surface irrigation after the pesticide application. Go to FC3.



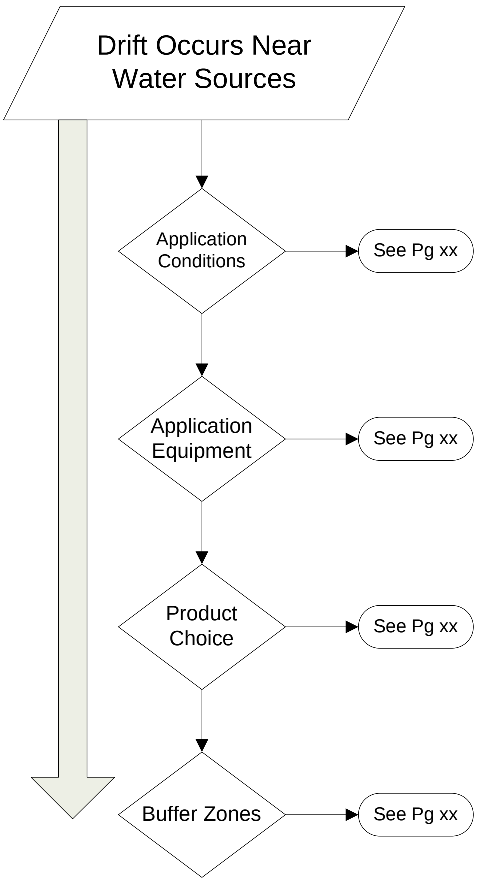
Flowchart 3 (FC3). Pressurized Irrigation Runoff Risk. If runoff occurs, this leads us first to an assessment of IPM practices, pesticide selection, mixing and loading practices and, in the management section, ways these can be improved. Following this, the flowchart leads us to consider irrigation management, methods to reduce runoff volume, capturing, filtering, and recycling and, finally, ways that runoff water–if it still occurs, could be treated to reduce any pesticide residues it may contain.



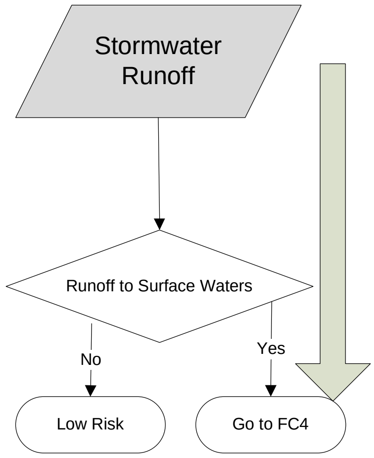
2) **Beginning again at FC1. Spray Drift to Open Water Risk.** During spray applications, pesticides may drift into the drainage ditch along the edge of the field; Go to FC5.



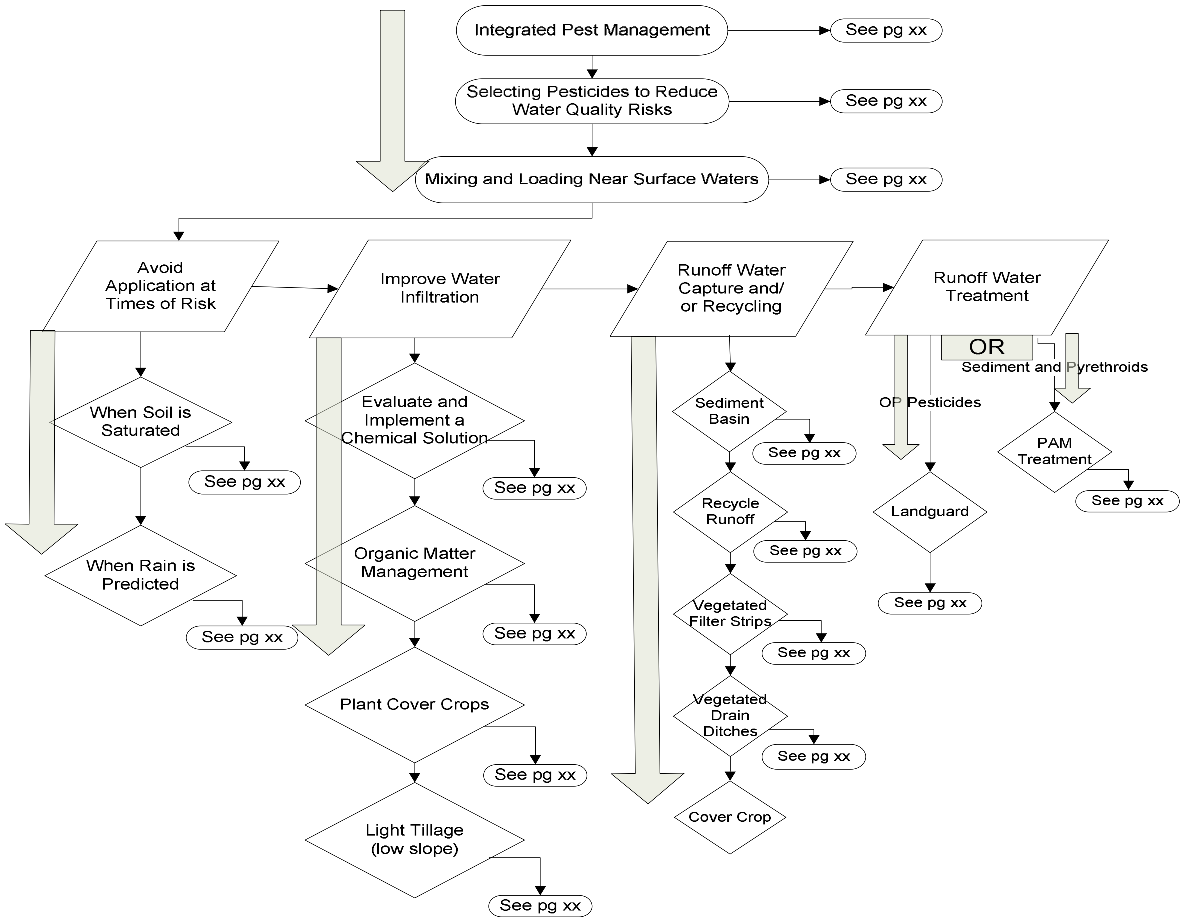
Flowchart 5 (FC5) Spray Drift to Open Water Risk presents various factors related to drift control. Each factor leads to a portion in the management information section of the manual where drift management practices are discussed.



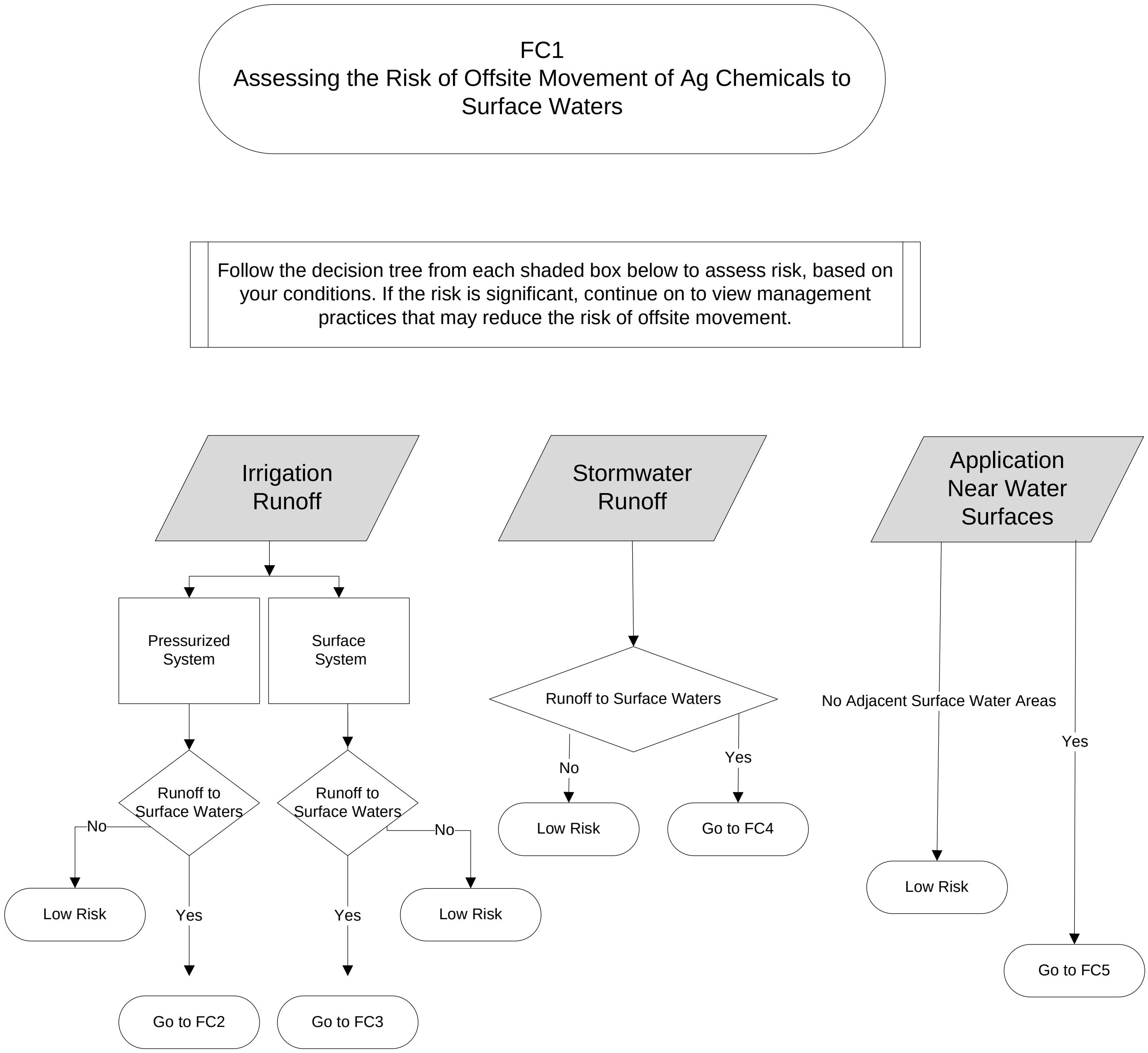
3) Beginning again at FC1. Stormwater Runoff Risk. Pesticides may be carried in the stormwater runoff as dissolved and sediment adsorbed residues. Since applications occur during the crop season, the risk is generally low; however persistent insecticides can still contribute to surface water degradation during stormwater runoff. Go to FC4.

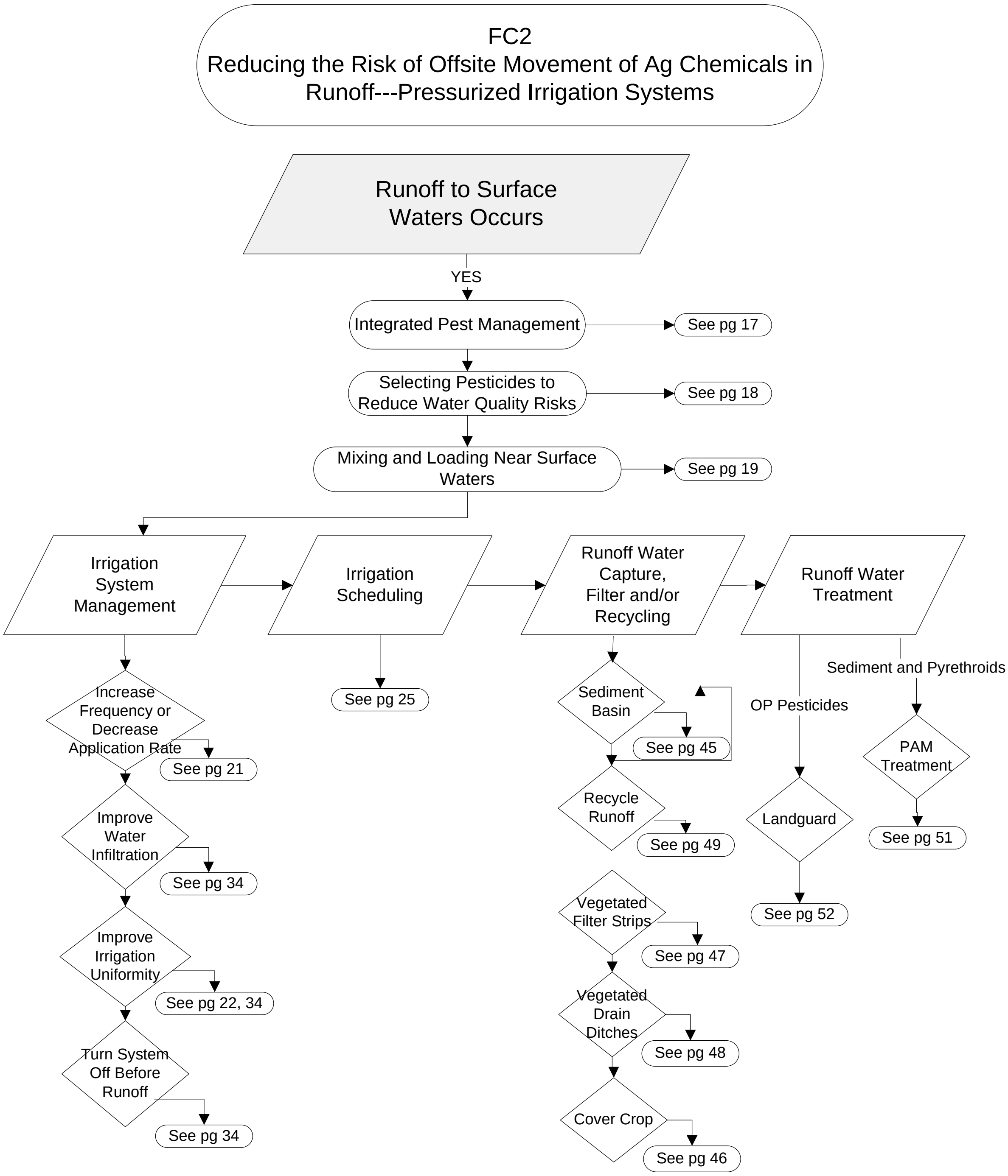


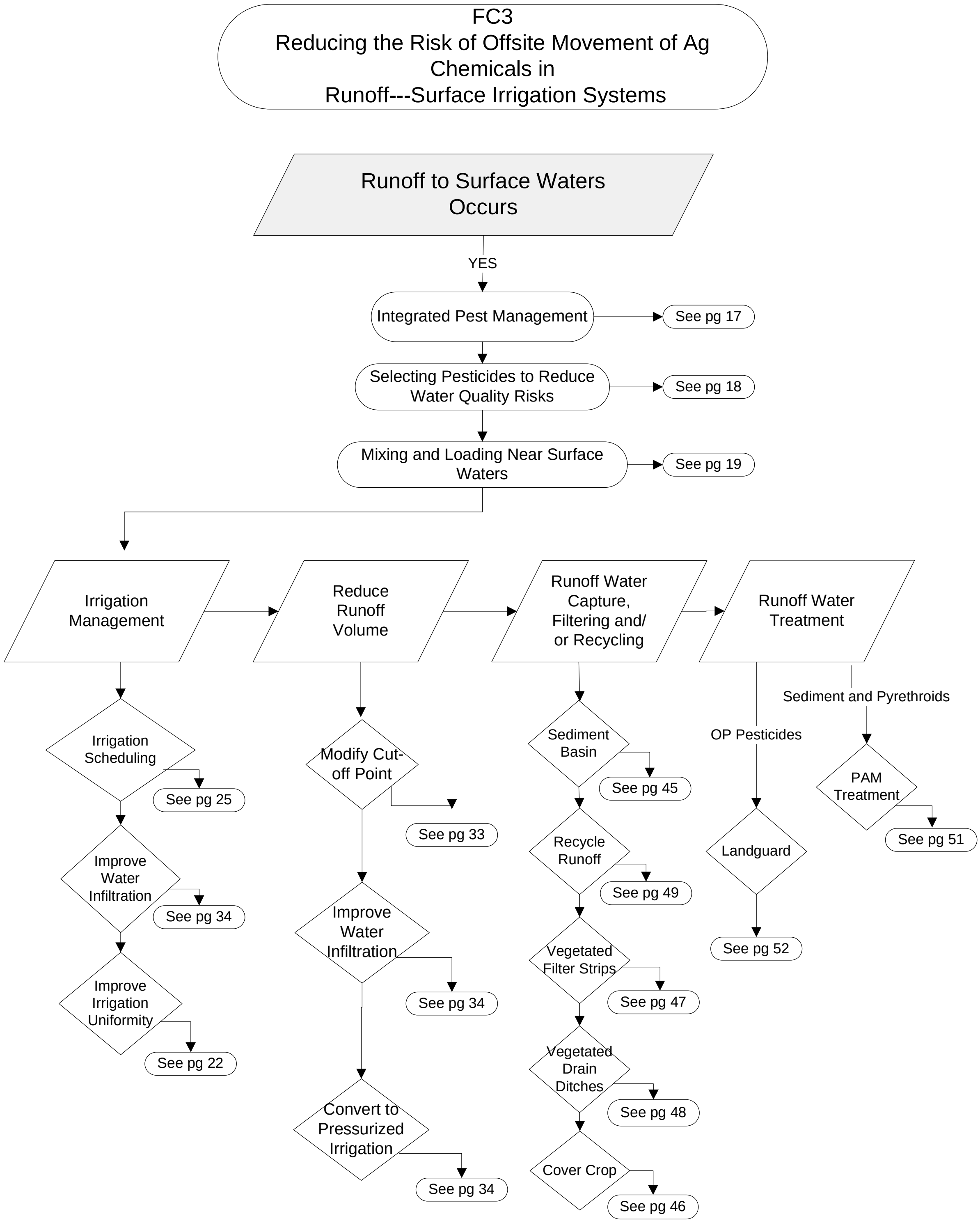
Flowchart 4 (FC4) Stormwater Runoff Risk presents various factors related to stormwater runoff risks. Each factor leads to a portion in the management information section of the manual where management practices are discussed to reduce pesticide residues in stormwater runoff.

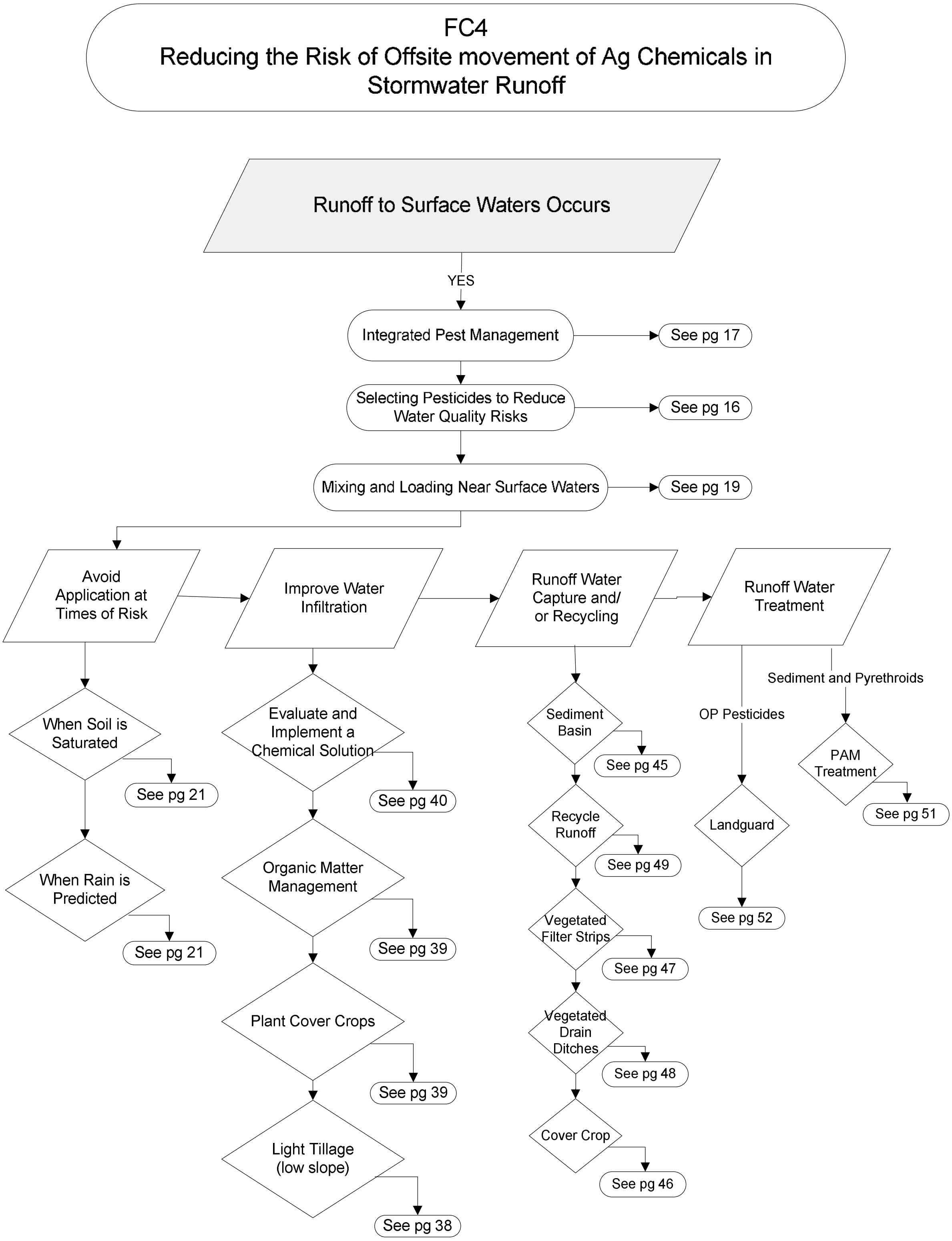


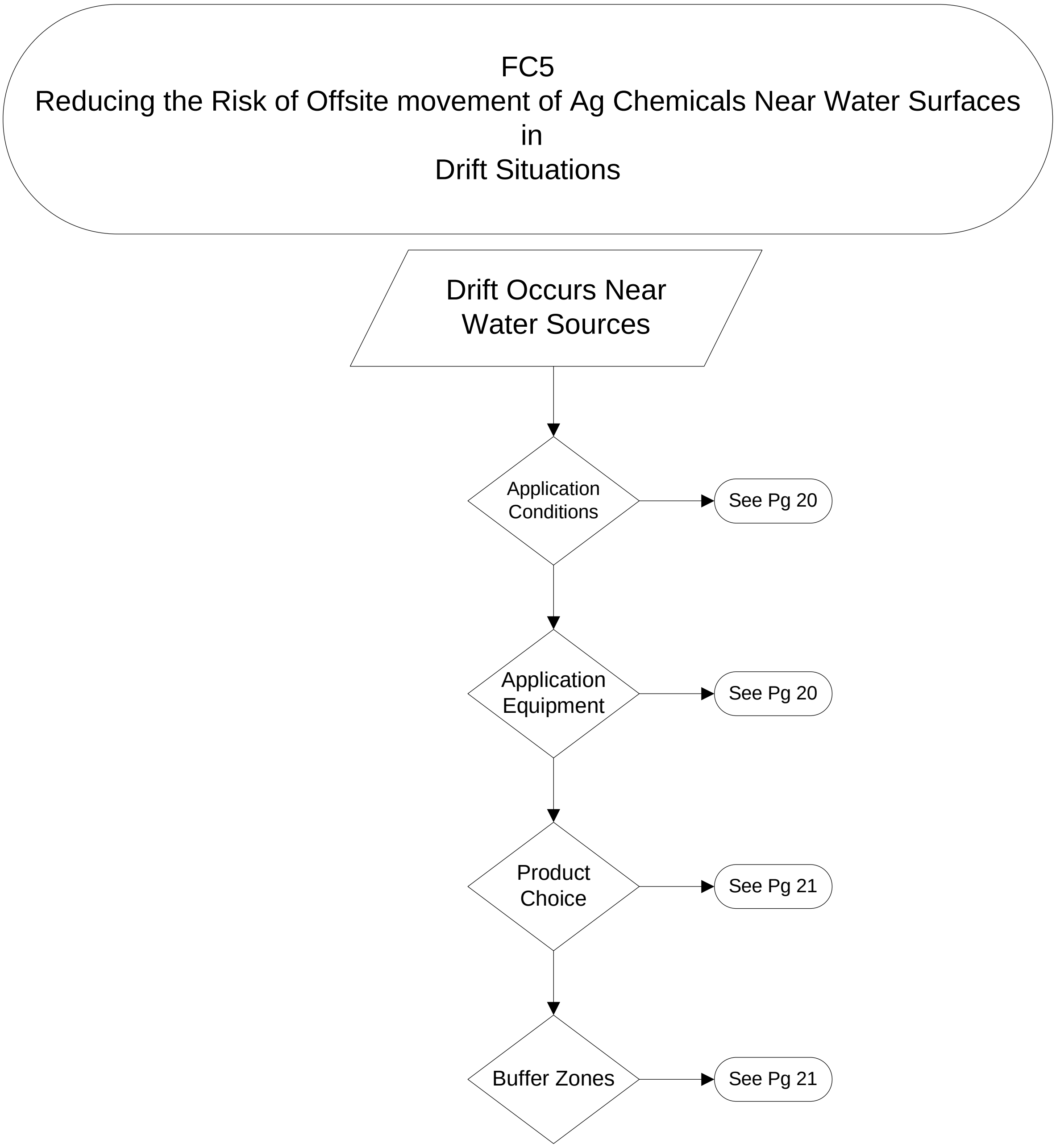
Risk Evaluation Flowcharts




FC2
Reducing the Risk of Offsite Movement of Ag Chemicals in Runoff---Pressurized Irrigation Systems
Runoff to Surface Waters Occurs
YES
Integrated Pest Management
See pg 17
Selecting Pesticides to Reduce Water Quality Risks
See pg 18
Mixing and Loading Near Surface Waters
See pg 19
Irrigation System Management
Irrigation Scheduling
Runoff Water Capture, Filter and/or Recycling
Runoff Water Treatment
Increase Frequency or Decrease Application Rate
See pg 21
Improve Water Infiltration
See pg 34
Improve Irrigation Uniformity
See pg 22, 34
Turn System Off Before Runoff
See pg 34
See pg 25
Sediment Basin
See pg 45
Recycle Runoff
See pg 49
Vegetated Filter Strips
See pg 47
Vegetated Drain Ditches
See pg 48
Cover Crop
See pg 46
OP Pesticides
Landguard
See pg 52
Sediment and Pyrethroids
PAM Treatment
See pg 51


FC3
Reducing the Risk of Offsite Movement of Ag Chemicals in
Runoff---Surface Irrigation Systems
Runoff to Surface Waters Occurs
YES
Integrated Pest Management
See pg 17
Selecting Pesticides to Reduce Water Quality Risks
See pg 18
Mixing and Loading Near Surface Waters
See pg 19
Irrigation Management
Reduce Runoff Volume
Runoff Water Capture, Filtering and/ or Recycling
Runoff Water Treatment
Irrigation Scheduling
See pg 25
Improve Water Infiltration
See pg 34
Improve Irrigation Uniformity
See pg 22
Modify Cut-off Point
See pg 33
Improve Water Infiltration
See pg 34
Convert to Pressurized Irrigation
See pg 34
Sediment Basin
See pg 45
Recycle Runoff
See pg 49
Vegetated Filter Strips
See pg 47
Vegetated Drain Ditches
See pg 48
Cover Crop
See pg 46
OP Pesticides
Landguard
See pg 52
Sediment and Pyrethroids
PAM Treatment
See pg 51


FC4
Reducing the Risk of Offsite movement of Ag Chemicals in Stormwater Runoff
Runoff to Surface Waters Occurs
YES
Integrated Pest Management
See pg 17
Selecting Pesticides to Reduce Water Quality Risks
See pg 16
Mixing and Loading Near Surface Waters
See pg 19
Avoid Application at Times of Risk
Improve Water Infiltration
Runoff Water Capture and/ or Recycling
Runoff Water Treatment
When Soil is Saturated
See pg 21
When Rain is Predicted
See pg 21
Evaluate and Implement a Chemical Solution
See pg 40
Organic Matter Management
See pg 39
Plant Cover Crops
See pg 39
Light Tillage (low slope)
See pg 38
Sediment Basin
See pg 45
Recycle Runoff
See pg 49
Vegetated Filter Strips
See pg 47
Vegetated Drain Ditches
See pg 48
Cover Crop
See pg 46
OP Pesticides
Landguard
See pg 52
Sediment and Pyrethroids
PAM Treatment
See pg 51


FC5
Reducing the Risk of Offsite movement of Ag Chemicals Near Water Surfaces
in
Drift Situations
Drift Occurs Near Water Sources
Application Conditions
See Pg 20
Application Equipment
See Pg 20
Product Choice
See Pg 21
Buffer Zones
See Pg 21

MANAGEMENT PRACTICES TO REDUCE SURFACE WATER PESTICIDE CONTAMINATION

INTEGRATED PEST MANAGEMENT

The University of California Integrated Pest Management Programs defines IPM as:

> "…an ecosystem-based strategy that focuses on long-term prevention of pests or their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines, and treatments are made with the goal of removing only the target organism. Pest control materials are selected and applied in a manner that minimizes risks to human health, beneficial and non-target organisms, and the environment."
> http://ucipm.ucdavis.edu

IPM is a systematic approach to pest management. The decision process includes:

- select varieties that are well adapted to local conditions with a high degree of pest and disease resistance;
- proper pest identification;
- understanding pest life cycles and conditions conducive to infestation;
- monitoring for the presence, locations and abundance of pests and their natural enemies;
- treat when established action thresholds (economic, aesthetic, tolerance) are reached;
- consideration of multiple tactics for pest suppression – biological, cultural, and chemical—and selection of the lowest-risk practical and effective approach; and
- evaluate results.

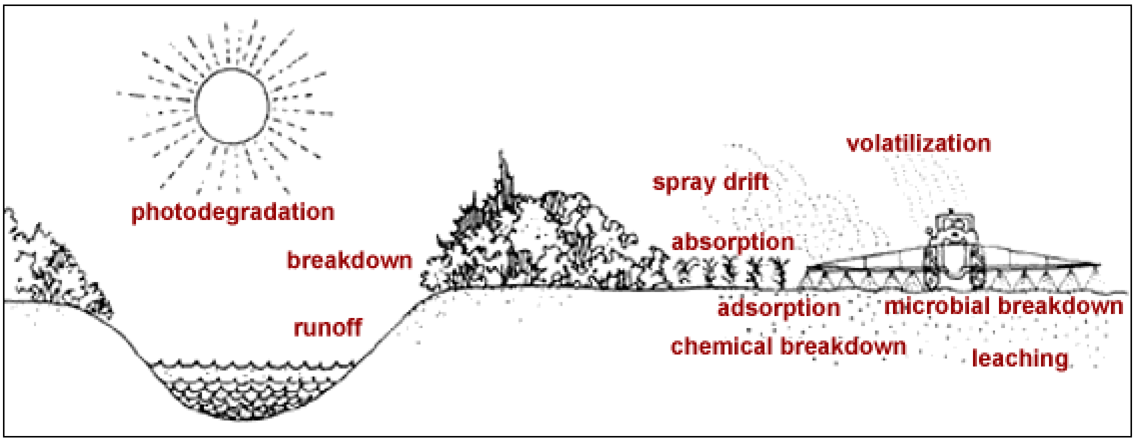
Because many print and on-line publications are available to help growers use IPM in their fields, they are not discussed in detail here. Pest and disease biology, monitoring, management, as well as water quality considerations in selecting and using pesticides, may be found in and from:

- The online UC IPM Guidelines for winegrapes http://www.ipm.ucdavis.edu/PMG/selectnewpest.grapes.html
- The UC IPM Year Round Program for grapes, with annual checklist, http://www.ipm.ucdavis.edu/PMG/C302/m302yi01.html
- UC Grape Pest Management Publication 3343,
- Licensed Pest Control and Crop Advisers, and
- UC IPM Advisors and Farm Advisors.

SELECTING PESTICIDES TO REDUCE WATER QUALITY RISKS

Knowledge of how pesticides move and degrade in the environment is useful for product selection. Pesticides and pesticide residues can move along several different pathways, depending on properties of the pesticide, the application method, and conditions at the application site (Figure 1). This movement is a complex process and, combined with several other factors, influences a pesticide's fate and potential water quality impacts. From a surface water management perspective, keeping the pesticide on or in the soil by preventing runoff is the most desirable option.

Figure 1. Pesticide fate processes



Winegrape pesticide active ingredients vary in water solubility, soil adsorption and half-life. Pesticides with high water solubility can move directly in runoff waters while those adsorbed to soil sediments (and generally with low water solubility) move with the sediment. Half-life is an indication of the persistence in the environment, usually the number of days it takes for the pesticide for one-half the amount in soil to degrade. The soil adsorption coefficient (Koc) can be considered an index for pesticide mobility. USDA-NRCS has a model that takes these characteristics into consideration in determining a pesticide's tendency to move in dissolved form with water or move with adsorbed to the sediments. The potential to move offsite, either in solution or with the soil, was categorized as high, intermediate, and low (Table 2.)

Aquatic toxicity rankings were extracted from the U.S. E.P.A. ECOTOX database (2007). The toxicity for EPA indicator species was then used to rank the overall aquatic risk (Long et al. 2005). The overall likelihood to cause negative impact (risk) on surface water quality is a product of the runoff potential and the aquatic toxicity of the pesticide. Table 2 indicates this relationship for commonly used insecticides in winegrape production; products without a risk category listed here are new and/or not yet categorized in this system. The table can be used to select pesticides based on the risk of offsite movement to surface waters. A change in pesticide within a same class or to a different class can significantly reduce the environmental risk.

Table 2. California-registered winegrape insecticides and their potential to move in solution or as adsorbed particles and overall pesticide runoff risk.

Insecticide active ingredient (common name)	Trade name	Chemical Class	Solution runoff potential[1]	Adsorption runoff potential[2]	Overall runoff risk[3]
diazinon	Diazinon	organophosphate	high	high	very high
endosulfan	Thiodan	organochlorine	high	high	very high
chlorpyrifos	Lorsban	organophosphate	high	intermediate	very high
abamectin	Agri-Mec, Zephyr	glycoside	high	intermediate	High
permethrin	Pounce	pyrethroid	low	high	High
carbaryl	Sevin	carbamate	intermediate	low	Moderate
malathion	Malathion	organophosphate	intermediate	low	Moderate
methomyl	Lannate	carbamate	intermediate	low	Moderate
phosmet	Imidan	organophosphate	intermediate	low	moderate
fenpropathrin	Danitol	pyrethroid	low	intermediate	moderate
imidacloprid	Provado	neonicotinoid	high	intermediate	low
spinosad	Success, Tracer	spinosad	intermediate	intermediate	low
dimethoate	Cygon	organophosphate	low	low	low
naled	Dibrom	organophosphate	low	low	low
spirotetramat	Movento	keto-enol	intermediate	intermediate	low
methyoxfenozide	Intrepid	diacylhydrazine			

[1] Likelihood that the active ingredient will transport from the area of treatment as dissolved chemical in runoff.

[2] Likelihood that the active ingredient will transport from the area of treatment as attachment to soil or sediment particles in runoff.

[3] Overall likelihood to cause negative impact on surface water quality as a product of the runoff potential and the aquatic toxicity of the pesticide

Source: Pesticide Choice: Best Management Practice for Protecting Surface Water Quality in Agriculture, Long et al. 2005, UCANR Publication 8161,http://anrcatalog.ucdavis.edu/pdf/8161.pdf

HANDLING PESTICIDES TO REDUCE WATER QUALITY RISKS

The risk of offsite pesticide movement is great during mixing and loading due to the possible spillage of undiluted pesticides. Care should be taken to ensure all of the pesticide goes in the tank. Partially fill the tank with water prior to adding the pesticide to prevent high strength materials entering spray lines. Agitation and the use of a bypass can assist good mixing. Avoid over filling the tank, because spillage can move offsite aided by cleanup waters. Mix and load at a distance of greater than 50 feet from sensitive areas (open surface water)—more if there is a potential for movement in the direction of the sensitive area. Triple rinse pesticide containers and pour the rinsate into the sprayer tank for use on the field. Also apply tank rinse water to the field. The use of a concrete pad with a catchment sump is a good way to reduce risks from mixing and loading near surface water sources.

PESTICIDE APPLICATION PRACTICES TO REDUCE OFFSITE PESTICIDE MOVEMENT

Minimizing Spray Drift

Drift is the physical movement of pesticide droplets or particles through the air at the time of pesticide application or soon thereafter, from the target site to any non- or off-target site. All applications produce some drift. How much drift occurs depends on such factors as the formulation of the material applied, how the material is applied, the volume used, and prevailing weather conditions at the time of application, and the size of the application job. Drift can impact surface water quality through direct contact with open ditches or surface water adjacent to the treated field.

Spray drift can be mitigated by management practices to reduce off-target drift. Application practices that take weather and other site conditions into consideration, appropriately equipped delivery systems (low-drift nozzles), appropriate product choice (low vapor pressure, low water solubility), and the use of buffer zones can significantly reduce the risk of offsite movement of pesticides.

Application Conditions

- Don't apply pesticides under dead calm or windy/gusty conditions; don't apply at wind speeds greater than 10 mph, ideally not over 5 mph. Read the label for specific instructions.
- Apply pesticides early in the morning or late in the evening; the air is often more still than during the day.
- Determine wind direction and take it into account when deciding whether or not or how to make an application.
- Calibrate and adjust sprayers to accurately direct the spray into the canopy "target."
- Delay treatments near ditches and surface water bodies until wind is blowing away from these and other sensitive areas.
- Don't spray during thermal inversions, when air closest to the ground is warmer than the air above it.

Application Equipment

- Use as coarse a spray as possible (250 - 400 microns or larger) while still obtaining good coverage and control. Droplet size is one of the most important factors affecting drift.
- Use low drift nozzles that produce larger droplet sizes. Fitting a sprayer with air induction nozzles instead of standard nozzles will reduce spray drift up to 50 percent compared to standard nozzles.
- Use a directed spray to minimize the contact with soil.
- Check to verify the spray deposition pattern expected.
- Service and calibrate spray equipment regularly.

- Check the system for leaks. Small leaks under pressure can produce very fine droplets. Large leaks contaminate soil which can be moved offsite by water.
- Use low pressure and spray volumes appropriate for canopy size.

Product Choice

- Choose an application method and a formulation that are less likely to cause drift. After considering the drift potential of a product/formulation/application method, it may become necessary to use a different product to reduce the chance of drift.
- Use drift control/drift reduction spray additives/agents. These materials are generally thickeners designed to minimize the formation of droplets smaller than 150 microns. They also help produce a more consistent spray pattern and deposition.
- Use spray adjuvants, which can greatly reduce application volumes without compromising pesticide efficacy.
- Use maximum spray volume per acre and low pressure.
- Treat buffer zones with materials that are the least risk to aquatic life.

Buffer Zones

- Maintain adequate buffer zones around the treated site to ensure that pesticides don't drift onto sensitive areas. Read the label to determine the size of buffer zone required as related to the rate of active ingredient.
- Wolf et al. (2003) documented 75 to 95 percent reductions in drift deposits up to 98 feet downwind when setback distances were vegetated with grass or shrubs.

Avoid Application Risk Prone Times

Management practices to mitigate the offsite movement risk include avoiding application when rain is predicted, especially when soils are saturated by previous rainfall. Soluble organophosphate materials applied after harvest is at risk cause runoff of residues when followed by the heavy rain season. Apply as near harvest as possible.

IRRIGATION WATER MANAGEMENT TO REDUCE RUNOFF

Irrigation management entails assessing the crops water needs and applying irrigation water to supplement stored winter moisture. Irrigation frequency and duration should ensure that all water infiltrates such that plant water use is met while preventing water loss through runoff and deep percolation. The extent of runoff depends on several factors, including: 1) the slope or grade of an area; 2) the texture and moisture content of the soil; 3) how well the soil surface supports water infiltration; 4) the amount and timing of irrigation or rainfall. Runoff containing pesticides can cause direct injury to non-target species, harm aquatic organisms in streams and ponds, and lead to groundwater contamination.

Vineyard Irrigation Systems

Two basic types of irrigation systems are used in vineyard production: surface systems (furrow, or border-check), and pressurized systems (sprinklers and microirrigation). Each has distinct cultural, cost, and offsite movement advantages and disadvantages. Some disadvantages can be overcome using specific management practices.

In *pressurized irrigation systems,* water should be applied at a slower rate than it is absorbed by the soil, to prevent runoff. However, as irrigation progresses the infiltration rate declines, making runoff more likely. In order to prevent runoff, the system should be turned off before significant runoff occurs. When properly managed, pressurized irrigation systems cause no irrigation water runoff, effectively reducing the risk of pesticide residue moving offsite.

In *surface systems,* soil characteristics control the amount of water infiltrated and its distribution across the field as it travels down slope. Runoff is necessary to maximize distribution uniformity (how even the water is applied across the field) within the field. Limiting runoff after a reasonable uniformity has been achieved is a good practice to reduce the continued movement of residues offsite. Closed-end furrows used on relatively flat ground can also eliminate runoff. The successful use of this practice relies on a high infiltration rate and precise irrigation cutoff. Lastly, an irrigation recycling system can capture runoff and return it to the irrigation inflow, to be applied to adjacent sets or another field. At sites with runoff risks, changing from surface irrigation to pressurized irrigation is recommended when possible.

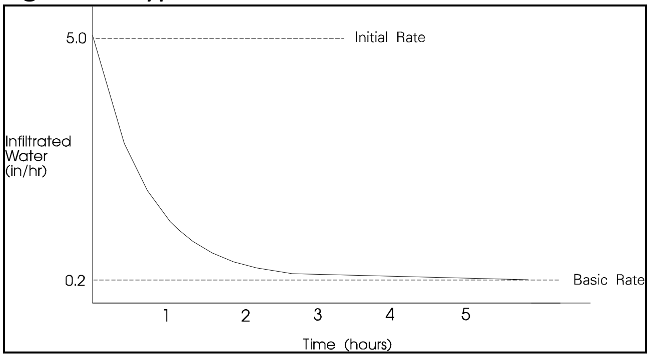
Growers must determine the amount of irrigation water to apply, when to apply it, and the **most efficient** method of irrigation for a given set of conditions. That avoids problems associated with over- or under-irrigating. The goal is to maintain root zone moisture content at a level that will balance vine growth and not reduce yield or quality in the current or subsequent years.

Surface Irrigation Systems

Surface irrigation systems, (border-check, and furrow irrigation) while being the simplest irrigation systems with regard to hardware, are the most difficult ones to manage properly. Control of runoff water is essential for controlling offsite movement of pesticides, sediments, and nutrients.

With surface methods, water is applied to the soil surface and gravity moves the water across the field. Soil characteristics control both the rate at which water enters the soil and its distribution across the irrigated area. As irrigation begins, the rate at which water enters the soil is high, primarily because of soil dryness and easy access to the soil pores. As irrigation proceeds, the infiltration rate declines rapidly to a basic or sustained rate. Figure 2 shows the typical relationship between the amount of water infiltrated into the soil and hours of irrigation.

Figure 2. Typical water infiltration characteristics.



A soil's water intake characteristics depend on both its physical and chemical composition as well as the chemical composition of the water. Irrigation water containing very low salt content or higher sodium and/or bicarbonate levels can reduce infiltration rates. For more information, see the section: “Reducing Runoff by Improving Water Infiltration.”

In general, the objective of any irrigation system is to have water infiltrating for the same length of time in all parts of the field. This is difficult to accomplish with furrow systems because it takes time for water to flow, starting from the head of field, down the furrow to the end of the field (called “advance time”) resulting in a variable time for infiltration. This shorter time that water is in contact with the soil means less water is infiltrated.

For surface irrigation, the head of the vineyard irrigation run almost always has more water applied to it than the tail of the run. The exception is if water is allowed to pond at the end of the row. The part of the field which gets the least water applied to it is frequently at approximately 2/3 to 3/4 of the distance down the row. Often, water onflow rate to the furrow or check is increased to get water down the row more quickly and improve irrigation uniformity. Unfortunately, this practice will increase runoff volume.

In general, it is advantageous to keep furrows or checks as short as practical, which keeps irrigation uniformity high. The tradeoffs with short furrows or checks are increased labor, pipeline costs and increased runoff volumes. Tailwater return systems can be used with these irrigation systems to increase their efficiency and eliminate discharges.

One difficulty with managing surface irrigation systems is measuring the water going onto the field. If water supplies are from a pump, a flow meter such as a propeller meter can be installed in the outlet pipe. Following the manufacturer's recommended installation criteria is important for accurate measurements. If water supplies are from an open ditch, etc., water measurement is difficult. Consulting the irrigation district may help in getting a good estimate of the flow rate to the field.

The following formula may be used to determine the average amount of water applied to a field using a meter that indicated cubic feet per second (cfs).

$$D = Q \times T / A$$

Where D = depth of applied water (inches), Q = flow rate into the field (cubic feet per second), T = time required to irrigate the field (hours), and A = acres irrigated

Note: If the flow meter reads in gallons per minute (gpm) rather than in cubic feet per second (cfs), the conversion is as follows:

1cfs = 449 gpm

An example: Flow = 2.67 cfs (1200 gpm)
Irrigation on time = 24.7 hours
Area = 8 acres

$$\frac{2.67\text{cfs} \times 27.7 \text{ hours}}{8 \text{ acres}} = 3.3 \text{ inches (Depth of water applied)}$$

Depth of water applied in the above formula should match the amount of water used by the crop since the last irrigation and is roughly equivalent to evapotranspiration (ET) (see section: "Irrigation Scheduling to Meet Crop Requirements). Remember that some additional water should be applied because no irrigation system is 100 percent efficient. The efficiencies of furrow-irrigated fields are generally lower than with pressurized irrigation systems.

Measuring distribution of infiltrated water under surface systems is difficult at best. The overall goal is to provide near equal opportunity time along the length of the furrow.

The photo at right shows a relatively flat vineyard using large furrows fill quickly, providing reasonable distribution.

Pressurized Irrigation Systems

Pressurized vineyard irrigation systems include overhead full coverage sprinkler and microirrigation systems. Overhead sprinklers are not common in vineyards, due to disease and irrigation water nutrient content concerns. Drip irrigation systems allow small amounts of water to be applied slowly and frequently through emitters spaced along polyethylene tubing. When properly designed and operated, these systems apply water uniformly to a relatively small volume of soil.

Unlike surface irrigation systems or full coverage sprinklers where soil water is recharged on an infrequent basis and then drawn down by vine use, microirrigation, by virtue of frequent applications, can be operated to replace water used by the vine. The process occurs on a time scale of a day or a few days. This frequency of irrigation is well suited for deficit irrigation strategies by providing greater consistency in plant water stress and allowing quick response to changing climate conditions.

Irrigation Scheduling to Meet Crop Water Requirements

Crop water use or evapotranspiration (ET) is the sum of plant water use (transpiration) and evaporation from the soil surface. Climate factors affecting the crop evapotranspiration include solar radiation, temperature, wind, and humidity. Plant and soil factors affecting evapotranspiration include plant type, canopy size, health of the plant, and available soil moisture.

Irrigations should be applied to: (1) meet the variable crop requirements over the season, (2) be distributed evenly to maximize irrigation efficiency and facilitate the uptake of nutrients, and (3) minimize saturated soil conditions that encourage diseases and result in excess runoff. Some water in excess of the crop requirement may be needed to maintain a favorable salt balance in the root zone.

"Appropriate irrigation scheduling" entails scheduling irrigation water to apply an optimum quantity that maximizes productivity. This often results in maintaining soil water content near field capacity. In recent years, it became clear that maintenance of a moderate plant water deficit can improve the partitioning of carbohydrate to reproductive structures such as fruit, and also control excessive vegetative growth (Chalmers, et al. 1981), giving rise to the concept termed 'regulated deficit irrigation' (RDI) by Chalmers et al. (1986). RDI is the practice of regulating or restricting the application of irrigation water, limiting vine water use to less than that of a fully watered vine. By irrigating at less than the full potential winegrape consumptive use, the chance of offsite water movement from runoff is minimized

Achievement of successful RDI requires accurate soil moisture or plant 'stress' sensing, the ability to estimate crop water demand, and the ability to irrigate frequently. RDI can be a component of a "standard" irrigation strategy or utilized in a "drought strategy" to curtail vine water use during periods of limited water availability.

Deficit Irrigation Scheduling

Typical deficit irrigation scheduling relies upon an assessment of vine water stress level to begin irrigation(stress threshold) and an estimate of full vine water use and selecting an appropriate level of deficit irrigation (RDI%). When used together, this method is called "Stress Threshold RDI Irrigation." If irrigation begins too early, water deficits are postponed or eliminated, effectively losing the positive effects of water deficits. For detailed information on when to begin irrigation and how to measure water deficits, see Prichard et al. 2010. Once the determination is made to begin irrigation and a specific RDI% is selected, an irrigation schedule can be constructed.

An RDI schedule is established by first estimating the full potential water use of the vineyard then modifying it by using a deficit irrigation factor (RDI%). Full potential water use by the vineyard varies as a result of climatic conditions and the size of the canopy. The climate factor can be estimated using the reference evapotranspiration (ETo) values, which indicate variable vine water use over the course of the season. Water use is also influenced by vine canopy growth from bud break to full canopy expansion. Canopy growth is accounted for by a modifying factor of the ETo called the Crop Coefficient (Kc). Kc increases from a small value after bud break as the vine canopy expands to maximum size. Together, these factors (ETo × Kc) define a water use pattern that begins at a low rate in spring, peaks in mid-summer, and then declines as leaf drop approaches.

$$\text{Vine water use} = \text{ETo} \times \text{Kc} \times \text{RDI\%}$$

Where ETc is the crop water use, ETo is the reference evapotranspiration for a given area, Kc is a crop coefficient, and RDI% is the deficit irrigation factor.

Estimating Water Requirements

The reference ET information is available from a network of nearly 100 CIMIS (California Irrigation Management System) weather stations that provide daily reference evapotranspiration values. Two good web-based sources are the UC Statewide Integrated Pest Management website (www.ipm.ucdavis.edu) and the California Department of Water Resources CIMIS website (www.cimis.water.ca.gov). Some newspapers and irrigation districts also provide CIMIS ETo data. The CIMIS program provides real time, current values. Historical or long-term average ETo can be more convenient than real-time ETo information and can be used to prepare an irrigation plan well ahead of the irrigation season. Table 3 lists historical daily values for ETo for selected Central Valley locations.

Table 3. Historical crop evapotranspiration reference (inches/day)
for various California Central Valley locations, CIMIS Stations, and ETo Zones.

Location:	**Lodi**	**Esparto**	**Hanford**
Station No.:	**166**	**39**	**196**
ETo Zone:	**12**	**14**	**16**
Jan	0.025	0.031	0.032
Feb	0.053	0.064	0.060
Mar	0.106	0.115	0.109
Apr	0.172	0.172	0.182
May	0.212	0.218	0.222
Jun	0.250	0.254	0.271
Jul	0.254	0.260	0.274
Aug	0.221	0.224	0.241
Sep	0.170	0.168	0.193
Oct	0.106	0.110	0.137
Nov	0.051	0.055	0.068
Dec	0.025	0.029	0.037

The Crop Coefficient (Kc) is a factor that is used with reference evapotranspiration values (ETo) to estimate full grapevine water use (ETc) in a non-water stressed vineyard. Kc values have been experimentally linked to the percent shaded area measured on the vineyard floor at midday. They can be measured at any time of the season, but when using the Stress Threshold RDI Method, it is only necessary to measure at the threshold or beginning of the irrigation season. At that time, canopy expansion is essentially complete. The canopy should be re-measured if growth continues or canopy reductions occur, such as those due to hedging or leaf removal.

Larry Williams, Professor of Viticulture at UC Davis, using a weighing lysimeter, demonstrated that vineyard water use and Kc increase linearly with the percentage of land surface shaded by the crop. He suggests measuring the percent shaded at midday and using the following equation to determine the Kc (Williams 2001):

Simplified Equation: Kc = 1.7 × percent shaded area (e.g., 0.40 for 40 percent shaded area)

For example, let's look at the vineyard illustrated in the photo below, with 11-foot row spacing and 7-foot vine spacing. The average amount of shade between two vines is measured at 31 sq ft. Comparing the 31 sq ft. to the single vine area of 77 sq ft (7x11) yields a 40 percent shaded area. The Kc is calculated as follows:

Kc = (1.7 x 0.40) = 0.68

Example of 40 percent shaded area at noon on a 7 x 11 foot vine spacing

<u>Calculating Full Potential Water Use with Historical Average ETo</u>

The best way to illustrate calculation of the amount of water to apply is to select a vineyard with specific site conditions and to perform the calculations using a spreadsheet. Specific vineyard conditions in the above example are:

<u>Variety:</u> Cabernet Sauvignon, mature vines
<u>Spacing:</u> 7 x 11 feet bi-lateral cordon
<u>Application Rate:</u> 1 gal/hr emitter, one emitter per vine = 0.021 in/hr application rate

<u>Vine Water Status</u>: Leaf water potential threshold of -13 bars reached July 8
<u>Shaded area:</u> 40 percent or 0.40
Kc = 0.68 (1.7 x 0.40)
<u>Area:</u> Lodi, CA CIMIS station # 166
<u>Harvest:</u> October 1

The spreadsheet below is divided into two parts (Tables 4 and 5) to illustrate each step. The first step is to calculate full potential water use of the vineyard.

Table 4 shows an example calculation of weekly full potential water use for Lodi, California using the 1984 to 2003 historical average ETo for CIMIS stations #42 and #166. After the -13 bar threshold was achieved (July 8 in this example), the net irrigation requirement can be calculated in weekly increments from the threshold date to the end of the season using average historical ETo values. The Kc used is 0.68 for a 40 percent midday shaded area. Calculations are made only after the threshold midday leaf water potential (-13 bars) was measured in the vineyard on July 8. The product of ETo and Kc yields the full potential water use:

$$ETo \times Kc = \text{Full Potential Water Use (ETc)}.$$

Table 4. Irrigation scheduling worksheet to determine
full potential water use - Lodi, California.

Assumptions:

1. Leaf Water Potential threshold was reached July 8th.
2. Harvest Date, October 1.

Date (Period)	A = Historical ETo[1] (inches/period)	B = Crop Coefficient[2] (Kc)	C = A x B: Full Potential Water Use (in)
July 8-14	1.82	0.68	1.24
July 15-21	1.72	0.68	1.17
July 22-28	1.69	0.68	1.15
July 29 - Aug 4	1.68	0.68	1.14
Aug 5-11	1.63	0.68	1.11
Aug 12-18	1.56	0.68	1.06
Aug 19-25	1.49	0.68	1.02
Aug 26 - Sept 1	1.45	0.68	0.98
Sept 2-8	1.37	0.68	0.93
Sept 9-15	1.23	0.68	0.83
Sept 16-22	1.17	0.68	0.80
Sept 23-29	1.05	0.68	0.72
Sept 30 - Oct 6	0.97	0.68	0.66
Oct 7-13	0.88	0.68	0.60
Oct 14-20	0.78	0.68	0.53
Oct 21-27	0.66	0.68	0.45
Oct 28 t- Nov 3	0.54	0.68	0.37
Total			**14.75**

[1] http://www.cimis.water.ca.gov/cimis or http://ucipm.ucdavis.edu/ ETo are the averages of daily data from 1984 to 2003 from the Lodi (CIMIS #42) and West Lodi (#166) weather stations, available at http://cesanjoaquin.ucdavis.edu

[2] Crop Coefficient calculated based on 40 percent midday land surface shaded (0.68)

Calculating the Vine Water Use Using the Regulated Deficit Percent (RDI%)

Once the full potential water requirement for the vineyard is calculated, the Regulated Deficit percent (RDI%) is used to calculate the amount of water the vineyard will use under the RDI selected. In our example, 0.50 or 50 percent of full potential water use was selected. As illustrated in Table 5, full potential water use x RDI% equals the net amount of water use for the selected RDI%. Notice that the RDI% increases to 1.0 or 100 percent after harvest, because full watering is required to encourage root growth, nutrient uptake, and further carbohydrate accumulation. An increase in RDI% to near 100% is common with extended maturity harvests near 19 °Brix measured by berry sampling.

Table 5. Irrigation scheduling worksheet using deficit irrigation - Lodi, California

Assumptions:

1. Leaf Water Potential threshold was reached July 8th.
2. Harvest Date, October 1.

Date (Period)	C = A x B: Full Potential Water Use (in)	D = RDI coefficient[1] (RDI %)	E = C x D: Net Irrigation Requirement (in)
July 8-14	1.24	0.5	0.62
July 15-21	1.17	0.5	0.58
July 22-28	1.15	0.5	0.58
July 29 - Aug 4	1.14	0.5	0.57
Aug 5-11	1.11	0.5	0.55
Aug 12-18	1.06	0.5	0.53
Aug 19-25	1.02	0.5	0.51
Aug 26 - Sept	0.98	0.5	0.49
Sept 2-8	0.93	0.5	0.47
Sept 9-15	0.83	0.5	0.42
Sept 16-22	0.80	0.5	0.40
Sept 23-29	0.72	0.5	0.36
Sept 30 - Oct 6	0.66	1	0.66
Oct 7-13	0.60	1	0.60
Oct 14-20	0.53	1	0.53
Oct 21-27	0.45	1	0.45
Oct 28 - Nov 3	0.37	1	0.37
Total	**14.75**		**8.68**

[1] Regulated Deficit is 50% (0.5)

After the net irrigation amount is determined--in this case using historical average ETo data--further adjustments can be made to account for the current season's climate (ETo), soil water contribution after irrigation begins, and in-season effective rainfall (Prichard et al. 2010).

Determining Irrigation Amount.

Once the crop water requirement has been determined, the irrigator must account for losses such as evaporation, runoff, or deep percolation and the lack of irrigation uniformity. These losses depend on both the irrigation system type and management. Furrow irrigation can have substantial runoff losses and has larger variability in infiltration than pressurized systems. This variability in infiltration requires additional water be applied to achieve a minimum amount of water to all parts of the field. Sprinkler irrigation systems have greater application uniformity, less deep percolative losses and little if any runoff when compared to furrow irrigation systems. Drip systems have the advantages of sprinkler systems and additionally have less evaporative losses.

To account for these losses and differences between irrigation systems, we use the term irrigation efficiency to adjust the net irrigation water amount to meet the water requirement of the crop. Irrigation efficiency is the amount of water stored in the root zone and beneficially used by the crop divided by the amount of water applied. To adjust the net irrigation amount for system efficiency and ensure that even the direst parts of the field receive the net irrigation amount, divide it by the system application efficiency factor (Table 6).

Furrow irrigation. For example, to supply a needed 2.5 inches of water to a furrow irrigated field would require 2.5 ÷ 0.75 = 3.3 inches of water would need to be applied. This amount considers that the runoff is recycled using a tailwater recovery system. If such a system is not available reduce surface irrigation systems by 15%.

Drip irrigation. For example, to supply a needed 0.58 inches of water to a drip-irrigated field would require that 0.58 ÷ 0.90 = 0.64 inches of water be applied.

Table 6. Estimated application efficiency (percent) of irrigation systems (Hanson 1995)

System Type	Estimated Efficiency
Surface Irrigation	70-85*
Sprinkler	70-80
Microirrigation	80-90

**Efficiency reflects the use of a tailwater capture and return system. If not available reduce by 15%*

Since in our example vineyard the drip system is operated with no runoff and no deep percolation losses and evaporation is at minimum, the distribution uniformity nearly equals the irrigation efficiency. In this case the net irrigation can be divided by the measured system distribution uniformity to obtain a field specific gross irrigation volume (Hanson et al. 1999).

<u>Determine Irrigation Application Time (duration)</u>

The irrigation application time for a surface irrigation system is determined by simply dividing the amount of water applied by the land area it is applied to. For example, the duration of irrigation can be calculated by:

$$T= (A \times D) / Q$$

Where T = time required to irrigate the field (hours), A = acres irrigated, D = depth of applied water (inches), and Q = flow rate into the field (cfs). 1cfs = 449 gallons per minute

Furrow irrigation. Using our example of 3.3 inches for 30 days in the July- August period and a 20-acre field with a 1200 gallon per minute supply the on time would be:

$$T= (20 \times 3.3) / 2.67 = 24.7 \text{ hrs}$$

Once the irrigation amount and timing of irrigation is determined to meet the crop water use, the application can be problematic and site-specific. When using surface irrigation on high infiltration soils, it may be difficult to apply the relatively small amount of water (3.3 inches in our example) due to the large amount of water required to move water down the furrow and the time to advance the water to the end of the field. Excess infiltrated water would percolate below the rootzone. The selection of appropriate onflow volumes and cutoff times discussed below can minimize over application of water.

Sprinkler and drip irrigation. To determine the irrigation time for hand-move sprinklers:

$$T = D / AR$$

Where = T = time of irrigation (hours), D = depth of water (inches), and AR = application rate (inches/hour).

Using our example for the second week in July, the applied water is 0.64 inches. The application rate is 0.052 inch per hour. The on time would be:

$$T= 0.64 / 0.021 = 30.5 \text{ hrs}$$

Check Up on the Calculations and Applications

The climate-based method described above for determining crop water needs gives an estimate of demand which should be verified and fine-tuned by soil based monitoring of actual soil water status and or plant water status.

There are many soil moisture-monitoring devices which measure soil moisture content and soil tension (Schwankl and Prichard 2009). If decreasing soil water occurs over the season or an increase in soil water tension is evident, too little irrigation was applied. If soil water content increases or tension is reduced progressively after each irrigation, too much applied water is indicated.

Plant water status can be measured using a pressure chamber to assess the adequacy of an irrigation schedule. Measure plant water status just prior to irrigation to determine the maximum stress level. If levels climb past the desired levels or water stress is reduced causing new shoot growth the schedule needs to be adjusted. For detailed information on when to begin irrigation and how to measure water deficits, see Prichard et al. 2010.

Managing Irrigation Systems to Reduce Runoff

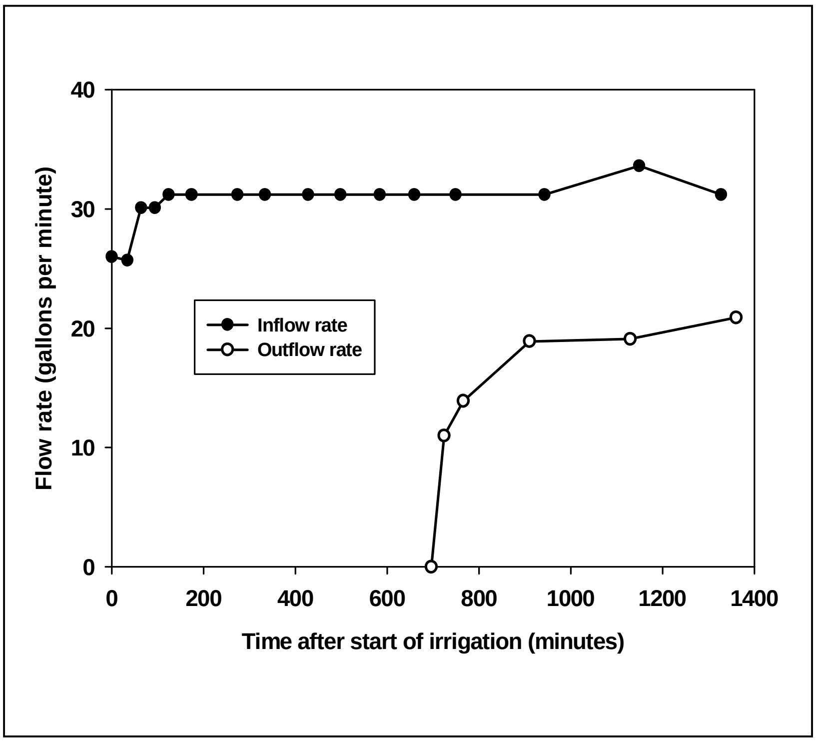
As a general rule, the depth of water applied in the above formula should match the amount of water used by the crop since the last irrigation and is roughly equivalent to evapotranspiration (ET) (see section: “Irrigation Scheduling to Meet Crop Requirements). Remember that some additional water should be applied because no irrigation system is 100 percent efficient. The efficiencies of furrow irrigated fields are lower than those of pressurized irrigation systems.

Surface Irrigation Systems.

Irrigation runoff that enters surface waters can carry both dissolved and sediment-adsorbed pesticide residues. Soluble residue concentrations in runoff waters are fairly consistent for the entire runoff period. Therefore any reduction in the total runoff volume will reduce the amount of residues discharged. The degree to which soils erode during irrigation will depend on a number of factors, with soil aggregate stability, the ability of soil particles to cling together and resist the forces of flowing water, being the most important. Aggregate stability can be enhanced by chemical and physical amendments and management practices discussed in the section: "Reducing Runoff by Improving Water Infiltration." Soil erosion rates will depend on the soil conditions, including the amount, size, and density of loose particles on the soil surface. For example, erosion increases after cultivation. The degree of soil erosion depends on the velocity of the water and the duration of runoff. Therefore, reducing the peak volume and duration of runoff will reduce sediment loss.

The cutoff time is the time that an irrigation set is ended and no more water is applied to the furrow. Decreasing the cutoff time of the irrigation water (shortening the amount of time a field is irrigated) can reduce the amount of surface runoff from furrow-irrigated fields. The cutoff time for a given field depends on the time needed to infiltrate sufficient water along the lower part of the field. It may need to be determined on a trial-and-error basis. In cracking clay soils, infiltration times of only two to three hours may be adequate because water flow into the cracks results in a very high initial infiltration rate. After the cracks close, infiltration rates become very small. Thus, in cracked soils the cutoff time should occur about two to three hours after water reaches the end of the field (Hanson and Schwankl 1995). Figure 3 illustrates inflow and outflow rates in a field using furrow irrigation. Note the 700 minutes of water advancing to field end (before runoff begins) and the nearly equal time the irrigation is allowed to continue in order to have equal intake opportunity time at the tail end of the field. The result is significant – about 2/3 of the inflow water running off for 500 minutes. A shorter cutoff time would have reduced runoff volume but may also slightly reduce the distribution uniformity across the field.

Figure 3. Furrow irrigation inflow and outflow rates over the term of irrigation.



Source: Hanson and Schwankl 1995

Blocking furrows by making small dams in the length of the furrow using soil or plastic dams can increase infiltration and help uniformity. This practice of monitoring each furrow during irrigation is labor intensive can reduce runoff volumes.

Converting to pressurized irrigation can reduce runoff. This option significantly reduces the chance of runoff, but requires a significant investment. See section: "Pressurized Irrigation Systems."

Capturing and recycling runoff by using a tailwater collection system can mitigate runoff and therefore offsite residue problems, and make irrigation more efficient. For more information, see section: "Tailwater Runoff Collection and Recycling."

Pressurized Irrigation Systems

Pressurized systems should be operated to meet the vineyard's water requirement while eliminating any surface runoff. Uniformity is designed into pressurized irrigation systems, with management left to ensure not only efficiency but the elimination of runoff losses by turning off the system before runoff occurs. In vineyard planted on sloping land, a small amount of runoff tends to accumulate from each emitter or sprinkler, potentially causing offsite movement. Improving uniformity of water application can avoid runoff. Sprinkler nozzle wear can increase application rates exceeding the soils infiltration rate at the end of the irrigation when infiltration rate declines. All nozzles should be the same size to minimize pressure differential application rates. Unfortunately, most of these highly engineered irrigation systems are not managed to their full potential because they need constant monitoring and maintenance. Problems such as clogged emitters decrease uniformity, leading to under application in some areas and over application in others.

REDUCING RUNOFF BY IMPROVING WATER INFILTRATION

Poor water infiltration can increase runoff from irrigation or winter rains. Irrigation runoff is typically associated with surface irrigation but can occur with pressurized systems on soils with poor infiltration or sloping land.

The first step in determining how to mitigate a water infiltration problem is to understand the soil and water factors that influence it.

At the onset of irrigation, water infiltrates at a high rate. Initially the soil is dry and may have cracks through which water can infiltrate rapidly. After the soil near the surface wets for a few hours, these factors become less important in sustaining infiltration rates. The clay particles swell, closing cracks and limiting access to soil pores and decreasing infiltration rates. As the wetting process continues, the salinity and salt composition of the soil-water (water contained between soil particles) begins to more closely reflect that of the irrigation water, which is generally less saline. This reduction in soil water salinity retards water infiltration.

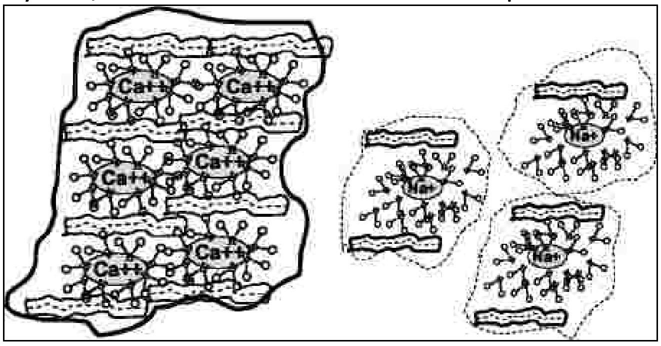
Water infiltration can only be improved by increasing soil total pore volume and/or individual pore size, and providing easy access to surface pores. Physical soil disruption practices and chemical and organic amendments are all attempts to influence one or more of these factors.

Soil Structure and its Impact on Water Infiltration

Pores are the spaces between mineral and organic particles in soils through which water and air move. Soils with a predominance of sands (larger spherical particles) tend to have larger pores, while clay-dominated soils (clays are plate-like particles) tend to be smaller. With some exceptions, soils with larger pores generally have higher infiltration rates. Water usually moves more slowly through small-pored soils because the smaller pores provide more surface area for water to adhere to. On the other hand, clay soils which form cracks as the soil dries and shrinks can help increase water infiltration.

Individual soil particles can clump together, forming larger structures called aggregates. The small pores between particles remain, and larger pores formed between the aggregates significantly enhance water infiltration and gas exchange (Figure 4). Soil water salinity and individual mineral constituents as well as organic matter content play a significant role in stabilizing soil aggregates and increasing pore size.

Figure 4. Conceptual illustration of soil aggregate stability: forming stable aggregates with plentiful calcium on clay exchange sites (left), compared to weak soil aggregates due to low salinity and/or excessive sodium in the soil pore water.



Soil Crusting

Soil crusts or surface seals reduce infiltration by impeding water access to soil pores beneath the crust layer. Crusts form at the soil surface when the soil aggregates become dispersed, causing a loss of porosity at the soil surface. Weak cementation of the crust often follows when the soil dries, slowing water penetration during succeeding irrigations.

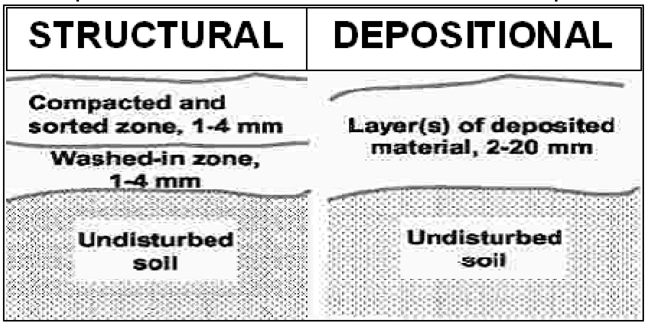
Soil surface crusts can be divided into either structural crusts or depositional crusts, as defined below.

Structural crusts form when surface soil aggregates are destroyed by the impact of rain or sprinkler droplets. The mechanical breakdown of soil aggregates tends to sort soil particles, leaving a film of finer particles on top (sealing layer) that blocks the entry of water into the larger intact pores beneath. Another type of structural crust forms under furrow irrigation, through a process is called “slaking.” As the soil is wetted, a combination of mechanical and chemical dispersion of soil aggregates occurs, causing the structure to collapse. Upon drying the crust becomes hard.

Depositional crusts form when small (usually clay- and silt-sized) soil particles, suspended and transported in flowing water, settle out of suspension and form a thin low-porosity surface layer. In agricultural settings, this type of soil crust is most often the result of high-velocity water in the head end of the furrow or check eroding fine particles that settle out when the water slows.

Both structural and depositional crusts are thin, characterized by higher density, greater strength and smaller pores than the underlying soil. These crusts are usually less than one tenth of an inch thick but often limit infiltration for the entire root zone (Figure 5). Structural crusts are a far more common cause of poor water infiltration problems in California vineyards than depositional crusts.

Figure 5. Conceptual illustration of structural and depositional crusts.



In fine-textured silty soils, soil crusts are often the result of sodic conditions caused by excess exchangeable sodium in the soil or irrigation water, and/or too little total salinity. In coarse- to medium-textured, nonsaline and nonsodic soils, continued cultivation can reduce pore size and number to the point where water infiltration is affected. This problem can be made worse where very low salinity irrigation water is used, such as from irrigation districts on the east side of the San Joaquin Valley. Additionally, wells that contain high bicarbonates and relatively low calcium levels encourage crusting. The increased use of herbicides for no-till management can also decrease soil organic matter and soil microbial activity. This also results in decreased soil aggregation and reduced pore size.

Irrigation Water Quality

Irrigation water quality influences water infiltration rates through affecting whether soil particles tend to absorb water, stay together, or become separated by swelling. Swelling of soil particles causes aggregate breakdown and soil particle dispersion, resulting in surface crust formation.

Salinity

The higher the salinity of the irrigation water, the more likely the aggregates will remain stable, preserving infiltration rates. Salinity is measured by determining the electrical conductivity (EC) of the irrigation water (ECw) or soil water extracted from a saturated soil paste (ECe).

Sodicity

The index for sodicity is the sodium adsorption ratio (SAR), which depends on the relative amounts of sodium, calcium, and magnesium content of the irrigation water. SAR of a soil sample can also be used to estimate exchangeable sodium levels in the soil. With increasing levels of exchangeable sodium, the affinity of soil particles for water increases and aggregate stability decreases reducing water infiltration rates.

Combined Effect of Salinity and Sodicity

Since both salinity and sodicity of the irrigation water effect aggregate stability and water infiltration rate, both must be assessed when diagnosing an infiltration problem. In the top three inches of soil, salinity and sodicity of the irrigation water and soil are closely linked. Consequently both surface soil samples and water samples are necessary to diagnose the problem and evaluate the success of mediation practices. In general, aggregate stability increases as EC increases and the SAR decreases (Table 7). As a general guideline, the SAR should be less than 5 times the EC (Figure 6). The exception is low salt waters with EC values of less than 0.5 dS/m. They are corrosive and deplete surface soils of readily soluble minerals and all soluble salts. They often have a strong tendency to dissolve all sources of calcium rapidly from surface soils. The soils then break down, disperse, and seal, resulting in poor water infiltration.

The EC and SAR-based guidelines discussed above may not necessarily work for all California soils. Some soils contain a large amount of serpentine clays rich in magnesium (Mg) and low in calcium (Ca). In these soils, Mg may have the same soil-dispersing effect as sodium. Soils with a predominance of montmorillonite and illite clays are also easily dispersed by excess magnesium. Although the diagnostic criteria for such conditions have not been extensively tested, some studies suggest that when the Mg to Ca ratio of these soils exceeds 1:1, they may be prone to water infiltration problems. Some reports report that high soil potassium levels can also promote aggregate dispersion and soil crusting.

Table 7. Potential for a water infiltration problem

SAR*	**Problem Likely ECe[1] or ECw[2] dS/m**	**Problem Unlikely ECe or ECw dS/m**
0.0 – 3.0	< 0.3	> 0.7
3.1 – 6.0	< 0.4	> 1.0
6.1 – 12.0	< 0.5	> 2.0

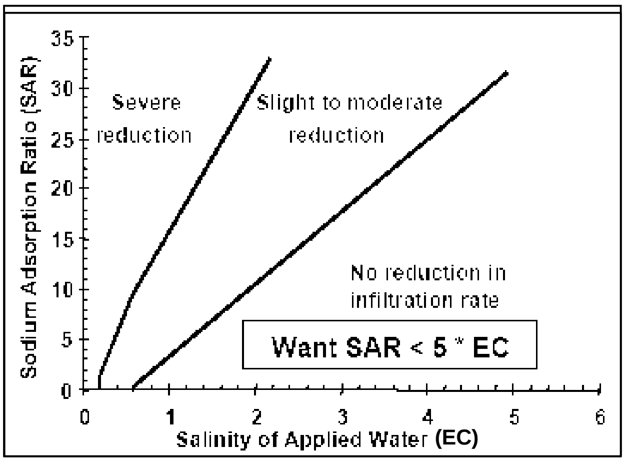
Source: Ayers and Westcot (1985).

* Sodium Adsorption Ratio.

[1] Electrical conductivity of soil extract (soil is saturated paste soil salinity).

[2] Electrical conductivity of water (irrigation water salinity).

Figure 6. Interaction of total salinity as EC with the sodium adsorption ratio of applied water for causing potential infiltration problems. (Ayers and Westcott, 1985)



High carbonate (CO_3^-) and bicarbonate (HCO_3^-) levels in water increase the sodium hazard of the water to a level greater than that indicated by the SAR. In alkaline soils, high CO_3^- and HCO_3^- tend to precipitate calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) when the soil solution concentrates during soil drying. The concentrations of calcium and magnesium in soil solution are reduced relative to sodium, and the SAR of the soil solution tends to increase.

An adjusted SAR value may be calculated for water high in carbonate and bicarbonate if the soil being irrigated contains free lime (calcareous soil). The adjusted SAR and knowledge of soil properties help determine management practices when using high bicarbonate water.

Mitigating Water Infiltration Difficulties

Solving an infiltration problem by modifying irrigation practices – as discussed in other sections of this manual – should always be the starting point and will generally be less costly than the soil and water modifying treatments discussed below. Water infiltration problems not amenable to improvement by optimizing irrigation system design and operation may be mitigated by improved soil organic matter management, or use of chemical amendments as discussed later in this manual.

Tillage

Shallow tillage can be used to disrupt both structural and depositional crusts. Where crusting problems reduce infiltration rates, a single tillage can restore infiltration rates. However, in soils with severely reduced infiltration, tillage before each irrigation is common. Shallow tillage using shallow disking or harrowing can break up the surface crust. Shallow tillage to incorporate the pesticide after application can effectively reduce the residues available for offsite. Some vineyards have been planted to non-uniform layered soils without any deep tillage prior to planting, and examination of backhoe pits reveals significant hardpan and other layers that limit root development. Tillage of vineyard middles is limited to a single pass with depth related to the draft force required and traction of the tractor.

CAUTION: Ripping will damage existing roots, especially in vineyards where water infiltration has been limiting root zone depth. However, the improved soil characteristics and root pruning will help to encourage new root growth. Roots take time to begin growing and re-growth varies with the season and the carbohydrate status of the vine. In any event, do not till all the middles at once. Modifying alternate middles each year produces the best results. Ripping should be most effective in the fall, after harvest when vine water use is low and soils are dry and easy to shatter and mix.

Managing Soil Organic Matter to Reduce Runoff

Soil organic matter helps stabilize soil aggregates by increasing the number of exchange sites in the soil matrix and encouraging microbial activity. Soil microbes that decompose soil organic matter produce polysaccharides and polyuronides, which act as binders to stabilize aggregates, thus improving porosity and water infiltration. Over time, continued cultivation and the use of herbicides reduces the organic matter content and aggregate stability of soils. These changes can reduce water infiltration and increase runoff potential.

It is difficult to increase and sustain soil organic matter under warm semiarid conditions that prevail in most of California, which favor rapid organic matter decomposition. Organic matter additions aimed at improving or sustaining aggregate stability and water infiltration must be incremental and continual to be effective. There are several ways for growers to achieve this as follows.

Crop Residues

Vine leaves and prunings, shredded or soil incorporated, can be left to decompose adding organic matter (and some nutrients) to the soil.

Manure and Other Organic Materials

With proper handing and management to avoid risk of crop contamination by human pathogens, animal manures or compost can help increase soil organic matter content and improve water infiltration. However, the application of manures is currently uncommon due to the limited nitrogen requirement of the modern vineyards and limited availability of manures. If nitrogen requirements are low, grape pomace and composted pomace can provide many of the infiltration benefits without exceeding the nitrogen requirement.

Cover Crops

Cover crops can help protect the soil surface from droplet impact under winter rainfall or sprinkler irrigation and provide significant organic matter biomass for decomposition and microbial stabilization of soil aggregates. In addition, cover crop residue can slow the velocity of surface water; reducing erosion and subsequent depositional crusting. Winter annual cover crops are most often planted in vineyards because they grow during the wet season, reducing the competition for water and nutrients that is a disadvantage of perennial covers. They are sown or allowed to reseed in the fall and mowed or disked in the spring. A winter annual cover crop for example, planted in fall, grown during the winter and early spring, then mowed or disked at budbreak, can produce as much as 3 tons of dry matter (above and below ground) per planted acre. A comprehensive review of this topic is available in: Cover Cropping in Vineyards—a Grower's Handbook. ANR Publication 3338 (Ingels et al. 1998)

Chemical Amendments Used to Improve Water Infiltration

The addition of chemical amendments to water or soil can improve water infiltration by improving the chemical makeup of the water or soil. Most chemical amendments work by increasing the total salt concentration and/or decreasing the sodium adsorption ratio (SAR) of the soil-water. Both of these actions enhance aggregate stability and reduce soil crusting and pore blockage.

Four types of materials are used to ameliorate water infiltration problems: salts, as fertilizers; calcium materials; acids or acid-forming materials; and soil conditioners, including polymers and surfactants.

Salts

Any fertilizer salt or amendment that contains salts, when applied to the soil surface or dissolved in irrigation water, increases the salinity of the irrigation water and ultimately influences the soil-water. Whether increased salinity is advantageous depends on the SAR of the irrigation water. The largest effect of a salt addition is with very low salinity (less than 0.5 EC) irrigation water. Increasing salinity above an EC of 4 dS/m has little effect on infiltration.

Calcium Materials

Adding calcium (Ca) salts to soil and water increases both the total salinity and soluble calcium. Calcium salts commonly used on alkali (high pH) soils include gypsum ($CaSO_4$), calcium chloride ($CaCl_2$), and calcium nitrate ($CaNO_3$). These are fairly soluble and can easily be applied though the irrigation water. Care should be taken if waters contain more than 2 meq/L of bicarbonate (HCO_3). Adding gypsum to such waters through a drip system significantly increases the chances of plugging the system with lime precipitate. In these cases, an acid application to decrease bicarbonate concentrations may be necessary. Lime and dolomite are used only for broadcast applications on acid soil, as they are virtually insoluble under alkali conditions.

Gypsum Injection Rates for Water

Amendment rates from 1.0 to 3.0 meq/L calcium in the irrigation water are considered low to moderate; rates that supply 3.0 to 6.0 meq/L calcium are considered moderate to high. The following example calculations show the reader how to estimate the quantity of gypsum required to improve infiltration. Table 8 lists the amount of gypsum and other products needed to increase the calcium (Ca) content of irrigation water by 1 meq/L per acre-foot. Applying 234 pounds of 100 percent pure gypsum per acre-foot of water equals 1 meq/L of Ca.

It is rarely necessary to inject gypsum constantly. Injection every other or every third irrigation may be all that is necessary to end the season with the required amount. The benefits of gypsum injection during the season in drip irrigation systems are usually superior to those of dormant season applications.

Table 8. Amounts of amendments required for calcareous soils to increase the calcium content in the irrigation water by 1 meq/L.

Chemical Name	**Trade Name and Composition**	**Pounds/Ac-ft of Water to Get 1 meq/L Free Ca***
Sulfur	100% S	43.6
Gypsum	$CaSO_4 \cdot 2H_2O$ 100%	234
Calcium polysulfide	Lime-sulfur 23.3% S	191
Calcium chloride	Electro-Cal 13% calcium	418
Potassium thiosulfate	KTS -- 25% K_2O, 26% S	256
Ammonium thiosulfate	Thio-sul 12% N, 26% S	110** 336***
Ammonium polysulfide	Nitro-sul 20% N, 40% S	69** 136***
Monocarbamide dihydrogen sulfate/ sulfuric acid	N-phuric, US-10 10% N, 18% S	148** 242***
Sulfuric Acid	100% H_2SO_4	133

* Salts bound to the soil are replaced on an equal ionic charge basis and not equal weight basis.

** Combined acidification potential from S and oxidation of N source to NO_3 to release free Ca from soil lime. Requires moist, biologically active soil.

*** Acidification potential from oxidation of N source to NO_3 only.

Gypsum Rates Broadcast to Soils

An alternative to water treatment is broadcasting amendments such as gypsum on the soil surface and irrigating the amendment into the soil. The primary advantage of this approach is that it is often less expensive than water treatments. However, for surface application to be nearly as effective as water treatment, it must be properly timed. If infiltration is a problem in the summer months, then apply the amendment at the onset of those months—not in the preceding fall or winter. If the application is made too early, the amendment will percolate with post harvest irrigations and winter rainfall to depths below that where the crust forms. Surface applications are most effective when gypsum is applied at rates equivalent to 500 to 1,000 pounds of gypsum per acre, prior to the onset of irrigation. Use finely and consistently ground gypsum products in surface applications. Applications that are limited to the berm have been successful at decreased field rates (same rate per unit area but applied to the berm only) when using drip irrigation. For maximum effect on surface crusting, do not till the soil after the gypsum is applied.

Acids and Acid-Forming Materials

Commonly applied acid or acid-forming amendments include sulfuric acid (H_2SO_4) products, soil sulfur, ammonium polysulfide, and calcium polysulfide. The acid from these materials dissolves soil-lime to form a calcium salt (gypsum), which then dissolves in the irrigation water to provide exchangeable calcium. The acid materials react with soil-lime the instant they come in contact with the soil. The materials with elemental sulfur or sulfides must undergo microbial degradation in order to produce acid. This process may take months or years depending on the material and particle size (in the case of elemental sulfur). Since these materials form an acid via the soil reaction, they will reduce soil pH if applied at sufficiently high rates.

Acids are applied to water for two different purposes in relation to water infiltration problems. The first is to dissolve soil lime (the soil must contain lime if acids are used), increasing free calcium in the soil/water matrix and improving infiltration. The second is to prevent lime clogging in drip systems when adding gypsum to waters containing greater than 2 meq/L bicarbonate.

Table 8 indicates that it takes 133 lbs/ac-ft of 100 percent pure sulfuric acid to release 1 meq/L Ca. This assumes the acid contacts lime ($CaCO_3$) in the soil, neutralizing the carbonate molecule and releasing Ca. This is the same amount of acid required to neutralize 1 meq/L of HCO_3 in the water. If the water contains bicarbonate the acid will neutralize it, converting it to carbon dioxide which is released to the atmosphere. Acid applications must exceed the bicarbonate level of the water before the pH of the water decreases to dissolve lime in the soil.

Soil Conditioners

There are two types of amendments in this category, organic polymers and surfactants. Other amendments include synthetic and natural soil enzymes and microbial soups. Although there is a long history of soil conditioner development and testing, not enough data exists on the materials to conclude that they are uniformly effective. For an in-depth analysis of water infiltration problems and solutions see: "Water Penetration Problems in California Soils: Diagnosis and Solutions," Singer et al. 1992.

Organic Polymers

Organic polymers, mainly water-soluble polyacrylamides (PAM) and polysaccharides, are used to stabilize aggregates at the soil surface. These extremely long-chain molecules wrap around and through soil particles to bind aggregates together. This action helps resist the disruptive forces of droplet impact and decrease soil erosion and sediment load in furrow irrigation systems. They can improve infiltration into soils with illite and kaolinitic clays common in the northwest United States, but USDA researchers have found that infiltration is not improved in soils with the mostly montmorillinite clays typical of the San Joaquin Valley.

Water-soluble PAM is not to be confused with the crystal-like, cross-linked PAMs that expand when exposed to water, and does not influence water infiltration. Cross-linked PAMs enhance the water-holding capacity of soils for small-scale applications, for example in container nurseries.

Organic polymers can have different effects on infiltration. The effect depends on polymer properties—such as molecular weight, structure, and electrical charge—and salinity of the irrigation water. There are charged (ionic) and non-charged (nonionic) polymers that can behave differently depending on whether they are added to very pure water (surface waters where EC is 0.03 to 0.1 dS/m) or higher-salinity well waters (above 0.8 dS/m).

Polymers have been shown to work best when sprayed on the soil surface at a rate of about 4 pounds per acre, followed by an application of gypsum in soil or water.

Surfactants

Surfactants *or "wetting agents"* are amendments that reduce the surface tension of water. They are not effective in agricultural soils.

Other Amendments

Other amendments include synthetic and natural soil enzymes, and microbial soups. Although there is a long history of soil conditioner development and testing, not enough data exists on the materials to conclude that they are uniformly effective.

CAPTURING AND FILTERING SURFACE WATER AND SEDIMENTS

Reducing the volume or velocity of runoff waters can reduce offsite movement of residues whether they be in solution or sediment-attached. There are several methods of capturing and filtering surface water and sediment. Some are temporary and used with a new vineyard or in emergency situations where the need for runoff control is short lived, and some are permanent. Steep hillside vineyards should have several types of permanent erosion control measures in place, such as permanent cover crops, adequately sized filter strips between the vineyard and any waterways, and permanent sediment basins for collection and or recycling or the use of vegetation at the tail of the field or in the drainage ditch.

Storing Runoff

Storage of runoff waters from storm events in impoundments is often suggested as a mitigation practice. The sheer volume of runoff makes this a poor option. Storms are rated as to the frequency at which a particular amount of rainfall in a given duration is expected to return, on average. A 2-year, 24-hour storm would be the rainfall event one could expect during a 24-hour period on the average of every 2 years. For example, a 2-year, 24-hour storm in Stockton, California falling on a 40-acre parcel would produce over 1,700,000 gallons or 5.3 acre feet of water—equivalent to a one acre pond over 5 feet deep. A hundred-year storm would require three times that volume for just a single storm. Of course, some of the water would infiltrate into the field. However, if one storm came on the heels of another, most of the rainfall would run off. For more information on runoff storage and storm precipitation rates, see: "Storing Runoff from Winter Rains," Schwankl et al. 2007a, ANR Publication 8211.

Temporary Measures

Filter Fabric Fencing

A barrier of filter cloth with woven wire stretched between temporary fence posts across a slope to reduce soil movement. Make sure the posts are on the downslope side of the fencing.

Straw Bale Check Dam

To construct a check dam, place bales of clean straw bound with wire or plastic twine across an area of surface sheet flow or gully erosion, and anchor them into the soil surface with rebar or stakes.

Straw Bale Water Bars

Straw bales used to create a temporary water bar across a road or a temporary sediment barrier. A series of straw bale water bars may be needed for long slopes.

Straw Wattles

Straw wattles or fiber rolls are designed to slow down runoff, reducing erosion and filtering and trapping sediment before the runoff gets into watercourses. Straw wattles must be installed on contour.

Straw wattles used for erosion control

Temporary Drainage Structure

Constructed at the tail of a field, the temporary drainage structures are designed to slow and trap runoff for short periods of time. The water eventually infiltrates the soil.

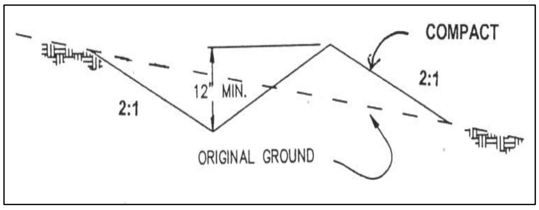


Diagram and photo of a temporary drainage structure

Temporary Sediment Basin

Temporary sediment basins are used to catch and settle out sediment before it can enter a waterway. They are usually placed at the base of a slope or drainage area. A small basin can be created from compacted soil and rocks or straw bales. The embankment should not exceed 4 feet in height, and a drain or outlet should restrict flow from the basin to allow sediment to be trapped.

Permanent Measures

Sediment Basins

A sediment basin or trap is created by constructing an embankment, a basin emergency spillway, and a perforated pipe-riser release structure. The basin may be located at the bottom of a slope where drainage enters a swale or waterway. These basins can be designed by the Natural Resources Conservation Service (NRCS) or a civil engineer on a site-specific basis and installed using proper construction and compaction for the berm and correct sizing and construction for water release structures and spillways. When runoff volumes are small, basins can be effective for reducing offsite movement of sediment containing adsorbed pesticide residues. If runoff is high enough to cause low retention times, sediment removal efficiency declines rapidly.

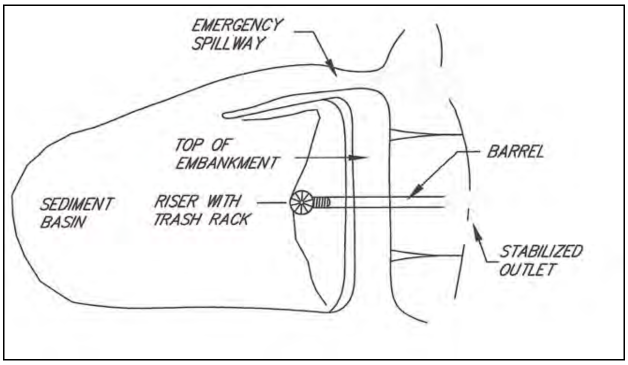


Diagram of a sediment basin with spillway and release structure

<u>Effectiveness in Removing Pesticide Residues</u>

Long et al. (2010b) found that 60- to 90-minute retention times effectively removed particles coarser than fine silts. The sediment basin was 1.4 percent of the irrigated area. Finer soil particles, which generally adsorb pyrethroid pesticide residues, were not removed from the runoff. During the first irrigation of the season, soon after cultivation, 39 percent of the sediment load entering the pond was removed. In the second measured irrigation, sediment removal was insignificant. The effectiveness of sediment traps was found to be limited by the time available for suspended sediments to settle out of the runoff. Sediment basins may be ineffective with finer soils at higher runoff rates. Long (2010a) suggests various size settling basins based on Stokes Law. Clay particles carry the bulk of the adsorbed pesticide residues. In order to provide enough holding time to settle out these small particles from a 50 gallon per minute tailwater runoff rate, a settling basin of 57 acre feet would be required.

A study was conducted in the Central Valley of California to measure pyrethroid removal by a tailwater recovery pond. The field was a border-check irrigated almond orchard to which a pyrethroid, lambda-cyhalothrin was applied at the rate of 0.04 lb ai/acre. Runoff waters were measured for volume, sediment, and pyrethroid residue concentration as inflow to a recycling pond and as outflow. About 15 percent of the irrigation onflow water exited the field as runoff. The pond was 19 feet by 16 feet by 7 feet deep. Sediment in the water was reduced by 80 percent, inflow to outflow. Pyrethroid residues were reduced by 61 percent. The difference in the removal efficiencies for sediment and pyrethroid residues was most probably due to the absorption of lambda-cyhalothrin residues to lighter weight clay particles, which did not have a chance to settle out in this trial. Removal efficiency may have been further improved with lower flow rates or longer retention times in the ponds (Markle 2009).

<u>Permanent Cover Crops</u>

Cover crops are usually grown in vineyard middles with rows kept free of vegetation. Plant species used for cover crops may be annuals (planted, grown and removed each season) or perennials, which generally live three or more years. Annual cover crops can be composed of species that reseed themselves naturally each year (for example, annual clovers and medics) or others that are generally removed before they form seeds and must be intentionally replanted each year. Perennials such as ryegrass, orchard grass, and fescues are not often used because they will compete with the vines for water and nutrients during the summer.

Cover crops can help reduce offsite movement of water-borne pesticide residues in several ways. By shielding the soil from the impact of rain droplets, a winter-grown cover crop can help reduce the likelihood that soil particles will be eroded from the soil surface. Cover crop vegetation may also help slow sedimentation by directly “filtering” soil particles out of moving water and by slowing the speed of water moving over the soil surface. As the weather warms in late winter and spring, cover crops can help deplete excessive soil moisture and increase water storage potential (thus reducing runoff) from storm events at this time of year. Also see: "Cover Cropping in Vineyards—a Growers Handbook," Ingels et al. 1998, ANR Publication 3338. For further reading see: "Erodibility of Agricultural Soils with Examples in Lake and Mendocino Counties," O'Geen, et al. 2006a, ANR Pub 8194, and "Orchard Floor Management Practices to Reduce Erosion and Protect Water Quality," O'Geen, et al. 2006b, ANR Publication 8202.

Effectiveness in Removing Pesticide Residues

Early fall establishment of cover crops is critical to their effectiveness in capturing runoff waters and sediments containing pesticide residues. Among the best cover crops are perennial sods which have dense foliage and root systems. Reseeding winter annual grasses such as 'Blando' brome or 'Zorro' fescue work well after establishment (Ingels et al. 1998). Cover crops are often mentioned as being related to reducing the runoff of pesticide residues; however, research measuring such reductions is limited or nonexistent. However, numerous works measuring reduced runoff volumes and sediments when using cover crops have been published. In a Central Coast vineyard 'Trios 102' triticale and 'Merced' rye cover crops planted in vineyard middles reduced runoff volumes from 46 to 78 percent respectively, when compared to bare soil (Smith et al. 2008). The comparisons, made over a three year period, also found a significant reduction in suspended sediment and turbidity.

Vegetative Filter Strips

A vegetative filter strip (VFS) is any area of dense grass or other vegetation—natural or planted- between the vineyard and a nearby waterway. Filter strips help capture and filter surface runoff from cropland to protect water quality. Tall, sturdy, and hardy perennial grasses are preferred, since once established they withstand the force of runoff waters and summer drought conditions. The width of the VFS required to effectively remove sediments depends upon the slope of the area draining into the strip. For slopes of less than 1 percent, the strip should be at least 25 feet wide, increasing proportionally with the increase in slope up to 50 feet wide for 10 percent slopes. Filter strips can also be used to reduce sediment flow between vineyard blocks.

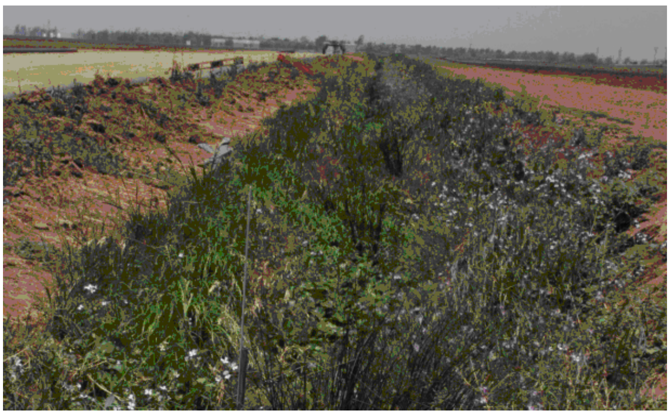
Vegetative filter strips function in three distinct layers—surface vegetation, root zone, and subsurface horizon (Grismer et al. 2006). As surface flow enters the VFS, water is infiltrated until the shallow surface and shallow subsurface is saturated. This infiltration phase is most important for reducing offsite movement of residues. The pesticide residues are trapped by soil constituents and organic matter, allowing pesticide degradation to occur. The remaining flow volume and velocity is decreased, reducing sediment transport. Sediment particles are trapped on the surface litter layer, which is high in organic matter. As the process continues, water continues to move through the subsurface horizon, further decreasing the volume of runoff.

Effectiveness in Removing Pesticide Residues

The chemical characteristics of different pesticides determine the type and amount of residue reduction achievable with vegetation systems. Organophosphate pesticides tend to be water-soluble, while pyrethroids are virtually non-soluble in water and are primarily adsorbed to sediments. Diazinon, an organophosphate of high solubility in water, can be expected to remain in solution for long periods (Bondarenko and Gan, 2004). Previous evaluations of the effectiveness of vegetation for removing diazinon from water have shown mixed results. Watanabe and Grismer (2001) evaluated diazinon removal by vegetated filter strips under controlled laboratory conditions and found that the majority of diazinon removal occurred via infiltration into the root zone and adsorption to vegetated matter. However, 73 percent of the applied diazinon was detected in the runoff water after the VFS. Long et al. (2010b) found that reduction in sediment load was directly related to pyrethroid residue removal in VFS. Sediment runoff was reduced by 62 percent when furrow runoff waters passed through a well-established VFS planted to either tall fescue or a perennial ryegrass and tall fescue mixture that represented 2.8 percent of the field being irrigated. They recommend 0.03 acres of vegetated filter per 100 gallons per minute of tailwater to significantly improve the water quality of field runoff (Long et al. 2010b). It should be noted that the vegetated filter strip is used once per irrigation, not for successive sets.

__Vegetated Drain Ditches__

Drainage ditches can be vegetated with plant material that will help capture sediments and other sediment-absorbed pollutants, as well as provide for some water infiltration. The common type of a vegetated drain ditch (VDD) is a “V”-shaped ditch, 2-3 feet deep and 4 feet wide at the top. Short, sturdy, and hardy perennial grasses such as the dwarf fescues and perennial ryegrass are preferred, since once established they withstand the force of runoff waters and summer drought conditions. Vegetation in the VDD can also be resident, such as rushes and bermudagrass. Residue removal efficiency is strongly influenced by runoff flow rate per unit ditch wetted area. Higher flow rates reduce the removal efficiency.


Vegetated Ditch

__Effectiveness in Removing Pesticide Residues__

Anderson et al. (2008) found that a vegetated ditch containing aquatic vegetation removed only 4 percent of diazinon in contaminated runoff. Moore et al. (2008) used a simulated runoff event to evaluate removal of diazinon in vegetated ditches in Yolo County, California. They described reductions in diazinon runoff using a V-shaped vegetated ditch, but significant concentrations of diazinon remained in the system outflow after five hours. Essentially, runoff waters containing residues which are not infiltrated were little reduced.

Chlorpyrifos, another organophosphate, is more hydrophobic than diazinon. Gill et al. (2008) applied chlorpyrifos at 1 pt/ac and found a 40 percent reduction in the water column concentration after passage through a vegetated ditch, though the outflow water was still at 33 times the water quality standard of 15 ppt. Anderson et al. (2008) found an average 35 percent reduction of chlorpyrifos concentration in two evaluations after passage through a vegetative ditch containing aquatic vegetation. On the other end of the spectrum, Cole et al. (1997), found VFS's effective in reducing 62-99 percent of chlorpyrifos residues in runoff waters. Local conditions including runoff flow rates, size of the vegetated area, and the initial residue concentration appear to have strongly influenced the effectiveness of these studies.

Because of their hydrophobic nature, pyrethroids adsorb readily to plant surfaces and soil particles and are therefore easier to remove from runoff waters than organophosphates (Moore et al. 2001; Schulz, 2004). Moore et al. (2008), for example, found that vegetation was much more effective at removing the pyrethroid pesticide permethrin than the organophosphate diazinon. Anderson et al. (2008) found nearly 100 percent reduction of permethrin after treatment in a vegetated ditch. Additionally, Gill et al. (2008) found a 25 percent reduction of pyrethroid (lambda-cyhalothrin) residues after moving runoff waters through a vegetated ditch.

TAILWATER COLLECTION AND RECYCLING

Water running off the tail end of a field, part of normal irrigation, is referred to as tailwater or runoff water. Tailwater is most often associated with surface irrigation (furrow and border-check irrigation), since well-designed sprinkler and drip irrigation systems should not produce tailwater runoff. Their use is an excellent management practice to improve irrigation efficiency and minimize tailwater runoff impacts.

Tailwater collection systems have most frequently been used in row and field crops and are not as common in surface irrigated tree and vine crops. There is no reason tailwater collection and recycling systems cannot be used in permanent crops using furrow or border-check irrigation. Their use is an excellent management practice to improve irrigation efficiency and minimize tailwater runoff impacts.

Tailwater collection system.

If a new tailwater return system is being planned, the planned management approach must be a key factor in its design. Tailwater generated by irrigation practices is most often pumped from the capture pond and conveyed via a pipeline system to where it will be reapplied. Such a system, well operated, maximizes irrigation efficiency and minimizes environmental impacts.

Advantages and Disadvantages of Tailwater Return Systems

Advantages:

- Offsite environmental impacts of tailwater potentially containing pesticide and fertilizer residues or sediment are minimized.
- Irrigation efficiency is improved since tailwater is beneficially re-used as irrigation water.
- Water costs may be reduced by re-using tailwater.
- Tailwater collection systems remove standing water that can cause crop loss and weed infestations from the tail end of the field.

Disadvantages:

- Cost of installation, maintenance, and operation of the tailwater return system. However, in many areas NRCS cost share programs available.
- Land must be taken out of production for the pond and other tailwater recovery system components.
- Good management, requiring timely recycling of tailwater pond contents, is necessary to prevent groundwater pollution by chemicals in the tailwater.

Tailwater Return System Management

There are numerous ways of managing tailwater return systems, and their management is often constrained by the system design. If a new tailwater return system is being planned, the planned management approach must be a key factor in the design. See ANR publication 8225, "Tailwater Return Systems" Schwankl et al. 2007b for information on design, construction, costs and operation, and National Conservation Practice Standard, Irrigation System, Tailwater Recovery, Standard 447-1, USDA Natural Resources Conservation Service, 2006.

TREATMENT OF RUNOFF WATERS

Runoff water can be chemically treated to reduce pesticide residues. This treatment can be done in the furrow or check, in a tailwater ditch, or in a holding basin. Two products are available and have been shown effective for this purpose: Polyacrylamide (PAM), for treatment of pyrethroid-laden sediments, and Landguard OP-A Enzyme®, for treatment of most soluble organophosphate pesticides. Work is underway to develop enzymes to treat pyrethroid residues, however they are unavailable at this time.

Polyacrylamide (PAM)

PAM is effective in controlling pesticide residues which are attached to soil particles (pyrethroids) that leave the field or are generated in the tailwater ditch through erosion during irrigation. Studies have shown that this erosion occurs along the field length for furrow irrigation. PAM is a solid or liquid water-soluble polymer that flocculates sediments, binding them together and causing them to drop out of the water. When added to runoff waters, PAM can mitigate transport of sediment-adsorbed pesticides from furrow and border-check irrigated fields.

Liquid PAM can be constantly injected into the irrigation water, constantly deposited in granular form into turbulent irrigation ditch water, or applied to the furrow as dry tablets (40 percent PAM) or granules (89 percent PAM), where it is slowly dissolved by irrigation water. The in-furrow methods are generally less expensive and easier to apply than liquid or granular PAM applied to the inflow ditch or piped water. However, they do not allow for equally precise control of product concentration. Table 9 shows a comparison of costs using the different forms of PAM for an 80-acre furrow-irrigated row crop planted on 5-foot beds, using data provided by a grower. The lowest cost occurred for granules placed in the furrow, while the costs were the highest using liquid PAM.

At a furrow length of 600 feet, 60-inch beds would require about one ounce or 2 tablets per furrow. It is applied in a "patch" in a 3-foot section of the furrow, far enough from the furrow head to prevent sediments from covering the PAM patch. In the Northwest, placement 5 feet from the furrow head was successful. In California, the patch was quickly covered and not effective; whereas 100 feet down furrow was successful. Once applied as a "patch," PAM seems to be effective for a few irrigations. If the soil is disturbed by cultivation, it must be reapplied. PAM is more effective in finer texture soils and in irrigation waters that contain calcium and little sodium.

Season-long control costs are difficult to estimate because effectiveness from a single application varies with the number of irrigations and the number of field cultivations.

Liquid PAM that contains oil-based carrier materials is available, but the cost per acre is high and the product can be toxic to some aquatic life at recommended field application rates (Weston et al. 2009).

Table 9. Cost comparisons for different single irrigation PAM formulations for a typical 80-acre furrow-irrigated row crop planted on 5-foot beds.

Application method	Unit cost of material	Cost per acre	Comments
Granules placed in furrow	$2.79 per pound	$1.05	1 oz of granules per furrow
Tablets placed in furrow	$4.82 per pound	$6.36	Two tablets per furrow
Granules injected into irrigation water	$2.79 per pound	$5.46	Target concentration = 5 ppm; injection time = 12 hours (time needed for water advance to end of furrows)
Liquid PAM injected into irrigation water	$34 per gallon	$32.31	Target concentration = 5 ppm; injection time = 12 hours
Liquid PAM injected into irrigation water	$34 per gallon	$12.93	Target concentration = 2 ppm; injection time = 12 hours

Source: Long et al. (2010a)
Costs per acre are based on the gross acreage of the 80-acre field.

Effectiveness in Removing Pesticide Residues

PAM has been shown to be effective in reducing sediments from furrow irrigation fields when applied to irrigation furrows. Sojka et al. (2007) in their Northwest studies on furrow-irrigated soils over a three-year period, found application rates of 1 pound per acre/irrigation (about 10 ppm) eliminated 94 percent of sediment loss in field runoff. A seasonal rate of 3-7 pounds per acre was used, depending on the crop and number of cultivations. One of the mechanisms of decreased sediment loss is increased infiltration of irrigation water into the field because PAM effectively reduces runoff water volumes (Trout et al. 1995). Sojka, using the recommended 10-ppm PAM rate, found increases in infiltration of 15 to 50 percent compared to untreated controls. In California, Long et al. (2010b) found no PAM effect on infiltration into loam and clay loam soils at a lesser application rate assumed to be near 2ppm.

In a California study conducted on loam and clay loam soils, Long et al. (2010b) found an application rate of 1-2 ounces per 600-foot furrow using the “patch method” reduced sediment loss between 57 and 97 percent in numerous trials. Furrow flow rates averaged 17.5 gallons per minute. They found greater than 80 percent sediment control in 60 percent of the trials. The concentration of a pyrethroid, lambda-cyhalothrin or zeta-cypermethrin, was reduced by the same amount.

Landguard OP-A Degradation Enzyme

Runoff waters containing organophosphate insecticide residues can be treated with a degradation enzyme, Landguard OP-A, to reduce or eliminate residues in runoff water before water exits the farm. This product promotes the breakdown of most organophosphate pesticides into less toxic metabolites. The powder-like enzyme is mixed with water into a stock solution and applied to runoff water usually in the tail water ditch but can be applied to a holding basin. The enzyme treatment rate, residue concentration, and the time available before runoff discharge are all important to for ensuring degradation at a minimum material cost. Greater time available before runoff discharge allows a lower enzyme application rate.

The key factor in determining the correct dosing rate is the maximum expected runoff rate. Runoff rate is typically not constant over time. When using a single dosing rate based on the maximum estimated flow rate, over-dosing is likely at the lower flows that typically occur at the beginning and end of a runoff event. Additionally, the practice of irrigating more checks during a nighttime set can lead to different peak flows of different duration.

A comparison was made of the amount of enzyme required for single maximum rate dosing for the entire runoff period and for a variable rate dosed as required by flow rate—essentially keeping the dosing rate constant (Prichard and Antinetti 2009). A single rate setting to dose for the maximum volume during the first irrigation set resulted in a dosage that was more than double the amount actually needed. Estimating that the next set would be near the same runoff flow rate and using the same dosing rate, the second set required over 6 times that of a correctly dosed variable system do to the lower amount of runoff.

Effectiveness in Removing Pesticide Residues

A field trial in California found chlorpyrifos in runoff at a concentration near 10 ppb prior to Landguard OP-A treatment. Twelve minutes after the enzyme was added at a rate of 4.3 oz to one acre foot runoff water, the chlorpyrifos concentration declined to 0.4 ppb. At higher enzyme dosages, chlorpyrifos became undetectable. The effects of the enzyme on chlorpyrifos-related toxicity are equally dramatic. The enzyme reduces chlorpyrifos toxicity to *H. azteca* (a test organism) by at least 70 fold compared with untreated water (Weston and Jackson, 2010). Without enzyme, the concentration of chlorpyrifos required to kill half the test organisms was 141 ppb. With enzyme, they saw no ill effects to the test organisms.

A team led by Brian Anderson of the UC Davis Marine Pollution Studies Laboratory dosed Landguard OP-A at the rate of 4.3 oz/acre foot runoff water directly into a drainage ditch containing diazinon residues (Anderson et al. 2008). Samples of runoff water were collected from the ditch before dosing and 107 feet downstream from the electronic dosing unit (Figure 7).

In multiple trials, Anderson found that samples treated with Landguard OP-A demonstrated no detectable diazinon and all were non-toxic to *C. dubia*, another aquatic arthropod test organism.

Figure 7. Anderson trial showing vegetated ditch and electronic dosing unit 2008

This publication endeavors to gather into one place all the major strategies for minimizing offsite movement of pesticides in water and to use flowcharts to help guide growers and farm managers through the process of selecting which practices may be most appropriate for their operations. However, more detailed information on implementation of many of these practices is available from sources referenced throughout the publication (or search reference list below). If you need assistance in determining which practices would be best for your operation or how to implement them, please contact your local Cooperative Extension Farm Advisor for information and advice.

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APPENDIX I

A RISK ANALYSIS CASE STUDY - VINE MEALYBUG

Let's expand the example we introduced in the "How to Use This Workbook" to better understand how the management practices presented in this workbook can be used to prevent or correct water quality problems arising from field operations.

Crop: Mature Cabernet Sauvignon Vineyard
Pest: Vine Mealybug (VMB)
Pest Detection: Mid - late season—pre harvest
Topography: Undulating topography 0-4 percent slope
Soil: San Joaquin Sandy Loam, prone to soil surface crusting—limiting water infiltration
Irrigation system: Drip—post harvest irrigation applied
Irrigation water: pH 7.5, EC 0.2 dS/m
Drainage: Runoff moves to a drain at edge of field; then, on to a larger creek
Proximity to surface water sources: Edge of field drain contains irrigation runoff from neighboring lands.
Pesticide mixing and loading: A pesticide mixing and loading area is located about 40 feet from the drainage ditch.

We begin the risk assessment with Flowchart number 1 (FC1), considering possible routes by which pesticide could move off the field and the operations or conditions that may contribute and application to near surface water sources (drift). We will determine if a risk exists for each concern, and then review management practices to mitigate the risk.

THE IRRIGATION RUNOFF RISK

Since a post-harvest irrigation has been applied, no further irrigation runoff risk exists.

THE APPLICATION NEAR SURFACE WATER SOURCES RISK (Drift)

Our example vineyard is located near a drainage ditch which contains water draining to a surface water source, and therefore poses a significant risk. Consider ways of reducing **spray drift** that could enter the drainage ditch or creek near the example vineyard. This leads us to **FC5** (Evaluating the risk of chemical applications near surface waters) and the following drift management options:

<u>**Application Conditions**</u>

- Don't apply pesticides under dead calm or windy/gusty conditions; don't apply at wind speeds greater than 10 mph, ideally not over 5 mph. Read the label for specific instructions.

- Apply pesticides early in the morning or late in the evening; the air is often more still than during the day.
- Determine wind direction and take it into account when deciding whether or not or how to make an application.
- Calibrate and adjust sprayers to accurately direct the spray into the canopy "target."
- Delay treatments near ditches and surface water bodies until wind is blowing away from these and other sensitive areas.
- Don't spray during thermal inversions, when air closest to the ground is warmer than the air above it.

Application Equipment

- Use as coarse a spray as possible (250 - 400 microns or larger) while still obtaining good coverage and control. Droplet size is one of the most important factors affecting drift.
- Use low drift nozzles that produce larger droplet sizes. Fitting a sprayer with air induction nozzles instead of standard nozzles will reduce spray drift up to 50 percent compared to standard nozzles.
- Use a directed spray to minimize the contact with soil.
- Check to verify the spray deposition pattern expected.
- Service and calibrate spray equipment regularly.
- Check the system for leaks. Small leaks under pressure can produce very fine droplets. Large leaks contaminate soil which can be moved offsite by water.
- Use low pressure and spray volumes appropriate for canopy size.

Product Choice

- Choose an application method and a formulation that are less likely to cause drift. After considering the drift potential of a product/formulation/application method, it may become necessary to use a different product to reduce the chance of drift.
- Use drift control/drift reduction spray additives/agents. These materials are generally thickeners designed to minimize the formation of droplets smaller than 150 microns. They also help produce a more consistent spray pattern and deposition.
- Use spray adjuvants, which can greatly reduce application volumes without compromising pesticide efficacy.
- Use maximum spray volume per acre and low pressure.
- Treat buffer zones with materials that are the least risk to aquatic life.

Buffer Zones

- Maintain adequate buffer zones around the treated site to ensure that pesticides don't drift onto sensitive areas. Read the label to determine the size of buffer zone required as related to the rate of active ingredient.

- Wolf et al. (2003) documented 75 to 95 percent reductions in drift deposits up to 98 feet downwind when setback distances were vegetated with grass or shrubs.

Now that we have evaluated the risk of chemical applications near surface water, we go back to FC1 to evaluate the stormwater runoff risk.

THE STORMWATER RUNOFF RISK

In our example vineyard the pesticide application for vine mealybug is after harvest. There is a risk that residues could be moved offsite by storm water runoff.

Proceeding to FC4, the first step is to evaluate vineyard **IPM practices** used to control vine mealybug. (The following was adapted from the UC IPM Guidelines available at: (http://ucipm.ucdavis.edu)

Integrated Pest Management (IPM)

The Vine Mealybug Pest

Vine mealybugs are small (adult females are about 1/8 inch in length), soft, oval, flat, distinctly segmented, and covered with a white, mealy wax that extends into spines (filaments along the body margin and the posterior end). The adult male is smaller than the female, has wings, and flies short distances to mate. There are three to seven generations a year.

All or most life stages of the vine mealybug can be present year-round on a vine depending on the grape-growing region. During the winter months, vine mealybug eggs, crawlers, nymphs, and adults are under the bark, within developing buds, and on roots.

As temperatures warm in spring, vine mealybugs become visible as they move from the roots and trunk to the cordons and canopy. By late spring and summer, vine mealybugs are found on all parts of the vine: hidden under bark and exposed on trunks, cordons, first- and second-year canes, leaves, clusters, and roots. Ants may transport vine mealybug from the roots to above ground plant parts where they continue to tend vine mealybugs throughout the remainder of the growing season.

Damage by the vine mealybug is similar to that of other grape-infesting mealybugs in that it produces honeydew that drops onto the bunches and other vine parts and serves as a substrate for black sooty mold. If ants are not present, a vine with a large population of this pest can have so much honeydew that it resembles candle wax. Also, the mealybug itself will be found infesting bunches, making them unfit for consumption. Like the grape, obscure, and longtailed mealybugs, vine mealybug can transmit grape viruses.

Pest Monitoring

Pheromone traps for this pest are available for determining if a vine mealybug infestation is near or in your vineyard. The lure that is placed inside each trap contains the sex pheromone that female vine mealybugs use to attract winged adult males. Tent-shaped, red traps are recommended because the shape and color tend to reduce the number of non-target insects that are caught.

Place traps in and around the vineyard by April 1 in the southern San Joaquin Valley to May in areas further north:

- Choose two trap sites for each 20-40 planted acres.
- Put one trap in the center of the block and the other on the edge near a staging area. These traps can attract vine mealybug males from as far away as 1/4 mile.
- Attach traps to the trellis wires so that they are in the cluster area.
- Label the trap with the block name and row number of its location and the dates it remains in the vineyard.
- Check traps for the presence of male vine mealybug every 2 weeks through November.
- Follow the manufacturer's recommendations for storing and replacing pheromone lures.

Establishing an Action Threshold

After bloom, pull basal leaves to look for vine mealybug crawlers and honeydew in the canopy and look under the bark on the trunk and cordons. During bloom and veraison, treatment may be warranted for even a moderate population of nymphs on leaves (between 10 and 15 percent of the vineyard having mealybug present), but if possible it is better to wait until postharvest to treat in order to preserve natural enemies. Look for ant activity in vines and along drip lines. Also, the presence of ants moving up and down the vine may indicate the presence of *Pseudococcus* mealybugs, vine mealybug, or European fruit lecanium scale

Vine mealybug produces more honeydew than other mealybugs, and this is particularly noticeable if there are no ants present. Thus, when searching for vine mealybugs during summer, look for honeydew exudates on the clusters, trunk, and cordons. These exudates will resemble melted candle wax, if the infestation is severe, and basal leaves will appear shiny and sticky. Sooty mold will grow on the honeydew, and permanent parts of the vine will appear black in fall and winter. Also look for fallen leaves beneath the canopy in July and August. To locate less severe infestations, it is necessary to look for all stages of the insect under the bark predominately at the graft union, on trunk pruning wounds, and below the base of the spur.

If vine mealybug is found in the vineyard, treatment is recommended. There are two approaches to managing mealybugs: eradication and yearly management. Eradication using chemical applications is most likely to be successful in young vineyards or in vineyards where only a few isolated vines are infested. In mature vineyards with heavy, loose bark, strip the bark off the trunk and cordons before a chemical application to increase chances of success. Eradication is most probable in areas where there are no nearby vine mealybug-infested vineyards. If 2 years of effort do not eliminate vine mealybug from the vineyard, then switch to a yearly management program.

Management Options

Biological Control

The parasites that attack *Pseudococcus* mealybugs do not attack the vine mealybug, therefore two potential candidates for natural control have been imported and released in Riverside, Kern and Fresno counties. The most successful of these has been *Anagyrus pseudococci.* This species has provided up to 20 percent parasitism in some vineyards in the Coachella Valley and up to 90 percent parasitism in the San Joaquin Valley. It is extremely important to promote parasites because they are active late in the growing season and can reduce vine mealybug populations before the pest begins to move to the lower part of the trunk in October. To a limited extent, they can parasitize vine mealybug when it is located under the bark where chemicals cannot penetrate. Ants must be controlled to keep them from interfering with these natural enemies.

In the coastal regions a lady beetle called the mealybug destroyer, *Cryptolaemus montrouzieri,* attacks vine mealybug eggs and crawlers.

Cultural Control

The female mealybug is unable to fly so it must be carried by humans, equipment, birds, or be present on vines at the time of planting. Do not allow contaminated equipment, vines, grapes, or winery waste near uninfested vineyards. Movement of equipment that pushes brush or any over-the-row equipment can be a major source of infestations in new locations; steam sanitize equipment before moving to uninfested portions of the vineyard. Do not spread infested cluster stems or pomace in the vineyard. To reduce contamination, cover all pomace piles with clear plastic for several weeks and avoid creating piles that consist predominately of stems.

Organically Acceptable Methods

Biological and cultural controls are organically acceptable management tools. The use of 415 oils repeatedly during the spring and summer has shown good results in winegrapes. This also helps manage mildew but the use of sulfur must be avoided. No research studies have yet been done in California on the efficacy of oils or calcium polysulfide in controlling vine mealybug, but they have not proven effective in controlling the grape mealybug.

Chemical Control

If vine mealybug is discovered in the vineyard in late summer or fall, apply a foliar insecticide immediately after harvest if possible (before the nymphs begin to move to the lower parts of the trunk), to kill mealybugs on the leaves and wood so that the infestation is not spread to other parts of the vineyard when leaves drop or when the vines are pruned. If preharvest interval restrictions permit, apply methomyl or dimethoate to infested vines. Take precautions during harvest operations to prevent movement of insects to non-infested vines.

The following year, apply a delayed dormant treatment of chlorpyrifos or buprofezin and then, in areas with light soils, treat with imidacloprid (soluble formulation) at bloom. Make either a single application of imidacloprid through the drip system or a split one, depending on soil type. During summer, treat with buprofezin. Other materials (methomyl and dimethoate) are available for treating vine mealybug during summer, but they are not as effective and are more disruptive of beneficials. (In the North Coast, the first application of buprofezin is not recommended until late spring or early summer; imidacloprid is not as effective in controlling pests in heavy clay soils.) The University of California IPM Program recommends following this program for a maximum of 2 years. If vine mealybug is still present in the vineyard after 2 years, switch to a yearly management program.

Yearly Management Program

Areas with light-textured soils— In vineyards known to be infested with vine mealybug, make a bloom time application of imidacloprid either as a single application or a split application through the drip-line. The following year, either treat with chlorpyrifos in the delayed dormant period, or with buprofezin in the delayed dormant period and again in the summer. Alternating insecticides each year helps to prevent the development of insect resistance.

Areas with heavy clay soils— In vineyards known to be infested with vine mealybug, make an application of buprofezin or methomyl as soon as crawlers are present on the leaves (in late spring to early summer); a second application can be made no sooner than 14 days later. (For table grapes, an application can be made earlier than late spring.) Apply a foliar insecticide immediately after harvest to kill mealybugs before the nymphs begin to move to the lower parts of the trunk in late October

Continuing to work our way through FC4, the next step is to select pesticides for the first and subsequent treatments.

Selecting Pesticides to Reduce Water Quality Risks

Treatment options are derived from the UCIPM Pest Management Guidelines for grapes (Table A1. (http://www.ipm.ucdavis.edu/PMG/selectnewpest.grapes.html) combined with the potential for runoff risk and overall risk from Table 2. Table A1 includes two organophosphates and one a carbamate.

Table A1. Common treatment options for vine mealybug
for conventional winegrape production

Chemical	Trade Name	Chemical Class	Solution Runoff potential[1]	Adsorption runoff potential[2]	Overall runoff risk[3]
Chlorpyrifos	Lorsban	organophosphate	high	intermediate	very high
methomyl	Lannate	carbamate	intermediate	low	Moderate
dimethoate	Dimethoate	organophosphate	low	low	low

[1] Likelihood that the active ingredient will transport from the area of treatment as dissolved chemical in runoff.

[2] Likelihood that the active ingredient will transport from the area of treatment as attachment to soil or sediment particles in runoff.

[3] Overall likelihood to cause negative impact on surface water quality as a product of the runoff potential and the aquatic toxicity of the pesticide

Having read the sections of this manual about the water quality risks associated with various classes of chemicals, we know that many organophosphates are highly water soluble and subject to runoff risk while pyrethroids are highly hydrophobic and adsorb readily to soil sediments—also subject to offsite movement.

Since VMB was first discovered in late summer, apply a postharvest treatment of a foliar insecticide (chlorpyrifos, methomyl or dimethoate) to kill mealybugs on the leaves and wood so that the infestation is not spread to other parts of the vineyard when leaves drop or when the vines are pruned. Postharvest treatments are only recommended the first season that vine mealybug is discovered.

A post harvest or a delayed dormant application is at risk of causing offsite movement of pesticide residue in stormwater runoff. Selection should be based on efficacy, persistence in solution and adsorbed runoff potential and the water toxicity. In this case, the materials recommended for a late season application are organophosphate or carbamate insecticides. However, there are differences between them in the potential for the pesticides to runoff. Dimethoate and methomyl have much lower solution aquatic toxicity and less persistence in the environment than chlorpyrifos. Both have good efficacy, however dimethoate has the lowest overall runoff risk.

The next consideration in FC4 for managing vine mealybug is to consider pesticide mixing and loading practices and their impact on surface water quality

Mixing and Loading Pesticides Near Surface Waters

The mixing and loading site in our example field is within 50 feet of a surface water ditch. Mixing and loading practices include not over-filling the tank, triple rinsing containers and adding the rinsate to the tank, and rinsing the tank and applying the rinsate to the field. The use of a concrete pad with catchment sump is also a good solution to reduce risks from mixing and loading near surface water sources.

Avoid Application Risk Prone Times

Management practices to mitigate the offsite movement risk include avoiding application when rain is predicted, especially when soils are saturated by previous rainfall. It is best to apply organophosphate materials immediately after harvest, to avoid the heavy rain season.

Protect the Soil Surface

Cover crops can help protect the soil surface from droplet impact under winter rainfall and provide significant organic matter biomass for decomposition and microbial stabilization of soil aggregates increasing infiltration rates. In addition, cover crop residue can slow the velocity of surface water, reducing erosion and subsequent depositional crusting.

Since the soil is prone to crusting, soil surface protection using cover crops during the previous winter and early spring will protect the soil surface from surface soil dispersion and the creation of water infiltration-limiting crusts—reducing runoff potential. Increased organic matter from the cover crop will also promote increased infiltration.

These practices would have been implemented in the previous and/or current season. In our case study, the soil tends to crust, and with some slope, high intensity rainfall is likely to cause surface runoff even if the soil was not saturated.

Improve Water Infiltration

Managing Soil Organic Matter to Reduce Runoff

Soil organic matter helps stabilize soil aggregates by increasing the number of exchange sites in the soil matrix and encouraging microbial activity. Soil microbes that decompose soil organic matter produce polysaccharides and polyuronides, which act as binders to stabilize aggregates, thus improving porosity and water infiltration. Over time, continued cultivation and the use of herbicides reduces the organic matter content and aggregate stability of soils. These changes can reduce water infiltration and increase runoff potential.

It is difficult to increase and sustain soil organic matter under warm semiarid conditions that prevail in most of California, which favor rapid organic matter decomposition. Organic matter additions aimed at improving or sustaining aggregate stability and water infiltration must be incremental and continual to be effective. There are several ways for growers to achieve this.

Crop Residues

Vine leaves and prunings, shredded or soil incorporated, can be left to decompose adding organic matter (and some nutrients) to the soil.

Manure and Other Organic Materials

With proper handing and management to avoid risk of crop contamination by human pathogens, animal manures or compost can help increase soil organic matter content and improve water infiltration. However, the application of manures is currently uncommon due to the limited availability of manures.

Tillage

If a crust is likely or has already formed, light surface tillage can improve water infiltration. If done after the pesticide application incorporates residues in to the soil reducing runoff potential.

Evaluate and Institute a Chemical Solution to Increase Water Infiltration

The addition of chemical amendments to water or soil can improve water infiltration by improving the chemical makeup of the water or soil. Most chemical amendments work by increasing the total salt concentration and/or decreasing the sodium adsorption ratio (SAR) of the soil-water. Both of these actions enhance aggregate stability and reduce soil crusting and pore blockage.

Calcium Materials

Adding calcium (Ca) salts to soil and water increases both the total salinity and soluble calcium. Calcium salts commonly used on alkali (high pH) soils include gypsum ($CaSO_4$), calcium chloride ($CaCl_2$), and calcium nitrate ($CaNO_3$). Gypsum is the most common calcium material applied in the fall prior to bedding up. Surface applications are most effective when gypsum is applied at rates equivalent to 1 to 2 tons per acre.

Acids and Acid-Forming Materials

Commonly applied acid or acid-forming amendments include sulfuric acid (H_2SO_4) products, soil sulfur, ammonium polysulfide, and calcium polysulfide. The acid from these materials dissolves soil-lime to form a calcium salt (gypsum), which then dissolves in the irrigation water to provide exchangeable calcium. The acid materials react with soil-lime the instant they come in contact with the soil. The materials with elemental sulfur or sulfides must undergo microbial degradation in order to produce acid. This process may take months or years depending on the material and particle size (in the case of elemental sulfur). Since these materials form an acid via the soil reaction, they will reduce soil pH if applied at sufficiently high rates.

Runoff Water Capture or Treatment

Intercept the Movement of Surface Water

Any reduction in the runoff volume or decrease in the velocity of runoff flow can reduce concentration of both soluble and sediment-attached residues. There are several methods of intercepting offsite movement of surface water and sediment. Some are temporary and used with a new vineyard or in emergency situations where the need for runoff control is short lived, and some are permanent. Steep hillside vineyards should have several types of permanent erosion control measures in place, such as permanent cover crops, adequately sized filter strips between the vineyard and any waterways, and permanent sediment basins.

Capture Runoff Water

Sediment basins can prevent runoff from entering surface water sources only if the capacity is great enough to store the runoff waters until they infiltrate. Some growers on higher infiltration soils install a berm around the lower end of the field to trap runoff waters until they infiltrate. On sloping soils, temporary structures including straw wattles can divert and slow runoff waters. Vegetated filter strips can help infiltrate runoff water containing soluble residues.

Treat Runoff Waters

Runoff waters containing organophosphate insecticide residues can be treated with the degradation enzyme Landguard OP-A to reduce or eliminate residues in runoff water before water exits the farm. This product promotes the breakdown of most organophosphate pesticides into less toxic metabolites. Since no pyrethroid insecticide is recommended for vine mealybug control, sediment reduction measures are not considered.