EM4885
IRRIGATION MANAGEMENT PRACTICES TO PROTECT GROUND WATER AND SURFACE WATER QUALITY STATE OF WASHINGTON

by

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WASHINGTON STATE DEPARTMENT OF ECOLOGY

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DATE: February 17, 1995

TO: Irrigation Management Manual Users

Dear Interested Persons:

The accompanying handbook, *Irrigation Management Practices to Protect Ground Water and Surface Water Quality, State of Washington,* represents a compilation of the best information we currently have in regards to irrigation management technology.

The handbook is the result of a cooperative effort between Cooperative Extension, the Department of Ecology and several conservation districts. The project was funded under the Section 319 Nonpoint Source Management Program. This handbook should strengthen the partnership between local conservation districts, USDA/Natural Resource Conservation Service, WSU Cooperative Extension, the Conservation Commission, the Department of Ecology, and individual farm operators as we work together to prevent pollution of the state's water resources.

The Conservation Commission, in its endorsement of this project, recognizes that irrigators need to have management options available to them in order to meet their three primary goals: water use efficiency; economic production of agricultural products; and protection of our natural resources. We believe that a balance of these interests has been met in the guidance contained in this handbook.

The Commission also recognizes that conservation districts must continually update their technical information in order to provide the best possible service to their cooperators. We believe that this handbook embodies the latest information on managing irrigation systems and resources.

However, users of this manual must be careful not to make broad assumptions regarding use of this information:

- First, technical information does and must exist in a fluid atmosphere. As we learn more about how we manage resources, as technology changes, as public policy debates shape resource use decisions, conservation districts and irrigators must be willing to adapt to changes. This handbook represents the best information available today, but it must be updated regularly if we are to serve our clients with accurate information.
- Second, the handbook emphasizes a *systems* approach to managing irrigation resources. We cannot assume that implementation of a single practice will meet the water quality protection goals. While a single practice may indeed provide the needed protection, more often than not, the producer will need to combine individual practices into a system of irrigation management. It is incumbent on the staff using these technical guides to ensure that the producer understands the relationship between individual practices and entire systems.
- Finally, producers need to understand that the systems outlined in this handbook do not guarantee protection of water quality. In some instances it may be possible for a producer to do everything called for in this manual and still have degradation of water quality. In those rare cases, it may be necessary for producers to go beyond what is currently in this handbook to achieve water quality protection. When faced with this situation, the Department of Ecology expects to seek solutions based on a philosophy of working cooperatively with farmers to assure that its efforts are targeted towards individuals who are contributing to the problem, not those who are working to implement solutions. Again, it is the technical advisors to the producers who need to ensure that this point is clear. We cannot let the irrigators assume that simply following these guidelines will protect water quality in all cases.

We have now accomplished our first goal, development of usable irrigation management practices for water quality protection. We are now faced with the challenge of reaching our true goal, protection of water quality. Through the efforts of conservation district, Cooperative Extension, and the Department of Ecology the Commission is convinced that this final goal will also be reached.

Sincerely,

Steven R. Meyer, Executive Director
Conservation Commission

Michael T. Llewlyn, Manager
Water Quality Program
Department of Ecology

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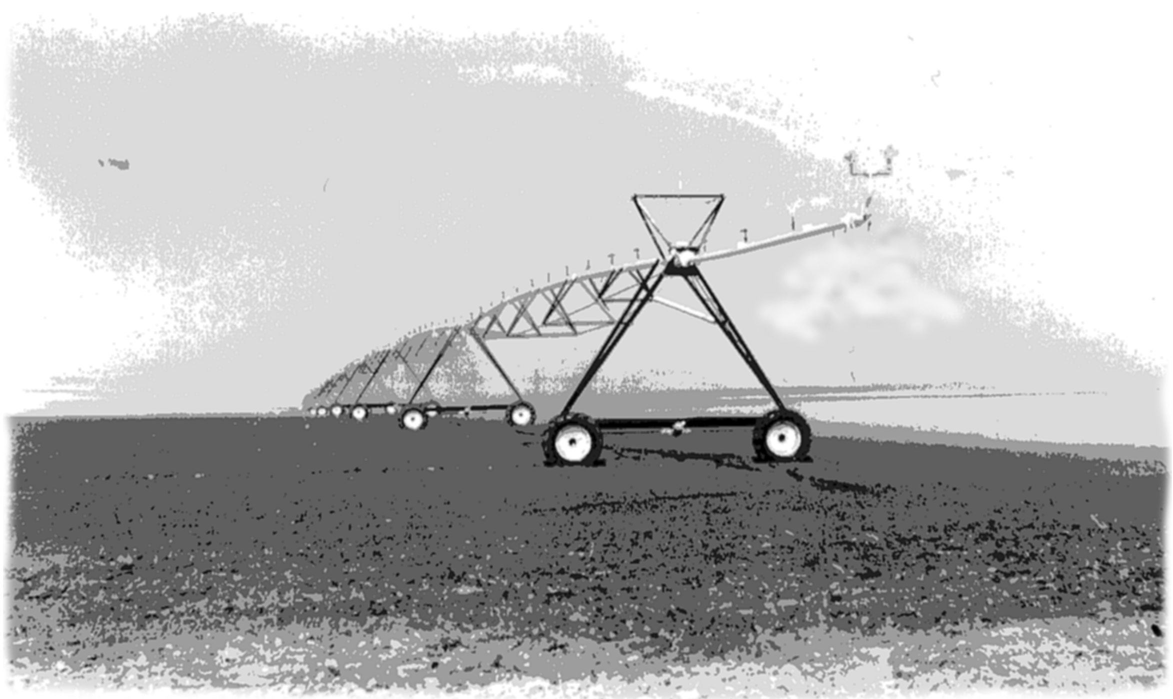


1 CHAPTER

INTRODUCTION

Purpose

This document is titled *Irrigation Management Practices to Protect Ground Water and Surface Water Quality - State of Washington.* It will be referred to as "the Manual."

The primary purpose of the Manual is to present a series of Overall Management Objectives (Objectives) for irrigated agriculture in Washington. The primary audience for the Manual is intended to be farm operators and their advisors. The Objectives address the problem of nonpoint source pollution from practices associated with irrigated agriculture. The Objectives will, if achieved, help to control nonpoint source pollution of ground and surface waters. It is the responsibility of the individual farm operator to achieve these Objectives under the current state and federal strategies of voluntary action for controlling nonpoint source pollution.

A series of Implementation Practices (Practices) is listed for each Objective to help achieve that Objective. The Practices are functionally equivalent to what have been generally termed Best Management Practices. The Practices address changes to both management and facilities for control of nonpoint source pollution.

It is important to realize that science is not static. The Objectives and Practices listed in the Manual are generally recognized to be effective in reducing the potential for point and nonpoint source pollution. However, there may be other Practices not presented in the Manual that are also effective. And, science and practical experience will develop new Practices in the future. The Manual is a "living" document; Objectives and Practices will be updated periodically.

Nonpoint source pollution as defined by the Federal Environmental Protection Agency is ". . . pollution . . . caused by diffuse sources that are not regulated as point sources. . . ." Further, the Washington Legislature has defined nonpoint source pollution as "pollution that enters the waters of the state from any dispersed water-based or land-use activities, including, but not limited to, atmospheric deposition, surface water runoff from agricultural lands, urban areas, and forest lands, subsurface or underground sources, and discharges from boats or other marine vessels."

Nonpoint source pollution is cumulative in nature. While any source of nonpoint source contamination may be insignificant, the cumulative effect of many such sources is measurable and leads to significant pollution of ground or surface waters.

It is difficult, by its nature, to assign responsibility for nonpoint source pollution when it occurs. Nonpoint source pollution is usually the result of land-use activities. Thus, modifying land-use activities can reduce or control nonpoint source pollution. The current state and federal strategies for reducing and controlling nonpoint source pollution rest heavily on education and voluntary adaptation of those actions which reduce the potential for pollution. The Manual provides education as well as lists of possible practices to help farm operators take those voluntary actions that can reduce and control nonpoint source pollution from irrigated agriculture.

Organization of Manual

Complete understanding and effective use of the Implementation Practices in achieving the Objectives requires an integrated knowledge of water quality issues and the contamination process. To that end the Manual provides the following:

1. A summary discussion of water quality issues in Washington.

2. A summary discussion of how water pollution occurs.

3. A summary discussion of irrigation science.

4. A presentation of Overall Management Objectives to reduce the potential for water pollution and Implementation Practices that will help achieve the Objectives.

5. A listing of Government and private resources available to growers to help achieve the Objectives.

There are eight chapters in the Manual. **Chapter 1** is the Introduction and lists the purposes of the Manual, describes the organization of the Manual, and tells how to use the Manual.

Chapter 2 is a summary discussion of water quality issues in the State. It describes the current status of both surface and ground water quality, discusses the impacts of this status on various aspects of society, and describes the current strategy for controlling nonpoint source contamination of surface and ground waters.

Chapter 3 is a summary discussion of how surface and ground water become polluted. It also contains a summary discussion of basic soil-water-plant relationships. These describe how water enters the soil, is held by the soil, moves in the soil and into the plant, and through the plant back to the atmosphere. The objective measures of irrigation performance, distribution uniformity, and application efficiency are identified and explained.

Chapter 4 is the presentation of Overall Management Objectives. These Objectives, if achieved, will reduce the potential for pollution of surface and ground water. Implementation Practices are identified. These are specific actions, either a change in hardware or a change in management, that will help achieve the Objectives.

Six Objectives are presented in Chapter 4:

1. Objective 1.00 - Minimize water losses in the on-farm distribution system

2. Objective 2.00 - Improve irrigation system performance and management to minimize deep percolation and surface runoff

3. Objective 3.00 - Manage fertilizer program to minimize excess fertilizer available for transport

4. Objective 4.00 - Manage crop protection program to minimize chemical residues available for transport

5. Objective 5.00 - Reduce contamination of surface water from sedimentation

6. Objective 6.00 - Prevent direct aquifer contamination via wells

Within some Objectives are separate sections of Implementation Practices. For example, within Objective 2.00 there are four sections, three of which list Practices for an individual irrigation system type. The science of managing those three system types is also discussed in these sections.

Chapter 5 provides guidance on how to develop a pollution-control program on a specific farm. Chapter 5 is also available for site-specific information that may be developed by State and Federal Agencies. This information might include average annual evapotranspiration for the various crops grown in the area, average annual rainfall, average water quality of surface and ground water supplies, and assessments of the potential for pollution in that area. Also, the Objectives and Practices presented in Chapter 4 assume an average physical/economic environment. There may be circumstances that would cause a Practice to lead to different results than indicated by the discussions in Chapter 4. Local Agencies might identify these situations and place the information in Chapter 5.

Chapter 6 is a summary discussion of the role of selected government agencies and entities in reducing water pollution. The Compliance Memorandum of Agreement between the Department of Ecology, the Washington Conservation Commission, and local conservation districts is explained in this chapter.

Chapter 7 is a listing of resources, both public and private, that are available to growers for help in implementing the Practices presented in Chapter 4.

A Glossary explaining the terminology used in the Manual is provided in **Chapter 8.**

How to use the Manual

The following is a recommended way of using the Manual in order to best decide which Practices to apply in achieving the Objectives:

1. Read Chapter 2 to become familiar with surface and ground water quality issues. It will indicate the importance of surface and ground water quality, summarize regulatory law that implements programs to control pollution, and discuss the strategy developed for reducing or preventing pollution. This Chapter will also introduce the important State and Federal agencies charged with protecting and improving water quality in Washington.

2. Read Chapter 3 to become familiar with the science of water pollution and irrigation. This Chapter is extremely important as it provides the background knowledge for complete understanding of the Overall Management Objectives and recommended Implementation Practices of Chapter 4.

3. Presentation of the six Overall Management Objectives in Chapter 4 is the primary reason for the Manual. It explains the purpose of the Objectives, their importance, and the potential and intended effects on surface water quality, ground water quality, and water diversions (both from wells and irrigation districts).

4. Next read the presentations of the Implementation Practices under the different Objectives. They will indicate how each Practice can help in achieving an Objective and whether the Practice is applicable to a given situation.

5. Chapter 5 provides guidance in how to develop a pollution control program on a specific farm. Also, any information that is specific to the target area is contained in Chapter 5.

6. Chapter 6 should be read to see how irrigation and conservation districts or other local, state, and federal agencies can help in reducing water pollution. Chapter 6 also contains a summary explanation of the Compliance Memorandum of Agreement between the Department of Ecology, the Conservation Commission, and local conservation districts. There is a list of Districts that have signed the Agreement and at what level of compliance.

7. Chapter 7 lists additional resources that are available to growers. The various agencies and types of consultants listed in this chapter can help to implement the Practices presented in Chapter 4.

CHAPTER 2.

2 CHAPTER

WATER QUALITY ISSUES IN WASHINGTON STATE

Purpose

This chapter provides a summary discussion of water quality issues in the state of Washington. The discussion includes:

1. Public health, environmental, economic, and regulatory aspects.

2. Results from ongoing assessments of the quality of surface and ground water resources in Washington.

3. The current strategy for protecting water quality in Washington that pertains to irrigated agriculture.

Uses and Sources of Water

Good quality water is essential to man's existence. Clean water for drinking is vital. However, many industrial processes also require extremely clean water. Other beneficial uses of water include irrigation, livestock, fish habitat (spawning, rearing, migration, and harvest), wildlife habitat, recreation (swimming and boating), and navigation.

Water supplies may come from surface waterbodies such as rivers and lakes. Or, they may come from ground water. Ground water is water (overland runoff, rivers, streams, or lakes) that has percolated (moved through ground) to a usable aquifer. An aquifer is an underground geologic formation, either fractured rock or porous soil, that provides water storage. A usable aquifer will allow sufficient water of suitable quality for the desired purpose to flow to a well for extraction.

Regardless of whether the supply is ground or surface water, the original source is precipitation as rain or snow. Chapter 3 discusses the hydrologic cycle, describing how water moves through the world from the ocean to the atmosphere, to land, and back to the ocean.

Ground water in Washington is an extremely important water supply. Approximately 60% of the population of Washington receives their drinking water from ground water. Virtually all of the rural population (which is about 20% of the total population) receives their drinking water from ground water. In addition, seepage from ground water to streams and lakes can contribute substantially to surface waters. Thus, ground water quality, while being most important for drinking water supplies, also affects fish and wildlife, and human recreation.

Water Quality as an Economic Issue

Degradation of water quality has an economic impact. If the degraded quality of a waterbody prevents a beneficial use, the economic value of that use is lost. For example, if stream or lake quality is impaired to such a degree that fisheries are not supported, the economic value of fishing as both recreation and a food supply is lost. Frequently the values of lost beneficial uses are difficult to estimate accurately; however, they must be considered when formulating policy or determining required actions.

The cost of degradation of domestic or industrial water supplies is more easily identified, especially if that supply is ground water. The minimum cost of individual household nitrate removal systems is in the $300 range. New domestic wells that might be required to reach a cleaner aquifer currently cost from $20-$30 a foot to drill. Note also that areas with contaminated ground water are not as attractive to new businesses that might want to relocate. And, in the worst case, home and land values may be reduced if located in an area with known water quality problems.

The assessment of economic impacts of ground water pollution, including both lost benefits and the (appropriate) cost of remediation and control, are complicated by several factors. As identified in WSU Cooperative Extension publication EB1751, *Economic Issues in Protecting Ground Water Quality,* these include:

1. Irreversibility - It may be difficult, if not impossible, and certainly takes substantial time and effort, to clean up a contaminated aquifer. As the costs of aquifer cleanup are more accurately identified (especially with the experience at Superfund sites), it becomes clearer that it is much less expensive to prevent pollution rather than have to clean up pollution.

2. Uniqueness - There may not be a substitute supply in areas where aquifers are a primary water supply. Then the cost of pollution prevention and cleanup are necessary requirements. An aquifer may be designated as a “sole-source” aquifer by the Federal Environmental Protection Agency. A sole-source aquifer is one that supplies 50% or more of an area’s drinking water and to which contamination would create a significant health hazard. There are seven sole-source aquifers in Washington:
   1) Spokane Valley-Rathdrum Prairie,
   2) Camano Island,
   3) Whidbey Island,
   4) Cross Valley,
   5) Newberg Area,
   6) Lewiston Basin,
   7) Cedar Valley.

3. Indivisibility - Aquifers serve many uses and many users. Different parts of aquifers cannot be “fenced off” like real property. If one user pollutes the aquifer, it is generally polluted for all users. Note that some contamination can be accommodated for some types of uses. Nitrate concentrations in water that preclude its use as drinking water do not adversely affect its use as an irrigation supply.

4. Uncertainty - There is some uncertainty as to what is a genuine health risk due to certain contaminants, especially for longterm exposures. Numerical limits are identified by State and Federal Law and are based on a wide variety of health-related studies. An important question is when do pollution prevention measures become required based on tests that only approach the limit. There is also uncertainty about what efforts are required to prevent pollution. Many factors governing pollution vary widely from area to area including soils, crops, topography, climate, and aquifer depth and size. Efforts that may be successful in one location may not be effective somewhere else.

5. Acceptable contamination - As stated, there are many uses and many users of ground water. What is contamination for one class of users may not be contamination for another. A continual concern for policymakers is putting too much of an economic burden on one class of users to prevent contamination for another class. This is especially important in areas of high agricultural activity where the economic viability of the region depends on the economic health of the agricultural sector.

Water Quality Law

Although there had been several previous Federal laws regarding water quality, growing concern about the degradation of the nation's water supply quality led to the passage of the Federal Water Pollution Control Act Amendments (Public Law 92-500) in 1972. This Act is more commonly known as the Clean Water Act. It has subsequently been renewed and expanded several times. The 1972 Clean Water Act is important because it was the first Federal law to focus primarily on maintaining in-stream water quality standards as the test for required reductions in polluting activities. The primary Federal mandates for protecting water quality are contained in this Act.

The U.S. Environmental Protection Agency is responsible for administering and enforcing these requirements. Most states, including Washington State, have been delegated some of these responsibilities including the administration of waste discharge permits.

There are two categories of water pollution, point and nonpoint. Point source pollution occurs when the source of the pollution is readily identifiable. Examples of point source pollution are a discharge pipe from a factory or the outlet from a city's sewage treatment plant.

Much State and Federal effort has been directed at controlling and reducing point source pollution as a result of the 1972 Act's passage. Most significant point sources now operate under discharge permits that define the conditions of the discharge. These conditions are designed to control the amount of contamination from the individual sources.

Because of the great strides in controlling point source pollution, the emphasis in recent years has switched to nonpoint source pollution. Nonpoint source pollution is diffuse. Typically it is a combination of many small, even insignificant, sources that have a significant cumulative effect on water quality. However, a specific agricultural return flow site that is fed by a large area may also be defined as nonpoint source pollution. Nonpoint source pollution is indicated by a general decline in quality of surface or ground water.

Nonpoint source pollution is usually the result of land-use activities. This includes dairies, irrigated and dryland agriculture, logging, rangeland management, and food processing (disposal of wastes). However, there are other significant sources of nonpoint pollution. These include:

1. Urban and suburban use of pesticides, herbicides, and nutrients.

2. Runoff from highways and other paved areas.

3. Maintenance of highway and railroad rights-of-way.

4. Mosquito abatement activities.

5. Naturally occurring contamination (arsenic-bearing bedrock in Snohomish County is an example of naturally occurring pollution).

Agricultural and other nonpoint sources are addressed in the federal Clean Water Act. In Washington State, comprehensive management plans were developed in 1979 under Section 208 of the Clean Water Act to address surface water impacts from nonpoint sources. These sources included dairy farms, irrigated and dryland agriculture, forest practices, and storm water runoff.

The Best Management Practice (BMP) concept was developed at this time. BMPs are defined as schedules of activities, prohibitions of practices, maintenance procedures, or other management practices to prevent or reduce the pollution of surface and ground water quality. BMPs were largely envisioned to be implemented on a voluntary basis as government funding was not then available. To date, voluntary implementation of BMPs has achieved very limited sustained success.

Section 319 of the Federal 1987 Clean Water Act amendments also required states to develop comprehensive nonpoint source pollution management plans. Funds to implement Section 319 were also authorized. The Manual, which describes practices that can help protect surface and ground water quality, was funded under Section 319.

At the state level, the Washington Water Pollution Control Act (Chapter 90.48 RCW) established state policies and requirements to protect both surface and ground water. Water quality standards for surface and ground water were also established in formal agency rule or WAC (Washington Administrative Code). WAC 173-200 addresses ground water quality and WAC 173-201A addresses surface water quality. These standards establish maximum contaminant levels (MCL) that protect the various beneficial uses.

State and Federal agencies recognize the contribution to pollution not only from agriculture, but from all of the activities identified previously. For example, Chapter 70.95 of the Revised Code of Washington (RCW) requires cities and counties throughout the state to develop local solid waste management plans. Chapter 70.105 requires development of *hazardous* waste management plans. A priority for both laws is reduction in the amount of waste that is discarded, including garden pesticides and fertilizers. Another example of response is the BMPs manual for reduction of nonpoint source pollution by forestry practices that is incorporated in the Forest Practices Rules and Regulations (WAC 173-202).

Complaints of water pollution from agricultural activities are presently being managed under a Compliance Memorandum of Agreement between the Washington Department of Ecology (Ecology), local conservation districts, and the Washington State Conservation Commission. The local conservation district disseminates information developed as a result of nonpoint source pollution planning. In the case of a water pollution complaint, Ecology first investigates the complaint. If a pollution problem is verified, the farm is required to correct the problem. The local conservation district is available to provide assistance to the farm to develop a conservation plan and address the problem source. This is currently occurring with dairy farms and may become more common on irrigated farms if contamination of water from irrigated agriculture is seen as a problem.

Assessment of Water Quality

A 1987 amendment to the 1972 Federal Clean Water Act required all states to assess water quality and develop a program for nonpoint source pollution. Ecology is responsible for carrying out this mandate in Washington. It published the *Nonpoint Source Pollution Assessment and Management Program* in October 1989 (1989 Management Program).

The 1989 Management Program reported the results of Ecology's assessment of water quality in the state as well as the developed management program. The assessment program included:

1. Identifying and characterizing waterbodies of the state - The surface waterbodies are defined as coastal waters, estuaries, rivers, lakes, or wetlands. These waterbodies may be classified as Class AA, Class A, Class B, Class C, or Lake depending on the number and type of beneficial uses supported. Table 2-1, taken from the Assessment and Management Program document, lists the beneficial uses and shows how the Class designation declines as the number and type of beneficial uses become restricted.

2. Identifying the beneficial uses associated with waterbodies - Beneficial uses include domestic and livestock water supplies, industrial uses, irrigation, fish habitat, wildlife habitat, recreation, and navigation.

3. Developing water quality standards to protect beneficial uses - Numerical water quality criteria are needed to provide benchmarks for protection. As water quality test results approach or exceed the standards, regulations may force certain actions to alleviate the contaminating activity. Table 2-2, also taken from the Assessment and Management Program document, is a summary of numerical water quality criteria for the various parameters used to define a waterbody class. Note that as the amount of bacteria, temperature, pH, and turbidity goes up, and as the amount of dissolved oxygen goes down, the waterbody rating goes down.

4. Testing for exceedance of water quality standards.

Ecology now gathers all available information concerning water quality in the state and reports it every two years. The latest report was *1992 Statewide Water Quality Assessment* (1992 Assessment).

Table 2-1. Beneficial uses by Waterbody Classification (Table 2-2 in *Washington Nonpoint Source Assessment and Management Program,* published by Department of Ecology, October 1989)

Beneficial Use	AA	A	B	C	LAKE
WATER SUPPLY					
Domestic	X	X	-	-	X
Industrial	X	X	X	X	X
Agricultural	X	X	X	-	X
Stock Watering	X	X	X	-	X
FISH AND SHELLFISH					
Salmonids					
Spawning	X	X	-	-	X
Rearing	X	X	X	-	X
Migration	X	X	X	X	X
Harvesting	X	X	X	-	X
Other Fish					
Spawning	X	X	-	-	X
Rearing	X	X	X	-	X
Migration	X	X	X	X	X
Harvesting	X	X	X	-	X
FISH AND SHELLFISH					
Clams, Oysters & Mussels					
Spawning	X	X	X	-	X
Rearing	X	X	X	-	X
Harvesting	X	X	-	-	X
Crustaceans & Other Shellfish					
Spawning	X	X	X	-	X
Rearing	X	X	X	-	X
Harvesting	X	X	X	-	X
WILDLIFE HABITAT	X	X	X	X	X
RECREATION					
Primary Contact	X	X	-	-	X
Secondary Contact	X	X	X	X	X
NAVIGATION	X	X	X	X	X

Table 2-2. Water Quality Criteria by Classification (Table 2-3 in *Washington Nonpoint Source Assessment and Management Program,* published by Department of Ecology, October 1989)

Parameter	AA	A	B	C	LAKE
BACTERIA (organisms/100mL)					
Freshwater	50.0	100.0	200.0	N/A	50.0
Marine	14.0	14.0	100.0	200.0	N/A
DISSOLVED OXYGEN (mg/L)					
Freshwater	9.5	8.0	6.5	N/A	**
Marine	7.0	6.0	5.0	4.0	N/A
TEMPERATURE (degrees C)					
Freshwater	16.0	18.0	21.0	N/A	**
Marine	13.0	16.0	19.0	22.0	N/A
pH					
Freshwater	6.5-8.5	6.5-8.5	6.5-8.5	N/A	**
Marine	7.0-8.5	7.0-8.5	7.0-8.5	6.5-9.0	N/A
TURBIDITY (NTU)	5.0	5.0	10.0	10.0	5.0
TOXICITY— See Chapter 173-201 WAC for specific numerical and narrative criteria ——					

** No change from background*

Summary of 1992 Statewide Water Quality Assessment

Figures 2-1 through 2-9 are from the 1992 Assessment. Figure 2-1 summarizes results for rivers and streams. Note that only 14% of total stream miles in Washington were assessed. However, 46% of the assessed mileage was found to not support designated uses. Another 6% was threatened. Figures 2-2 and 2-3 show the major causes impairing the use and the sources of contaminants in rivers and streams.

> *The term "threatened waterbody" is used to describe a waterbody that currently supports its beneficial uses but may not in the future due to nonpoint source pollution. A threatened waterbody could be a river used for primary contact recreation (swimming) that would likely be polluted by nearby septic tank systems or other pollution source in the future.*

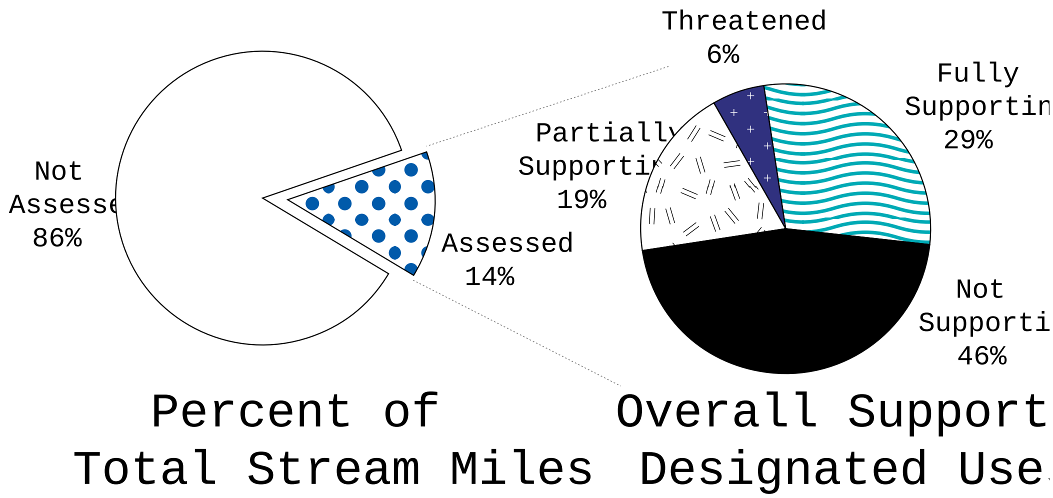


FIGURE 2-1. Percent of Stream Miles Assessed and Summary of Overall Support for Designated Uses

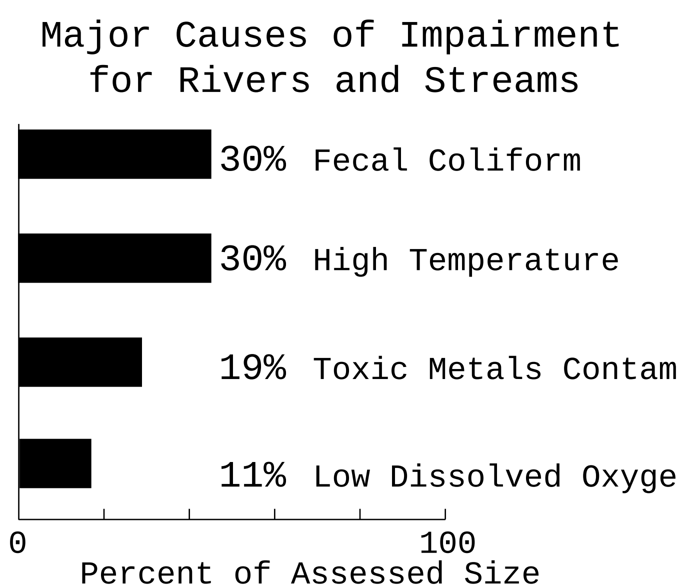


FIGURE 2-2. Major Causes of Impairment for Rivers and Streams

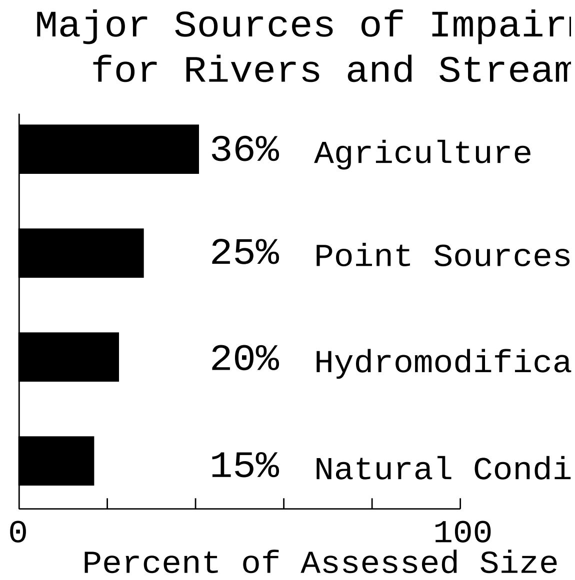


FIGURE 2-3. Major Sources of Impairment for Rivers and Streams

Figure 2-4 summarizes results for estuaries. Here, 37% of the total area designated as estuary was assessed and 54% of that area did not support beneficial uses. Another 13% was categorized as threatened. Figures 2-5 and 2-6 show the major causes impairing the use and the sources of contaminants in estuaries.

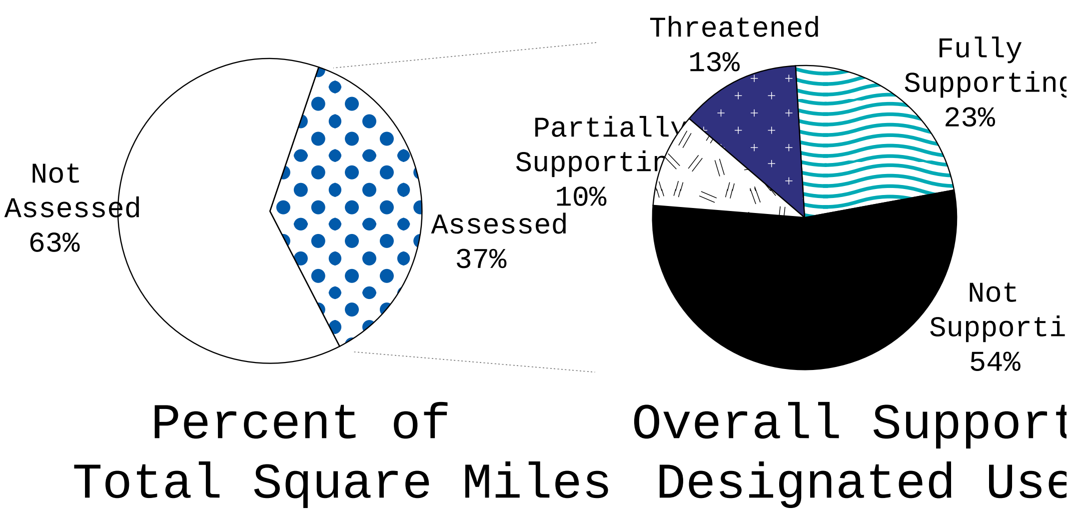


FIGURE 2-4. Percent of Square Miles Assessed and Summary of Overall Support for Designated Uses of Estuaries

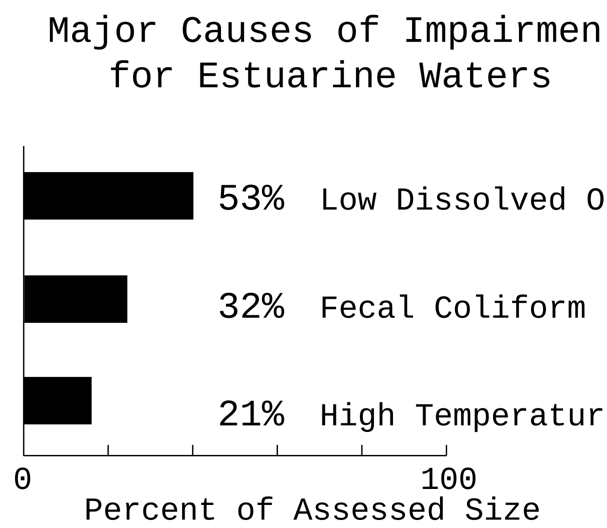


FIGURE 2-5. Major Causes of Impairment for Estuaries

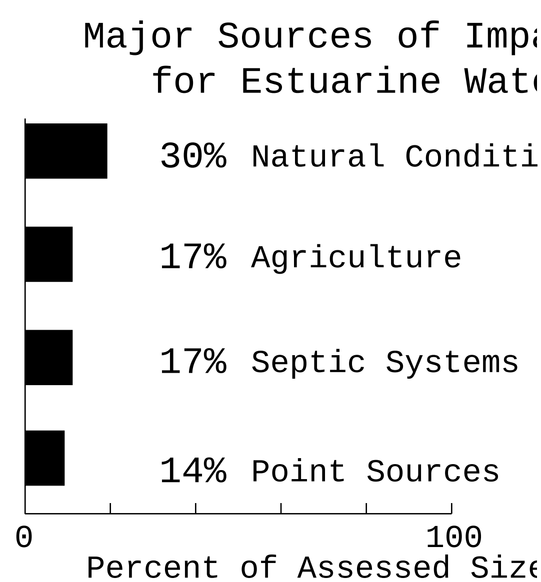


FIGURE 2-6. Major Sources of Impairment for Estuaries

Figure 2-7 summarizes results for lakes. Here, 13% of the total area was assessed and 27% of that area did not support beneficial uses. Another 5% was categorized as threatened. Figures 2-8 and 2-9 show the major causes impairing the use and the sources of contaminants in lakes.

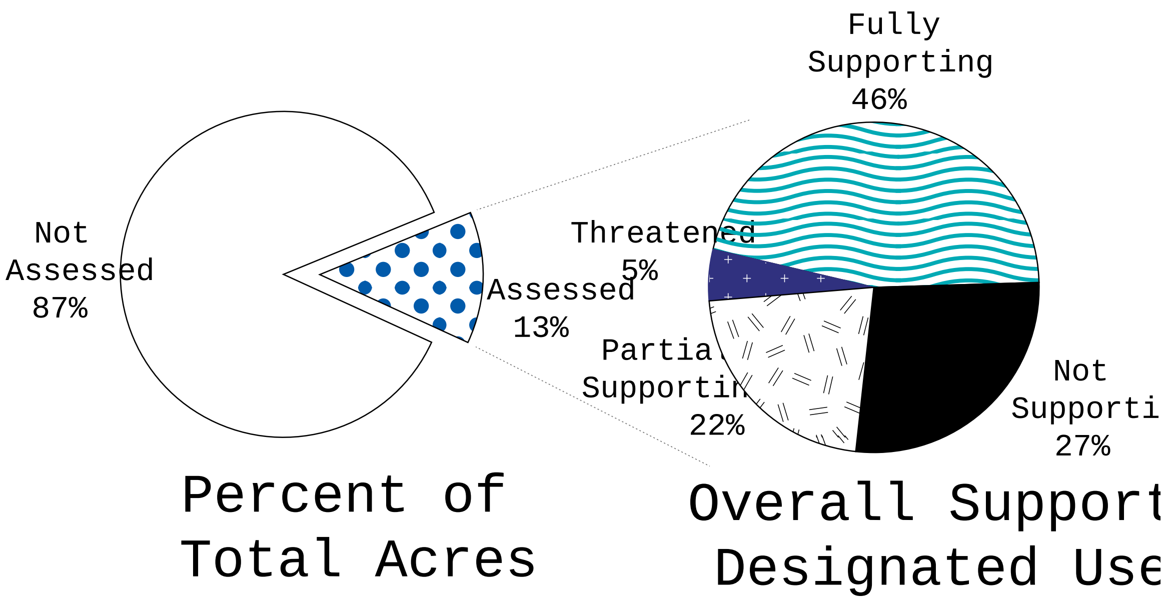


FIGURE 2-7. Percent of Acres Assessed and Summary of Overall Support for Designated Uses of Lakes

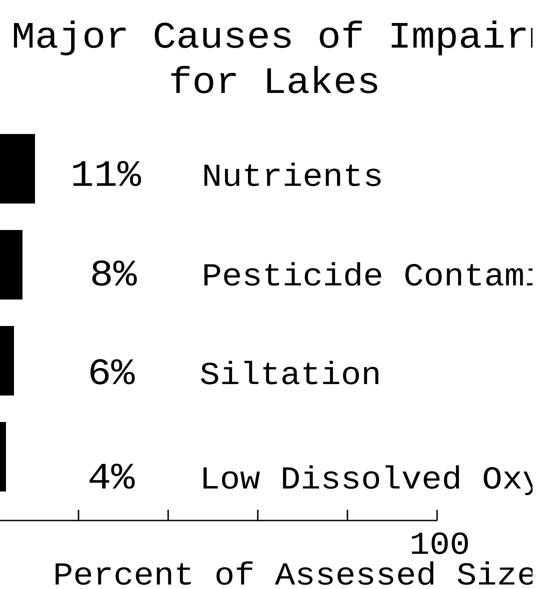


FIGURE 2-8. Major Causes of Impairment for Lakes

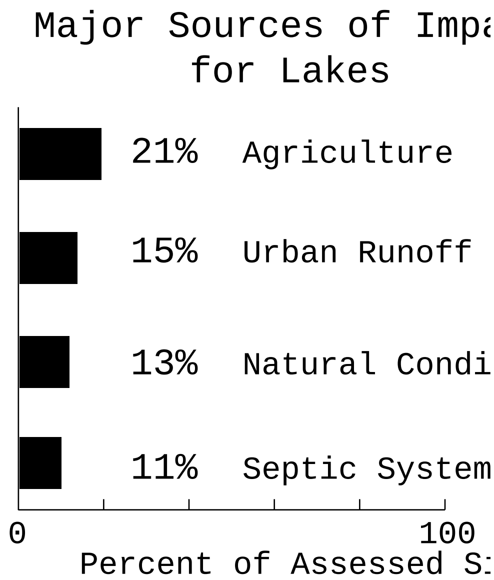


FIGURE 2-9. Major Sources of Impairment for Lakes

Standards for ground water quality

Standards for ground water quality in Washington State are set by WAC 173-200. It includes a table of contaminant criteria for primary and secondary contaminants, radionuclides, and carcinogens. In addition, it explains the enforcement limit as the "... value assigned to any contaminant for the purposes of regulating that contaminant to protect existing ground water quality and to prevent ground water pollution." Enforcement limits are to be met at the "point of compliance," the place where the enforcement limit shall be measured and not exceeded. Enforcement limits are set based on a number of considerations. Four of the nine listed are:

1. The anti-degradation policy of Washington State.
2. Overall protection of human health and the environment.
3. Protection of existing and future uses.
4. "Any other considerations the department [Department of Ecology] deems pertinent to achieve the objectives of this chapter."

The Chapter discusses "early warning values." The purpose of an early warning value is to "provide early detection of increasing contaminant concentrations that may approach or exceed enforcement limits." If a contaminant is detected at the point of compliance and exceeds the early warning value, a permit holder or other responsible person must notify Ecology within 10 days of the detection.

The Chapter provides that a ground water quality evaluation program will be required when Ecology determines that an activity has the potential to pollute. An approved evaluation program will have the ability to assess impacts on ground water at the point of compliance.

The Chapter also defines “special protection areas” where ground water requires special consideration or increased protection due to a number of possible reasons. An area may be designated as a special protection area if it is a sole-source aquifer.

An important concept embodied throughout the Chapter is “. . . all known, available, and reasonable methods of prevention, control and treatment . . . ,” known by the acronym AKART. For example, in setting enforcement limits, the Chapter states, “All enforcement limits shall, at a minimum, be based on all known, available, and reasonable methods of prevention, control and treatment.” When discussing the approval of quality evaluation programs the Chapter states, “. . . the evaluation program...shall include information on . . . the reliability of all known, available, and reasonable methods of prevention, control and treatment . . . . ” And finally, when discussing implementation and enforcement of the ground water quality standards, “This chapter shall be enforced through all legal, equitable, and other methods available to the department including, but not limited to . . . evaluation of compliance with all known, available, and reasonable methods of prevention, control, and treatment of a waste prior to discharge . . . . ”

The Practices presented in the Manual, if implemented correctly and appropriately, are intended to accomplish the purposes of AKART. However, it is important to note that implementation of one or more of the Practices may not be sufficient to protect water quality to the degree necessary.

Assessment of ground water quality

Assessment of ground water quality is difficult as Washington does not have a comprehensive ground water monitoring program. However, what information is available indicates that pollution of ground water, either real or potential, is a serious concern. This concern is highlighted by the fact that approximately 60% of the state’s population receives its drinking water from ground water sources.

For example, a pilot testing program in the late 1980s in Yakima, Franklin, and Whatcom Counties tested 27 wells in each County for 46 pesticides and nitrate contamination. Of the 81 wells tested, 23 tested positive for at least one of the pesticides and seven exceeded drinking water standards. Sixty-one of the wells tested positive for nitrates, at concentrations ranging from .10 to 24.4 mg/L, and 18 exceeded the 10 mg/L standard for drinking water.

Results from a study of ground water quality near Gleed (located about 5 miles northwest of Yakima) were released by Ecology in December 1992. Twenty-seven wells were sampled and analyzed for 74 compounds. Xylene was detected in five of the wells, arsenic in 13 of the wells, copper in 23 wells, and lead in 11. Nitrate plus nitrite-nitrogen was found in all tested wells at a mean concentration of 2.9 mg/L. However, none of the chemical concentrations exceeded drinking water standards. Also, sources of the chemicals could not be identified.

The results of a study of ground water quality in the Quincy area were released by Ecology in March 1993. Twenty-seven wells and two field drains were sampled in May 1991. One or more pesticides was detected in 26 of the wells and both drains. Ethylene dibromide was found at 62% of the sites and concentrations exceeded drinking water standards in nine wells and one drain. Concentrations of nitrate plus nitrite-nitrogen exceeded drinking water standards in two wells.

Blanket statements concerning ground water quality in all Washington aquifers cannot be made. However, identified contamination of some ground water resources can be taken as a warning concerning other aquifers in similar situations.

Overall Strategy for Reduction of Nonpoint Source Pollution

As previously stated, and as partially listed in Table 2-2, there are adopted water quality standards (WAC 173-201A) that protect the beneficial uses of surface waterbodies. These standards are intended to protect water quality, not to react to water pollution. The standards incorporate a portion of existing state law termed the anti-degradation policy (WAC 173-201-035(a)). This policy strictly forbids the degradation of water that would preclude its beneficial uses of drinking water, irrigation, and wildlife habitat.

Note that this is not a policy of *non-degradation.* As indicated by Table 2-2, some level of contamination is allowed, even of drinking water.

The overall strategy for protecting waterbodies is based on technology. If land-use activities are the primary causes of nonpoint source pollution, then modification of these activities should reduce the pollution. Thus, the strategy depends on the implementation of practices that will minimize contaminating activities. These practices have generally been termed “best management practices.” In the Manual they are referred to as “Implementation Practices” and are presented in Chapter 4.

Other parts of the strategy include technical assistance, education programs, and enforcement of state and local regulations. Enforcement and regulatory tools include the following:

1. State Water Pollution Control Act - This is Chapter 90.48 of the Revised Code of Washington. This Act authorizes the administration of programs mandated by the Federal Clean Water Act and also establishes the anti-degradation policy.

2. Water Quality Standards - Chapters 173-200 and 173-201A of the Washington Administrative Code set the numerical criteria for ground water and the various classes of surface water in the state. They are established to protect current and potential uses of the water. Action must be taken if testing shows that the waterbody is threatened or impaired. They specify that “all known, available, and reasonable methods of prevention, control, and treatment” will be implemented for those activities with the potential to pollute water. These methods are known under the acronym of AKART. AKART must be used no matter what the quality of the receiving water. Further, if existing AKART are not sufficient to protect water quality, additional controls must be used.

3. State Environmental Policy Act - This Act requires consideration of impacts on the environment by significant activities. These activities may be construction projects or implementation of policies, plans, ordinances, or regulations.

4. Shoreline Management Act - Chapter 90.58 of the Revised Code of Washington establishes a policy of . . . “protecting against adverse effects to the public health, the land and its vegetation and wildlife, and the waters of the state or their aquatic life.” Shorelines where the mean annual flow is less than 20 cubic-feet-per-second are exempt from regulation under this Act.

5. Coastal Zone Act Reauthorization Amendments - In 1990, Congress amended the original Coastal Zone Act of 1972. The amendments specifically charge the various States and Territories to address nonpoint source pollution in their water quality programs. Section 6217(b) of the Amendments states that the State programs " . . . provide for the implementation, at a minimum, of management measures in conformity with the guidance published under subsection (g) to protect coastal waters generally." "Management measures" are defined in section 6217(g)(5) as:

> economically achievable measures for the control of the addition of pollutants from existing and new categories and classes of nonpoint sources of pollution, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint source pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives.

Examples of specific State regulations are WAC 16-200-742 which governs application of fertilizers through irrigation systems and WAC 16-228-232 which governs applications of pesticides through irrigation systems.

State agencies with regulatory authority or responsibility, or who are developing water quality management programs, include Department of Ecology, Department of Agriculture, Department of Fisheries and Wildlife, Department of Natural Resources, Department of Health, Department of Transportation, Parks and Recreation Commission, and Conservation Commission.

Major Federal agencies that are involved in regulatory actions or educational, financial, and technical assistance include Soil Conservation Service, Agricultural Stabilization and Conservation Service, Forest Service, Bureau of Land Management, Bureau of Reclamation, and Environmental Protection Agency.

Washington State University Cooperative Extension is a State agency, partially funded by the Federal government, that performs research and develops and implements educational programs.

Specific Strategy for Protection of Ground Water Quality from Agricultural Activities

The State's strategy for controlling and reducing nonpoint source pollution was published by the Department of Ecology in October 1989 in a document titled *Nonpoint Source Pollution Assessment and Management Program* (the 1989 Management Program). This document addressed nonpoint source pollution of both ground and surface waterbodies from all activities. A subsequent joint effort between several State and Federal agencies and the agricultural community culminated with the publishing of *Protecting Ground Water: A Strategy for Managing Agricultural Pesticides and Nutrients* (the Strategy document) in 1992. The Strategy document lays out the strategy developed by the group for protecting ground water from pollution by agricultural activities (the Strategy).

Participating agencies included Washington State Departments of Ecology, Agriculture, Natural Resources, and Health, Washington State University Cooperative Extension, Washington State Conservation Commission, Washington State Water Research Center, United States Department of Agriculture, and Environmental Protection Agency. Also involved were independent scientists, businessmen, agriculturalists, environmentalists, and laypersons.

Included in the general strategy statement were two priorities:

1. support for statewide education and technical assistance programs.

2. support for expanded programs in areas with highly vulnerable ground waters.

Regulatory enforcement was also recognized as part of the strategy. However, it was felt that the need for enforcement is minimized by effective involvement of local agricultural communities and providing the information necessary for voluntary compliance in the anti-degradation activities. The strategy seeks a partnership between regulatory agencies and the agricultural community.

An example of this aspect of the strategy is WAC 16-228-232 which governs fertigation. This regulation was promulgated with input from agriculturalists. It clearly defines the approved hardware for applying fertilizers through irrigation systems. Thus, growers know that by following this regulation they are abiding by the law and protecting water quality at the same time.

General principles are identified which set the overall goals of the strategy. These include:

1. Prevention of contamination is the primary goal of the strategy - “No ground waters of the state will be regarded as unworthy of protection.”

2. Existing programs and structures provide an appropriate framework for action - However, the strategy calls for coordination of different agencies’ programs, improved information management, sufficient funding for research and education, and timely implementation of programs.

3. Protection of ground water is inseparable from other issues in the agricultural community - Importantly this includes the “economic viability of farms and the farming community.”

4. Surface and ground waters are integral parts of the same hydrologic system - Efforts to protect surface water must not adversely impact ground water and vice versa.

5. An effective means of reducing impacts of agricultural chemicals on the environment, including ground water, is to place the use of chemicals within the context of integrated and sustainable approaches to crop and animal management - Minimizing the use of chemicals will reduce the pollution potential.

6. The state should set priorities in order to make effective use of fiscal and human resources - Valuable and endangered water supplies should be identified so that the available government funding can be used effectively.

The General Principles lead to the Objectives of the strategy:

A. Coordination among agencies both in overall planning and in implementing activities of the strategy.

B. Development of tools needed by agencies for effective management of information and for evaluation of programs.

C. Identification and evaluation of agricultural practices and other measures to protect ground water from degradation by agricultural activities.

D. Effective implementation of measures to protect ground water from degradation by agricultural activities.

E. Effective and appropriate enforcement to ensure that voluntary efforts to protect ground water quality are not undermined.

F. Generation of adequate funding to implement recommended activities.

Objectives C and D of the strategy are addressed, in part, by the Manual. The Manual identifies Overall Management Objectives for irrigated agriculture that, if achieved, will reduce potential ground and surface water pollution. Implementation Practices that will help achieve those Overall Management Objectives are also presented. Education and dissemination of this information is one means of encouraging Growers to adopt those practices deemed applicable to their situation.

Identification of Practices to Protect Surface and Ground Water Quality

Previous efforts to identify practices that will help protect surface and ground water quality from agricultural land-use included the *208 Irrigated Agriculture Water Quality Management Plan.* This was a two-year planning effort mandated by Section 208 of the 1972 Federal Clean Water Act. As a part of this Plan, *Management Practices for Irrigated Agriculture* was published by Ecology in 1979 (DOE Publication #79-5B-1). This publication was a listing of best management practices for irrigated agriculture which would help in protecting surface water quality.

Surface and ground waters are interrelated as recognized by the ground water protection strategy discussed previously (see General Principle 4). Ground water is surface water (lakes, rivers, streams, or overland flow) that has percolated into and through the ground to an aquifer. Ground water may move back into surface waterbodies through seeps, springs, or base flow into a river or lake depending on the geology of an area. Contaminated ground water can move into uncontaminated aquifers or return to surface water, depending on the geology.

The Manual is a response to Section 319 of the Federal Clean Water Act which mandates development of programs for control and reduction of nonpoint source pollution of both surface and ground water. The Overall Management Objectives and Implementing Practices presented in the Manual also address Objective C of the specific strategy for protection of ground water from the activities of irrigated agriculture. The Manual addresses the interrelationship of ground and surface water and the concurrent impact of irrigated agriculture on them. In that sense the Manual also addresses General Principle 4 of the specific strategy, that is, protecting surface water must not adversely affect ground water and vice versa.

It is important to note that the Overall Management Objectives and Implementing Practices presented in the Manual may not be sufficient to absolutely protect ground or surface water quality depending on the situation. Measures beyond the implementation of the Practices presented in the Manual may sometimes be necessary to protect water quality.

Listings of best management practices for other sources of nonpoint source pollution are identified in Table 2-3, from Ecology's 1989 Management Program document.

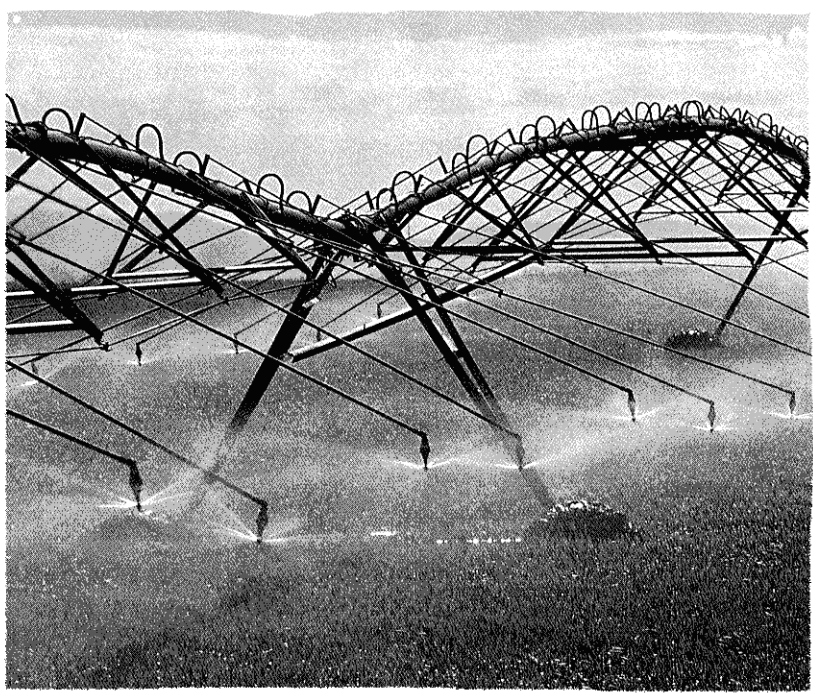


Table 2-3. Sources for Best Management Practice Lists (Table 3-1 in *Nonpoint Source Pollution Assessment and Management Program*, published by Department of Ecology, October 1989)

SOURCE CATEGORY	AGENCY[1]	ORIGIN
AGRICULTURE		
Dairy waste	CDs/Ecology	CWA "208" Plan
Dryland	CDs/Ecology	"
Irrigated	CDs/Ecology	"
Noncommercial	Ecology	Informal Guidance
FOREST PRACTICES	Forest Practices Board/Ecology	CWA "208" plan; Forest Practices Rules and Regulations (WAC 173-202)
RANGELAND	CDs/CC	Informal Guidance
STORMWATER	Ecology	Development in progress
CONSTRUCTION		
Land development	Ecology	Guidelines
Highway runoff	WDOT	Highway Water Quality Manual
RESOURCE EXTRACTION	DNR	Surface Mining Act (Chapter 78.44 RCW)
LAND DISPOSAL		
On-site sewage treatment	State Board of Health/DOH	On-site System Rules (Chapter 248.96 WAC)
Landfills	Ecology	State Solid Waste Management Act (Chapter 70.95 RCW) Recycling Program
Land treatment	Ecology	Guidelines
HYDROLOGIC MODIFICATION	WDF (Chapter 75.20 RCW)	Hydraulics Code
OTHER		
Boats and marinas	Parks	Development in progress
Storage tanks	DL&I	Uniform Fire Code (Chapter 19.27 RCW)

[1] Agency abbreviations
CDs - conservation districts
Ecology - Washington State Department of Ecology
CC - Washington State Conservation Commission
WDOT - Washington State Department of Transportation
DNR - Washington State Department of Natural Resources
DOH - Washington State Department of Health
WDF - Washington State Department of Forestry
Parks - Washington State
DL&I - Washington State Department of Labor and Industry

CHAPTER 3.

3 CHAPTER

BACKGROUND SCIENCE OF WATER POLLUTION

Purpose

The purpose of this chapter is to discuss certain aspects of the process of surface and ground water contamination. It will describe how an applied pesticide or nutrient, or soil itself, can become a contaminant. The major nutrients nitrogen and phosphorus will be examined in detail to show how they can move from the agricultural root zone to contaminate ground and surface water.

The basics of soil-water-plant relationships will be discussed since deep percolation or surface runoff from irrigation or rainfall are the prime transporters of contaminants. (Soil-water-plant relationships describe how water moves into the soil, is stored by the soil, moves in the soil, or is taken up by the crop and evaporated back to the atmosphere.)

Finally, there is a summary discussion of salinity in irrigated agriculture and the need for some level of intentional deep percolation to maintain agriculture's economic and physical viability.

Pollution Process

Pollution is the result of a series of processes. These can be generally categorized as availability, detachment, and transport.

1. Availability - There is a potentially polluting substance in some amount and in some place. The potential pollutant could be sediment (from a highly erosive soil), nutrient (excess fertilizer in or on the soil, or from mineralization of crop residues), pesticide, bacteria, or some other harmful matter.

2. Detachment - The potential pollutant or its environment is modified so that the substance can be moved from where it is supposed to be to where it should not be. For example, a pesticide is sprayed on a field. The residue adsorbs to soil particles. Due to excess irrigation or rainfall, or just a highly erosive soil in a high wind, the soil particles separate from the rest of the field. That is detachment.

   A substance dissolving into water or changing form may also be considered a form of detachment since in many cases the substance will move readily with percolation. This type of detachment may or may not result in significant pollution depending on the substance. For example, the ammonium form of dissolved nitrogen (NH_4^+) does not move readily with water while the nitrate (NO_3^-) form is highly leachable.

Hereafter, when the term “detachment” is used, it implies one of the following:

a. a physical separation of soil particles (with or without adsorbed chemicals or nutrients),

b. the dissolving of a substance that allows it to move readily with surface runoff or deep percolation. The surface runoff or deep percolation could be the result of natural rainfall or irrigation or,

c. the transformation of a chemical that allows it to move readily with surface runoff or deep percolation.

3. Transport - Transport is the movement of a contaminant to a place where it may be harmful. For example, a soil particle carrying pesticide residues is carried from a field by surface runoff from irrigation, or rainfall, or high winds. Runoff transporting the sediment can contaminate a river or lake. Another example is nitrate (NO_3^-) fertilizer leached into ground water through over-irrigation (intentional or not), to possibly degrade water quality.

To summarize, contamination of water occurs through availability, detachment, and transport. For contamination to occur, contaminants must be available at the source of supply. Mechanisms with strong forces separate (detach) contaminants from the source and move (transport) them to a water resource where they may harm people or the environment.

Reduce potential pollution by:

1. Minimizing availability of the potential pollutant in the environment.

2. Minimizing detachment of the substance.

3. Minimizing transport of the substance.

Some of the major potential pollutants will now be examined to see how they become real pollutants. The words “fate” and “destination” will be used often. These words refer to the end point of substance movement. That is, does the chemical break down into different compounds or does it persist? If it persists, does it stay on the field or is it detached and transported to a surface water body? For example, is applied nitrogen taken off the field as harvested crop? Or, is it leached to ground water as nitrate nitrogen?

To minimize the ***undesirable*** effects of applied chemicals and fertilizers, it is important to understand ***all*** effects.

WSU Cooperative Extension bulletin EB1722, *How Fertilizers and Plant Nutrients Affect Ground Water Quality*, (published January 1993) contains a detailed discussion of common plant nutrients and their pollution potential.

3 CHAPTER

Nitrogen as a Potential Pollutant

Nitrogen is the most critical of the essential elements for plant growth. The addition of nitrogen fertilizer to enhance crop growth is basic to modern irrigated agriculture. The ultimate source of this nitrogen is the inert gas N_2 which makes up about 78% of the atmosphere. However, except for legumes, plants cannot use nitrogen in this form. Most plants use nitrogen in either the ammonium (NH_4^+) form or the nitrate (NO_3^-) form. Both occur in solution. However, the nitrate (NO_3^-) form is much more leachable than the ammonium (NH_4^+) form.

Nitrogen is added to the soil in a number of ways:

1. Lightning may cause the formation of the nitrate (NO_3^-) form which falls to earth with rainfall.

2. Legumes such as alfalfa, soybeans, and clover can convert atmospheric N_2 into usable form through "rhizobia" bacteria. Rhizobia exist in a symbiotic (mutually beneficial) relationship with the crop. They form and inhabit nodules (abnormal growths) on the root systems of legumes. This process is termed "symbiotic fixation."

3. "Non-symbiotic fixation" occurs through some types of blue-green algae and what are known as "free-living" bacteria. These require no other plants for existence. The amount of nitrogen fixed by non-symbiotic fixation is relatively small, with estimates in the range of ten pounds/acre annually.

4. By far, the most important sources of plant-available nitrogen are through addition of commercial fertilizer and manure.

The disposition of nitrogen that enters the soil is a complex process with many possible avenues as indicated in Figure 3-1.

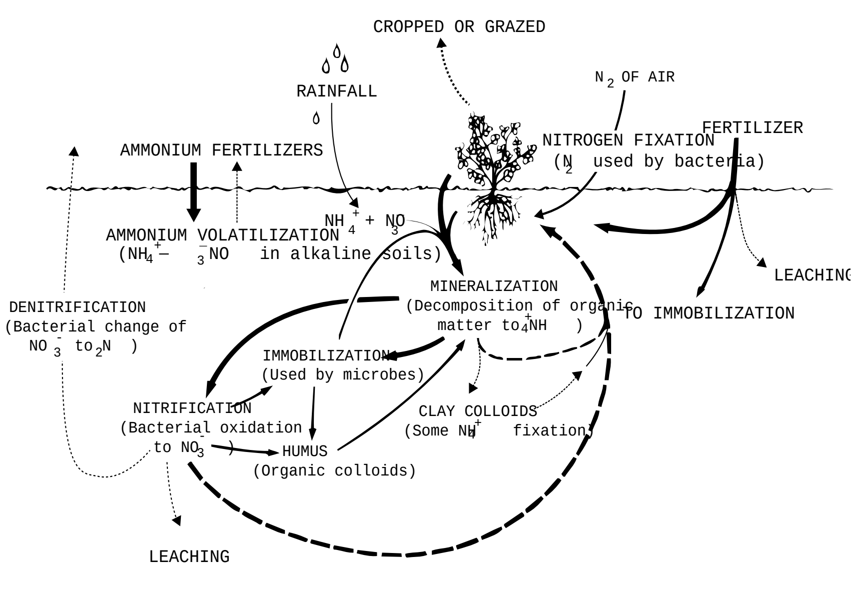


FIGURE 3-1. The nitrogen cycle, showing the different ways that nitrogen enters and leaves the soil.

The nitrogen cycle, shown schematically in Figure 3-1, is the name given to the movement of nitrogen in its different forms from the atmospheric gas N_2 into the soil in some form or another and then back to the atmosphere. Some of the more important processes that occur are:

1. Fixation - addition of nitrogen to the soil through the symbiotic action of rhizobia bacteria on the root systems of legumes or by other microorganisms (non-symbiotic) in the soil and water.

2. Mineralization - the breakdown of soil organic matter by the activity of microbes. Mineralization converts organic nitrogen to the ammonium (NH_4^+) form, which is available to the plant.

3. Nitrification - the conversion of the ammonium (NH_4^+) form to the nitrate (NO_3^-) form. Nitrification is the result of activity by soil bacteria. Nitrate (NO_3^-) nitrogen is readily available to plants. However, nitrate (NO_3^-) nitrogen is also readily leached since it stays in solution and does not adhere to soil particles. Nitrification is a relatively quick process. Nitrogen added to the soil via commercial fertilizer in the ammonium form can be transformed to the nitrate form within one to two weeks if conditions are favorable.

4. Immobilization - the conversion of inorganic nitrogen in organic matter which occurs when carbon is added to the soil. Plant residues are the chief source of this carbon. However, as the decomposition of plant residues continues, nitrogen is again released through mineralization as explained previously.

5. Denitrification - conversion of nitrate (NO_3^-) nitrogen into the atmospheric gas N_2 by soil bacteria in wet, poorly aerated conditions, such as would be found in water-logged, heavy soils. This process can also occur relatively rapidly but requires decomposing organic matter as a carbon source.

6. Volatilization - the movement of nitrogen in the form of ammonia gas to the atmosphere. Volatilization occurs when ammonium (NH_4^+) forms of nitrogen are applied to the soil surface and not properly worked into the soil. Volatilization increases with high temperatures and calcareous soils. Lack of rain following the application and high amounts of crop residue also increase the process.

7. Leaching - the movement of the nitrate (NO_3^-) form below the crop's root zone. Both the ammonium (NH_4^+) and nitrate (NO_3^-) forms will leach. However, the nitrate (NO_3^-) form is highly soluble and thus, is more readily leachable. Leaching occurs with deep percolation, the movement of soil water below the root zone. Unfortunately, many times, leachate moves to an aquifer and contaminates ground water.

An example of a path in the nitrogen cycle that includes the use of commercial fertilizer is:

1. Conversion of atmospheric N_2 into the ammonium (NH_4^+) form by a commercial fertilizer manufacturer.

2. Addition of the ammonium (NH_4^+) fertilizer to the soil by a grower.

3. Immediate uptake of some of the ammonium (NH_4^+) nitrogen by the plant.

4. Nitrification of some of the ammonium (NH_4^+) nitrogen into the nitrate (NO_3^-) form.

5. Uptake by the plant of nitrogen in the nitrate (NO_3^-) form.

6. Leaching of the nitrate (NO_3^-) to ground water as the result of heavy rainfall.

7. Reapplication of the nitrate (NO_3^-) nitrogen to the field through irrigation water supplied by a deep well pumping from the ground water.

8. Denitrification of the nitrate (NO_3^-) nitrogen back into atmospheric nitrogen gas (N_2).

9. Loss of organic nitrogen from the soil by crop harvest.

10. Mineralization of remaining crop organic matter.

Contamination of ground water aquifers by nitrate (NO_3^-) nitrogen can be a serious problem in areas of irrigated agriculture due to the large amounts of nitrogen fertilizer that are normally used to ensure satisfactory yields. The potential for nitrate contamination depends on several factors:

1. Soil texture and structure - coarse sandy soils do not hold as much water as finer clays and have higher permeabilities. Thus, any over-irrigation results in large amounts of leaching water. However, many soils are stratified due to either different texture (clay lenses) or structure (“plow-pans”). Leaching may be constrained in the root zone if there are restricting layers.

2. Timing and amount of irrigation and rainfall - over-irrigation, or unexpected rainfall create deep percolation, with the concurrent risk of nitrate leaching. It is important to control irrigation as much as possible.

3. The amount of nitrate (NO_3^-) nitrogen in the soil at the time of deep percolation - thus, it is important to minimize the amount of available nitrate (NO_3^-) nitrogen, subject to sound agronomic practices for maintaining yields.

It is important for the grower to know how much nitrogen is needed by the crop, what stage(s) in the growth cycle this nitrogen is needed, how much nitrogen is in the soil and the irrigation water and in what form, and how much water is required per irrigation.

Phosphorus as a Potential Pollutant

Phosphorus is another important element for plant growth. Like nitrogen it is a common component of commercial fertilizer. However, the “phosphorus cycle” is much different from the nitrogen cycle. The key difference is that while plants take up phosphorus in a soluble form, usually H_2PO_4 or HPO_4, the amount of phosphorus in solution is usually very small. Also, phosphorus does not move readily with soil water.

Organic forms of phosphorus, crop residues for example, can be converted to available inorganic forms through mineralization. This occurs with the breakdown of the organic material. Mineralization progresses more rapidly in warm, well-drained soils. However, the most significant source of phosphorus in agricultural soil is commercial fertilizer and manure.

There may be little phosphorus in solution and that will be largely fixed in place. One implication is that phosphorus fertilizer should be added to the soil very near the point of anticipated plant uptake because the phosphorus will not move with soil water. And since little phosphorus moves with soil water, leaching of phosphorus to ground water is not a large concern under most conditions. However, pollution of surface waters by phosphorus from direct runoff and sedimentation is a serious problem since the phosphorus readily adsorbs (adheres) to soil particles.

In summary, phosphorus pollution occurs mainly in surface waters. Reducing the pollution due to the activities of irrigated agriculture is mainly a matter of preventing erosion or removing sediment from surface runoff.

Other Nutrients as Potential Pollutants

Plants require many nutrients besides nitrogen and phosphorus for proper growth. These are often referred to as microelements or micronutrients. Examples are potassium, zinc, boron, and magnesium. Normally, none are as much a concern as nitrogen or phosphorus in terms of potential pollution. However, whenever site conditions include very coarse-textured soils overlaying a shallow aquifer there should be extra precautions against leaching of nutrients and other chemicals.

When micronutrients are applied as a foliar spray, care should be taken to minimize wind drift. Foliar sprays should be avoided if weather conditions indicate a strong chance of rain.

Pesticides as Potential Pollutants

Pesticides refer to chemicals that are applied to control insects, weeds, or plant diseases. Applied pesticides may evaporate, be carried off the field attached to soil particles or in solution, be broken down into other substances, or taken up by plants or insects. The primary factors that decide the chemical's fate are the pesticide properties, the soil properties, site conditions, and the application practices.

The important pesticide properties include adsorptivity, degradation rate, solubility, and volatility.

1. Adsorptivity - a measure of how strongly the chemical bonds to soil particles. The higher the adsorptivity, the less likely it is that the chemical will be leached through the root zone. However, high adsorptivity means that chemicals can move with sediment during soil erosion.

2. Degradation rate - a measure of how fast the chemical breaks down into other chemicals. The longer it takes for a chemical to break down, the more opportunity there is for detachment and transport. Breakdown may occur through a reaction with water (hydrolysis), through exposure to sunlight (termed photolysis), or through reactions with microorganisms. If a chemical does leach to ground water it will last a long time if slowly degradable. The degradation rate is reduced by low temperatures, no exposure to sunlight, and no exposure to microorganisms (which occur mostly in the root zone).

3. Solubility - a measure of how well the chemical dissolves in water. A highly soluble chemical can move readily with water. Thus, it may move with leaching water to ground water or with surface runoff from irrigation or rainfall.

4. Volatility - a measure of how fast a chemical evaporates. Highly volatile chemicals should be injected into the soil or worked in quickly to prevent losses.

Site Conditions Affecting the Pollution Process

Site conditions include the soil conditions in the immediate rootzone, the depth to ground water, climate, and geologic conditions. The shallower the aquifer, the less time it will take leached nutrients and chemicals to reach it. This means less time for chemicals to break down and less opportunity for adsorption by soil particles. Large and variable rainfall make it difficult to plan chemical and nutrient applications to prevent leaching. Colder climates decrease the rate of chemical reactions that might degrade harmful substances.

The main soil factors that affect the pollution process are soil texture, organic material content, amount of soil water, soil structure, and soil temperature.

1. Soil texture - refers to the relative amounts of sand, silt, and clay present. It is important because the soil texture governs the amount of surface area available for adsorptivity, that is, how much total soil surface there is available for chemical attachment. Sand particles are relatively large. Clay particles are very small. Thus, there are fewer soil particles in the same volume of sandy soil than clay soil. Consequently there is much less surface area in sandy soil than clay soil. Thus, less chemical will attach to sand particles and there will be more chemical available for leaching than in a clay soil.

   Coarse-textured soil holds less water and has a higher permeability than fine-textured soil making it more susceptible to leaching from rainfall or over-irrigation. Very fine-textured soil may be susceptible to excessive surface runoff from either rainfall or over-irrigation. Leaching can transport contaminants to ground water and surface runoff can transport sediments, along with any adsorbed chemicals, to surface water.

2. Organic matter - important because organic matter greatly increases the area available for adsorption.

3. Soil water conditions - most chemical reactions require some moisture to proceed. Thus, the amount of soil water can affect the availability of contaminants and the amount of deep percolation and surface runoff. Deep percolation is the transport mechanism for leaching chemicals to ground water. Surface runoff can carry chemicals in solution or soil particles with attached chemicals. Rainfall is hard to predict and some deep percolation or surface runoff cannot be avoided. Sound irrigation practices are extremely important for reducing contamination.

4. Soil structure - affects water movement (permeability) through the soil profile. Potential leaching will increase or decrease depending on the structure. Soil erosiveness will increase or decrease the possibility of adsorbed chemicals moving with soil particles that are detached by wind or water.

5. Soil temperature - chemical reactions proceed faster in warm soils. This is important in mineralizing crop residues to increase the amount of nitrogen available in the soil. Further, pesticides break down more quickly in warm soils.

Chemical application methods affect the pollution process. Desirable management practices are presented in Chapter 4 with the Overall Management Objectives and Implementation Practices. Basically chemicals should be applied only when needed and in the minimum amount needed. Applications should be timed to the irrigation schedule and the irrigation application efficiency should be as great as feasible.

Irrigation and Rainfall as Detachment and Transport Mechanisms

Water is extremely important in the detachment and transport processes. High flows in furrows or excessive application rates under a sprinkle irrigation system can cause soil erosion and subsequent sedimentation. High flows also can transport chemicals attached to the soil particles. Excess deep percolation can leach nutrients and other chemicals to ground water. Thus, when applying water carefully consider its fate.

The fate of applied water can be better understood if the hydrologic cycle is understood first. The hydrologic cycle, illustrated in Figure 3-2, describes the movement of water through its different forms and places.

Important processes in the hydrologic cycle are:

1. Evaporation - transformation of liquid water into water vapor from free water surfaces.

2. Precipitation - rain or snow.

3. Runoff - water moving overland or in a river or stream.

4. Infiltration - movement of water into the soil.

5. Percolation - movement of water through the soil.

6. Freezing - liquid water turning into ice.

7. Thawing - melting of ice.

8. Transpiration - movement of water vapor within a plant through the leaves into the atmosphere.

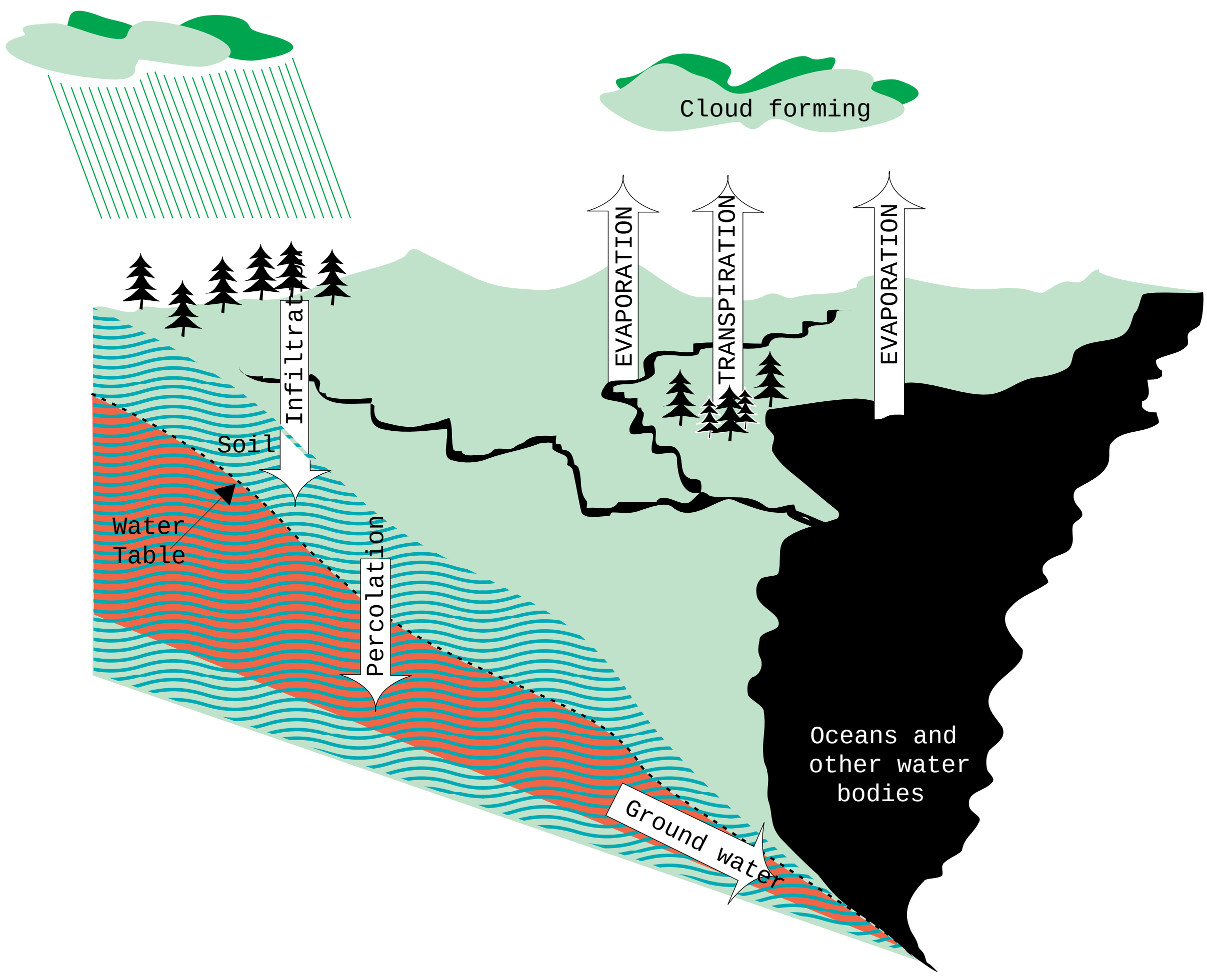


FIGURE 3-2. Schematic diagram of the hydrologic cycle

A term that is constantly used by agriculturalists is "evapotranspiration." Evapotranspiration is the total extraction of water from the soil when cropped. It consists of direct evaporation from soil surface and transpiration from the plant surface.

Essentially there is a constant amount of water in the world. It is in several forms (ice, liquid, or vapor) and in different places (the ocean, rivers as clouds, or in ground water aquifers). Importantly, the quality varies.

For example, a possible path in the cycle may start with evaporation of water from the ocean into vapor that forms clouds. These clouds then move over land and cause rainfall. Some of the rain percolates into the soil and moves to a ground water aquifer. A farmer pumps from the aquifer to apply to a crop. Then, the crop takes up the soil water and it returns to the air by evapotranspiration . In the air it forms clouds which again rain and the cycle repeats.

Another path would be for some of the rainfall to run off into a creek. The creek joins a river and the river flows into the ocean. The water then evaporates from the ocean to produce clouds again.

To further explain the above examples, when water is applied to a field through irrigation or rainfall, none of it is "lost." Different portions of that water will move through different paths in the hydrologic cycle. Some of the paths are more desirable than others. For example, most water applied should be stored in the root zone to be available for plant uptake.

Figure 3-3 is a schematic diagram of the root zone during an irrigation showing the possible fates of the applied water.

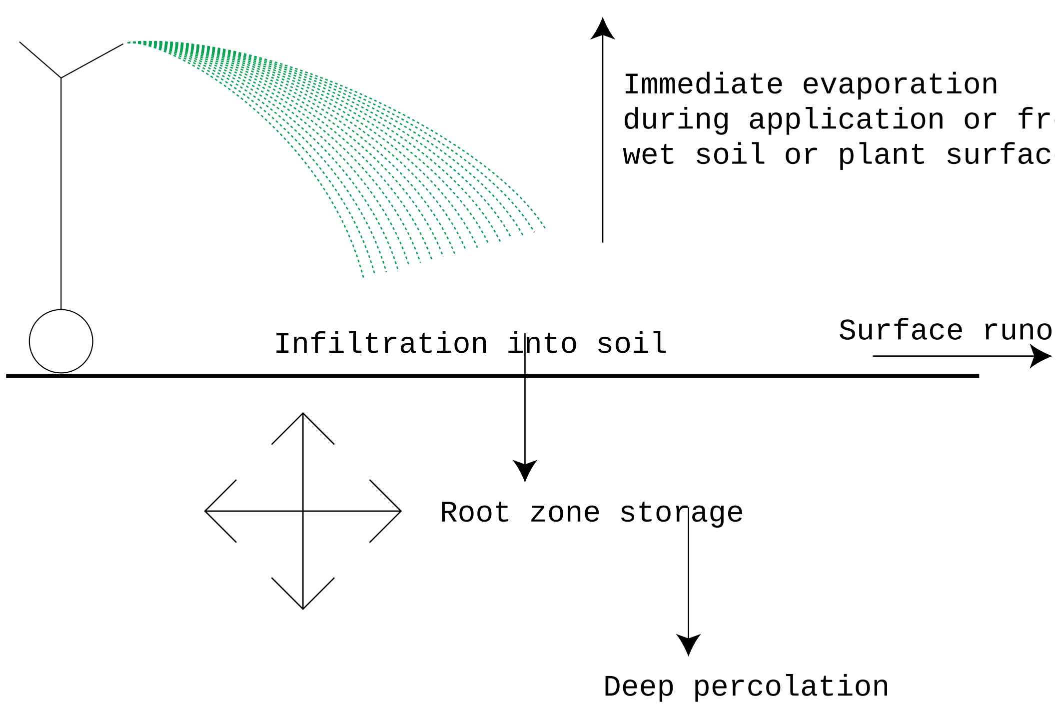


FIGURE 3-3. Schematic of the root zone during an irrigation

Specific fates of water applied to a field due to irrigation or rainfall are illustrated in Figure 3-3. They include:

1. Immediate evaporation - some water will evaporate immediately during an irrigation or rainfall. Evaporation losses during a sprinkle application may range from 6 to 15% or more depending on temperature, humidity, and wind conditions.

2. Surface runoff - if applied water does not infiltrate into the soil it will run off the surface. This runoff may go into a creek or stream, or may be picked up by a runoff reuse system on the farm, or on another farm downstream.

3. Deep percolation - water that infiltrates the soil may be used by the crop to become evapotranspiration, or may percolate below the root zone. The deep percolation could end up in a usable aquifer for later pumping and reapplication to the farm.

4. Root zone storage - eventually will be used by the crop and evapotranspired to the atmosphere.

A major Overall Management Objective for growers is to minimize the amounts of surface runoff and deep percolation. Surface runoff can be an important detachment mechanism depending on the erosivity of the soil. Deep percolation and surface runoff are the primary transport mechanisms causing contamination. They move sediment, chemicals, and fertilizers from the field to surface and ground waters.

Minimizing deep percolation and surface runoff (or its control) is the result of proper management of the irrigation to achieve good distribution uniformity and control the total application of water. Explanations of these two objective measures of irrigation performance, distribution uniformity and overall application efficiency are given in the discussion of Overall Management Objective 2.00 in Chapter 4. Discussions of the specific management concerns and techniques for each of the major irrigation systems are also included there.

Basic Soil-Water-Plant Relationships

Processes in the hydrologic cycle include infiltration, percolation, and evapotranspiration. An intermediate factor that is important to irrigated agriculture is the ability of soil to store water. That is, soil can effectively stop the movement of water through the hydrologic cycle. The science of soil-water-plant relationships provides an objective analysis of these phenomena.

Retention of water by soil

Soil holds water, retaining it against the pull of gravity. The matrix-like structure of soil will generate forces that retain water within the voids of the soil structure. The important aspect of this fact for mankind is that some of the water held is available for use by plants. There are limits to the amount of water soil will hold and the amount that the plant can extract.

The upper limit to a soil's water holding ability is termed "field capacity." Field capacity is not saturation. Saturation occurs when most, if not all, soil structure voids are full of water. The amount of water held in a soil at field capacity is much less than the amount of water in the same soil at saturation. In general, the amount of water held at field capacity is about one-half the saturated capacity.

> IMPORTANT!! Water will soak into soil that is at field capacity because there are still open voids in the soil. However, this water will not be held by the soil. It will drain down through the soil until it reaches an area that is less than field capacity or reaches a saturated zone.

Soil will not give up all its held water to the plant. The holding forces that retain water against the pull of gravity can also retain water against the plant. The key fact is that as the amount of water held by the soil decreases, the holding forces increase. Thus, as the plant extracts more and more water from the soil, these holding forces increase. At some point the holding forces of the soil are greater than the plant can overcome and no more water can be extracted. This is the "permanent wilting point."

Water in the soil above the permanent wilting point is "available water." That is, this soil water is available for the plant to use.

The amount of water held between field capacity and the permanent wilting point is the "available water holding capacity" of the soil. This is the most water that the soil will hold available to the plant.

The difference between the total amount of water in the soil at any one time and the soil's field capacity is termed the "soil water deficit" or "soil water depletion." This is a very important concept for irrigators. The soil water deficit is how much water is needed to refill a soil to field capacity.

Volumetric soil water measurement

There are two ways of describing the amount of water in soil. One is "volumetric" measure. This is a direct measure of the water in the soil. The standard of measurement is "inches of water held per foot of soil" or just "inches per foot." (Some will use a standard of measurement of inches of water held per inch of soil, or inches per inch.)

To explain this expression, consider that soil is a porous substance. Both water and air are contained within the pores. If a cubic foot of soil could be extracted from the soil and all of the soil solids pressed to one side, what would remain would be a layer of soil solids, a layer of water that had been held in the pores, and a layer of air that had also been in the pores. The standard for volumetric measurement is the depth of that water layer in relation to the original foot of soil, the inches of water held per foot of soil.

A coarse sand may have an available water holding capacity of .5 to 1.25 inches/foot.
A dense clay may have a capacity of 1.6 to 2.5 inches/foot.

Soil water tension

The other way of describing the amount of water in the soil is by measuring the forces that retain water within the soil pores. This is termed the "soil water tension." As the physical amount of water in the soil decreases, the soil water tension increases. Thus, as the amount of physical water in the soil decreases it becomes harder for the plant to extract water and stress is put on the plant. It is the grower's responsibility to manage that stress, usually by irrigating before the stress becomes excessive and harms yield or quality.

The standard for soil water tension is centibars, a measure of pressure. One hundred centibars (or 1 bar) is equal to a standard atmosphere, about 14.7 pounds per square inch of pressure. Field capacity occurs when the soil water tension is approximately 10 to 33 centibars, depending on the soil. Permanent wilting points (PWP) vary depending on the soil, climate, and ability of the plant to extract water, but scientists generally describe PWP at 1,500 centibars.

It can be said that the plant does not care how much physical water is in the soil, only how difficult it is to extract the water. For example, consider two similar crops, one growing in a clay soil and the other in a sand. Much less water can be held in the sand than in the clay. But, because the sand does not support as high a soil water tension as the clay, the crop in the sand will likely be under much less stress than the crop in the clay.

The two ways of measuring water in the soil are equally important to the grower. On the one hand, growers must know how much water is in the soil, or how much water is depleted, so that when they irrigate they do not apply too much water. To repeat, the amount of water in the soil must be known to avoid over-irrigation. Soaking water into a soil that is at field capacity will create deep percolation and increase the risk of leaching nutrients and harmful chemicals into the ground water. Further, it will not help the crop.

On the other hand, soil water tension must be known to manage plant stress. Irrigation is usually called for before soil water tension inhibits crop growth.

Soil water characteristic curve

As the amount of water in the soil decreases, the amount of water tension increases. A relationship between the amount of water in a soil and the soil water tension can be developed. This relationship can be described graphically as the soil water characteristic curve. The curve varies for a soil depending on whether that soil is being wetted or dried, a phenomena called "hysteresis."

Management allowed depletion

Most growers will measure either soil water or soil water tension. Rarely will both be measured. In many cases, only the soil water is measured. The question is, then, what value of soil water indicates that the soil water tension is stressful? Using experience, and possibly knowledge of the soil's water characteristic curve, growers will set a "management allowed depletion" (MAD). This is the amount of water that the grower will allow the plant to use before irrigating again. The MAD is set so that stress will not become excessive (although in some cases, stress is desirable for crop development).

Effective root zone

The "effective root zone" of the plant is the depth of soil that the grower should be managing. That is, the grower should be regulating the amount of nutrients and other chemicals, water, disease, etc., in this depth of soil to ensure a satisfactory yield and quality. The effective root zone may or may not be the actual extent of the plant's rooting system. It is just the depth of soil that is to be managed.

The soil's holding capacity, added up through the depth of the effective root zone results in a soil water reservoir that is available for the plant to use. For example, if the effective root zone of a crop is considered to be 4 feet and the available water holding capacity (AWHC) of the soil is 1.5 inches/foot, then when the soil is at field capacity there are 4 x 1.5 = 6 inches of water available for the crop to use. Note that there is more than 6 inches of water being *held* by the soil in the root zone. However, 6 inches is how much water is *available* for the crop to use. The rest of the water is held by the soil below the permanent wilting point.

Referring to the previous explanation of management allowed depletion, a common MAD is 50% of the available water holding capacity in the effective root zone. That is, the grower will allow the plant to use half the available water stored in the soil.

Evapotranspiration

The use of water by plants is termed evapotranspiration (ET). It is a combination of evaporation from the soil surface and transpiration through the plant surfaces. ET is measured in terms of a depth of water extracted from the soil per time period, usually inches per day.

Crop ET varies due to the type of crop, condition of crop, growth stage of crop, climate, and soil water content. Crop ET can vary from virtually nothing as a seedling emerges to as much as .4 inch/day or more for a mature crop in hot, windy climates. Crop ET increases with increased temperature, sunlight, and wind and decreases with increased humidity.

Infiltration rate

A characteristic of the soil that is extremely important to water management is the infiltration rate. This is how fast water will soak into the soil if ponded on the surface. Infiltration rates are measured in terms of inches per hour. If the infiltration rate of a soil is one inch per hour that means that if one inch of water was ponded on the soil, it would take an hour for all of the water to soak into the soil.

Infiltration rates change with the soil texture, structure, and water content. Since the soil's water content changes with time during an irrigation the infiltration rate will change throughout an irrigation. However, on a practical basis there is some constant "basic" infiltration rate that soils will reach during long irrigations. The infiltration rate will not fall substantially below this basic rate, which is unique for each soil.

If water is applied faster than it can infiltrate, surface runoff will occur. Obviously running water down a furrow is applying water faster than the soil can absorb it. On the other hand, hand-line/side-roll sprinkle irrigation systems are usually designed and intended to be managed so that the application rate of the system is always near or less than the infiltration rate of the soil.

Soil water movement/percolation

Once water is in the soil it can move in any direction, even up against the pull of gravity. This movement is due to the soil water tension forces that change as the plant extracts water from the soil, or as water evaporates directly from the soil surface. As an area of the soil dries out, the higher soil water tension in the dry area will attract water from wetter, adjacent areas.

Once water infiltrates the soil in excess of field capacity, gravitational forces will move it deeper into the soil.

Salts, Irrigation, and Drainage

All irrigation water contains salts to some degree. Thus, as irrigation proceeds, salts are continually being added to the soil. Most fertilizers contain salts which are added along with commercial fertilizers or manure. Depending on the chemistry of the water and the soil, salts may be dissolved or precipitated within the effective root zone.

The total level of salts in water is described in terms of electrical conductivity (EC) or in terms of Total Dissolved Salts in parts of salt per million parts of water (TDS ppm). Water that is tested at 300 parts per million total dissolved salts has 300 pounds of salt per million pounds of water.

Electrical conductivity is measured in millimhos per centimeter or deciSiemens per meter. It is a measure of how easy it is to pass an electric current through water. (Note that pure water will not conduct electricity.) The more salt in the water the easier it is to conduct electricity through it. An approximate relationship between EC and TDS is that 650 parts per million total dissolved salts is equal to 1.0 millimhos/cm electrical conductivity.

Excessive, or imbalanced, dissolved salts can cause four types of problems for irrigated agriculture:

1. General yield declines - dissolved salts create “osmotic forces.” Essentially, osmotic forces act in the same manner as the water holding forces that the soil structure creates (termed “matric forces”). They tend to hold water back from the plant. Effectively, excessive dissolved salts reduce the amount of available water in the soil. Thus, they create additional stress on the crop.

2. Soil structure problems - sometimes it is not the total amount of dissolved salts that is important, rather it is the relative amount of different types of salts. If the different types of salts are out of proportion, soil structure problems can result, generally manifested as low permeability. It becomes difficult for water to infiltrate the ground causing poor root penetration and expansion. The imbalance occurs if there is too much sodium in relation to magnesium and calcium in the soil water. However, the type and amount of clay in the soil helps determine the extent of the problem. Note that too low a level of salts in the irrigation water can also cause infiltration problems.

3. Specific toxicities - some salts, while necessary for crop growth in proper amounts, are toxic in excessive amounts. The prime example is boron. A benchmark of poor irrigation water quality for many growers is water that is tested at 1 part per million of boron or above.

4. Corrosion and other miscellaneous problems - salts can cause excessive corrosion of some irrigation system hardware. Depending on the specific chemistry, certain waters may require special handling to prevent clogging of drip irrigation systems.

There are specific management techniques for dealing with these problems. The two most common are maintenance leaching to maintain a salt balance in the soil and addition of chemical amendments to the soil or irrigation water to maintain the correct balance of salts.

Leaching

Assuming that there is an acceptable amount of dissolved salts in the effective root zone, leaching is required to prevent excessive amounts of salt from accumulating. Purposeful deep percolation leaches salts from the root zone. Some leaching is required for all irrigated agriculture to prevent excessive salts from accumulating in the root zone. Thus, irrigated agriculture always creates some potential for contamination of ground water aquifers.

There are several equations that are in use for determining the amount of leaching that is required. The important variables in determining the amount of leaching are the electrical conductivity of the irrigation water and the desired electrical conductivity of the soil water solution.

The desired conductivity of the soil water solution depends on the sensitivity of the crop to salt. Some crops are extremely sensitive to salts. Researchers have identified approximate levels of salt that different crops withstand with no yield decline. They also have been able to make estimates of how much yield will be lost as the root zone salinity increases. Growers try to maintain the root zone salinity at or below the point of yield decline if possible.

A commonly used leaching equation is one developed by Rhodes, et al., and described by Westcott and Ayers in *Water Quality for Agriculture* (FAO Irrigation and Drainage Paper 29, rev. 1). It states:

$$LF = \frac{ECiw}{((5 * ECe) - ECiw)}$$

where:

LF = the percentage of applied irrigation water that should become deep percolation

ECiw = electrical conductivity of the irrigation water

ECe = desired electrical conductivity of saturated extract (a standard laboratory test indicating root zone salinity)

Correcting infiltration and soil structure problems

Correcting an imbalance in the types of salts present may or may not be easy. An important factor is the amount of free calcium in the soil. If free calcium is not present a very common technique is to add gypsum to the soil on a regular basis. On the other hand, there may be plenty of calcium in the soil but it is tied up as calcium carbonate or calcium bicarbonate. Adding sulphur or sulfuric acid to the soil is common in these situations.

Gypsum can be added to water to increase the total salt content of the water when the combination of soil and water chemistry results in very low infiltration rates. Increasing dissolved salts in irrigation water acts to increase infiltration rates.

Other techniques for salt management include blending of water supplies, deep tillage, special seed bed configurations, and modified irrigation timing. Salt management can be complex. Experts should be consulted whenever salinity problems exist. Table 3-1, taken from Westcott and Ayers in its entirety (used by permission), provides a summary of potential problems due to different water qualities. The notes to this table are especially important. They indicate the conditions under which the guidelines in Table 3-1 are valid. Also, in the notes, references to other Tables or Figures are references to those in FAO 29A, not the Manual.

TABLE 3-1. Guidelines for Interpretation of Water Quality for Irrigation[1] (from FAO 29A, *Water Quality for Agriculture,* rev A by Westcott and Ayers, used by permission), NOTE: Figures and Tables referenced in the notes below are to the original FAO 29A document, not to the Manual

Potential Irrigation Problem		Units	Degree of Restriction on Use: None	Slight to Moderate	Severe
Salinity (affects crop water availability)[2]					
ECw		dS/M	< 0.7	0.7 - 3.0	> 3.0
(or)					
TDS		mg/L	< 450	450 - 2000	> 2000
Infiltration (affects infiltration rate of water into the soil; evaluate using ECw and SAR together)[3]					
SAR = 0 - 3 and ECw	=	dS/M	> .7	0.7 - 0.2	< 0.2
= 3 - 6	=	dS/M	> 1.2	1.2 - 0.3	< 0.3
= 6 - 12	=	dS/M	> 1.9	1.9 - 0.5	< 0.5
= 12 - 20	=	dS/M	> 2.9	2.9 - 1.3	< 1.3
= 20 - 40	=	dS/M	> 5.0	5.0 - 2.9	< 2.9
Specific Ion Toxicity (affects sensitive crops)					
Sodium (Na)[4]					
surface irrigation		SAR	< 3	3 - 9	> 9
sprinkler irrigation		me/L	< 3	> 3	
Chloride (Cl)[4]					
surface irrigation		me/L	< 4	4 - 10	> 10
sprinkler irrigation		me/L	< 3	> 3	
Boron (B)[5]		mg/L	< 0.7	0.7 - 3.0	> 3.0
Miscellaneous Effects (affects susceptible crops)					
Nitrogen (NO_3-N)[6]		mg/L	< 5	5 - 30	> 30
Bicarbonate (HCO_3) (overhead sprinkling only)		me/L	< 1.5	1.5 - 8.5	> 8.5
pH			Normal Range 6.5 - 8.4		

NOTES:

[1] Adapted from University of California Committee of Consultants 1974.

[2] ECw means electrical conductivity, a measure of the water salinity, reported in deciSiemens per meter at 25 C (dS/m) or in units of millimhos per centimeter (mmho/cm). Both are equivalent. TDS means total dissolved solids, reported in milligrams per liter (mg/L).

[3] SAR means sodium absorption ratio. SAR is sometimes reported by the symbol RNa. See Figure 1 for the SAR calculation procedure. At a given SAR, infiltration rate increases as water salinity increases. Evaluate the potential infiltration problem by SAR as modified by ECw. Adapted from Rhoades, 1977, and Oster and Schroer, 1979.

[4] For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; use the values shown. Most annual crops are not sensitive; use the salinity tolerance tables (Tables 4 and 5). For chloride tolerance of selected fruit crops, see Table 14. With overhead sprinkler irrigation and low humidity (< 30 percent), sodium and chloride may be absorbed through the leaves of sensitive crops. For crop sensitivity to absorption, see Tables 18, 19, and 20.

[5] For boron tolerance, see Tables 16 and 17.

[6] NO_3^--N means nitrate nitrogen reported in terms of elemental nitrogen. NH_4^--N and organic-N should be included when wastewater is being tested.

Assumptions in the Guidelines

The water quality guidelines in Table 3-1 are intended to cover the wide range of conditions encountered in irrigated agriculture. Several basic assumptions have been used to define their range of usability. If the water is used under greatly different conditions, the guidelines may need to be adjusted. Wide deviations from the assumptions might result in wrong judgments on the usability of a particular water supply, especially if it is a borderline case. Where sufficient experience, field trials, research, or observations are available, the guidelines may be modified to fit local conditions more closely.

The basic assumptions in the guidelines are:

Yield Potential: Full production capability of all crops, without the use of special practices, is assumed when the guidelines indicate no restrictions on use. A "restriction on use" indicates that there may be a limitation in choice of crop, or special management may be needed to maintain full production capability. A "restriction on use" does *not* indicate that the water is unsuitable for use.

Site Conditions: Soil texture ranges from sandy-loam to clay-loam with good internal drainage. The climate is semi-arid to arid and rainfall is low. Rainfall does not play a significant role in meeting crop water demand or leaching requirement. (In monsoon climates or areas where precipitation is high for part or all of the year, the guideline restrictions are too severe. Under the higher rainfall situation, infiltrated water from rainfall is effective in meeting all or part of the leaching requirement.) Drainage is assumed to be good, with no uncontrolled shallow water table present within 2 meters of the surface.

Methods and Timing of Irrigations: Normal surface or sprinkler irrigation methods are used. Water is applied infrequently, as needed, and the crop uses a considerable portion of the available stored soil-water (50 percent or more) before the next irrigation. At least 15 percent of the applied water percolates below the root zone (leaching fraction (LF) >= 15 percent). The guidelines are too restrictive for specialized irrigation methods, such as localized drip irrigation, which results in near daily or frequent irrigations, but are applicable for subsurface irrigation if surface applied leaching satisfies the leaching requirements.

Water Uptake by Crops: Different crops have different water uptake patterns, but all take water from wherever it is most readily available within the rooting depth. On average, about 40 percent is assumed to be taken from the upper quarter of the rooting depth, 30 percent from the second quarter, 20 percent from the third quarter, and 10 percent from the lowest quarter. Each irrigation leaches the upper root zone and maintains it at a relatively low salinity. Salinity increases with depth and is greatest in the lower part of the root zone. The average salinity of the soil-water is three times that of the applied water and is representative of the average root zone salinity to which the crop responds. These conditions result from a leaching fraction of 15-20 percent and irrigations that are timed to keep the crop adequately watered at all times.

Salts leached from the upper root zone accumulate to some extent in the lower part, but a salt balance is achieved as salts are moved below the root zone by sufficient leaching. The higher salinity in the lower root zone becomes less important if adequate moisture is maintained in the upper, more active part of the root zone and long-term leaching is accomplished.

Restrictions on Use: The "Restrictions on Use" shown in Table 3-1 is divided into three degrees of severity: non, slight to moderate, and severe. The divisions are somewhat arbitrary since change occurs gradually and there is no clear breaking point. A change of 10 to 20 percent above or below the guideline value has little significance if considered in proper perspective with other factors affecting yield. Field studies, research trials, and observations have led to these divisions, but the grower's management skill of the water user can alter them. Values shown are applicable under normal field conditions prevailing in most irrigated areas in the arid and semi-arid regions of the world.

Drainage

The leaching ratio equation previously presented calculates the percentage of applied irrigation water that must pass through the root zone to maintain the soil water salinity at a desired level. Thus, some deep percolation is required, desirable, and inevitable with irrigated agriculture. The key question is where does this deep percolation go?

There must be sufficient internal drainage in the soil so that the required deep percolation does not cause saturated conditions within the effective root zone. This drainage can be natural. That is, the soil profile is such that the deep percolation continues downward, or moves sideways, out of the effective root zone. The concern here is the effect of that deep percolation on any ground water it reaches. Regardless of any nutrients or chemicals that it may have leached out of the root zone, the deep percolation will always carry salts.

The other option for drainage occurs if there is insufficient internal drainage. This situation arises when an impermeable layer of rock or clay soil occurs relatively near the soil surface. With no other provision, deep percolation will create a saturated zone in the soil that can "back up" into the root zone. In these situations, "tile" drain systems are installed. These are systems of perforated, polyethylene pipe buried at various depths and spacings. The perforations allow the deep percolation to enter the piping system. The percolation is then gathered at collection points and pumped to the surface for disposal. The key question in this situation is where is the endpoint of disposal? The drainage pumped to the surface has the potential to contaminate surface waters depending on point and method of disposal.

Again, salinity and drainage problems in irrigated agriculture can be complex. Growers should consult experts and have laboratory tests performed to determine the best course of action.

CHAPTER 4.

4 CHAPTER

OVERALL MANAGEMENT OBJECTIVES AND IMPLEMENTATION PRACTICES

Purpose

This chapter will present six Overall Management Objectives (Objectives) and various Implementation Practices (Practices) that can help achieve the Objectives.

Overall Management Objectives, if achieved wholly or in part, should result in one or more of the following:

1. Minimized potential for pollution of ground and surface water.

2. Minimized water diversions for irrigation.

3. Minimized soil erosion.

4. Production of a profitable crop.

Implementation Practices are the specific management or hardware changes that will help achieve the Objectives. For example, Objective 2.00 is to improve the irrigation performance. A specific Practice that can help achieve this Objective is to install a runoff reuse system (IP 2.02.11). Some Practices will be fairly specific, such as the runoff reuse system. Others may be somewhat broad, such as the Practice to consider changing the irrigation system type (IP 2.01.08).

The various practices are presented as options to help in achieving the Objectives. The Practice, or Practices, that will be used depends on the specific situation. One of the results of achieving the Objectives should be to produce a profitable crop. It is expected that Practices used will be those that help achieve the Objectives while maintaining the economic viability of the farm.

The intended, primary effects of achieving the Objective on surface and ground water quality, water diversions (pumping a well or a river, or canal deliveries), and crop yields will be discussed in the presentation of the Objective. It should be understood that the effects of implementing any single Practice will vary depending on the specific situation and whether other Practices are implemented at the same time.

For example, the intended result of using dammer/dikers is to increase infiltration and thus reduce surface runoff. However, if good irrigation scheduling is not simultaneously practiced, an additional result could be increased deep percolation.

There may also be secondary effects which will have to be addressed so as to not worsen a situation. For example, a common Practice for improving furrow irrigation system uniformity is to speed the rate of water advance down a furrow. However, faster water advance may increase erosion and will certainly increase the amount of runoff that will have to be dealt with. Thus, many times, two or more Practices should be implemented together to achieve the intended results.

There are separate sections of Implementation Practices within some of the Objectives. For example, there is a section of Practices for each of the major irrigation system types within OMO 2.00. This should make it easier for the reader to find those Practices that are applicable to his/her situation.

Increasing On-farm Application Efficiency and the Effects on Water Quantity

Application efficiency as used in the Manual refers to application efficiency on the farming unit for a single irrigation. Thus, if application efficiencies are improved on-farm, then the total water supply needs for the farm will decrease and diversions from water supplies will decrease.

Application efficiency is assumed to result in reduced diversions. This may be indicated in the discussions of the individual Objectives by the phrase ". . . This in turn leaves more water available for other users and uses." It should be pointed out that deep percolation may go into a usable aquifer (although probably with some decrease in quality) where it is available for repumping, or reenter surface water supplies at some point downstream. Additionally, surface runoff will probably return to a source where others may draw from it. In summary, improvements in on-farm application efficiency may not always lead to actual increases in water supplies *on a basin- or region-wide basis.*

However, diverting and applying water costs money. Also, creating surface runoff or deep percolation almost always degrades the receiving water, a ground water aquifer or river/stream, to some degree. This is because deep percolation and surface runoff are primary transport mechanisms for moving detached substances. And, even if the ground water or receiving surface water is of worse quality than the deep percolation or runoff, it is not generally desirable to allow good quality water to be degraded.

There is a "time value" to water. That is, water needs to be at the right place at the right time for it to be useful. Surface runoff or deep percolation from excessive diversions may return to a usable water supply. However, if the amount of time for the returns to arrive is excessive the water may not be available, or sufficient, when needed.

There is a "location value" to water also. Although return flows from a farm may contribute to an overall high basin efficiency, the geographical point of return to the supply may make it infeasible for another farm to use. An example of this would be if the point of return was down-river of a potential user.

In summary, reducing diversions to a farm usually maintains water quality and flexibility for other users. Thus, it is said that improvements in application efficiency will result in effectively increasing water supplies to other users. Additionally, if the required diversions for one field are reduced, the grower may have more water to use on another field. Thus, the potential farm profitability may also be increased.

Implementing the Practices

Deciding that a Practice is appropriate is one thing, implementing it is another. First, choices of appropriate practices may involve physical and economic analyses of the specific situation. Competent and experienced engineers, scientists, agronomists, and financial analysts should be consulted. In some cases, there may be more than one Practice that can achieve the same result. It is expected that the least expensive option would be chosen, all else being equal. The grower may need advice in choosing the least expensive option, especially when considering new construction.

Good starting points for the grower wishing to improve on-farm operations are the local Conservation District, Washington State University Cooperative Extension, and the Soil Conservation Service. Both of the latter organizations maintain offices in the major agricultural regions of the state. If any of these groups do not offer a service directly they will know where to direct a grower for that service.

Chapter 7 of the Manual contains a listing of agencies and office locations that offer assistance to growers.

The Manual as a Living Document

As previously stated in the Introduction to the Manual, it is important to realize that science is not static. The Objectives and Practices listed in the Manual are generally recognized to be effective in reducing the potential for point and nonpoint source pollution. However, there may be other existing Practices not presented in the Manual that are also effective. Or, science and practical experience may develop new Practices in the future. The Manual is a "living" document. That is, there will be revisions from time to time to update the Objectives and Practices.

OVERALL MANAGEMENT OBJECTIVE 1.00
MINIMIZE WATER LOSSES IN THE ON-FARM DISTRIBUTION SYSTEM

Explanation and Purpose

The on-farm distribution system consists of the pipelines and/or ditches that transport water from the primary water source (canal, river, well) to the field irrigation system. Losses of water may occur while it is in the distribution system. Losses may be from evaporation, seepage, leakage, or by uptake by weeds or other plants along or within the distribution channels.

Some losses of water during transport to a field may be unavoidable, such as evaporation from an open ditch. However, achieving this Objective will help minimize required water diversions and has the potential for reducing impacts on both ground and surface water quality.

Possible Effects on Water Diversions

Minimizing water losses in the distribution system will contribute to increasing overall on-farm application efficiency and reducing required water diversions to the individual farm. There are situations where the seepage in the distribution system contributes substantially to recharge of a usable aquifer and in fact, may be desirable.

Possible Effects on Crop Yields

Crop yields in an individual field could be increased if seepage from the distribution system was adversely affecting the fields by creating saturated conditions. Total yields from the individual farm could be increased if the magnitude of losses in the distribution system were such to cause a loss of cropped land or insufficient irrigations. That is, the water that is saved by achieving this Objective might be used to bring more land into production or more effectively irrigate currently-cropped land.

Possible Effects on Ground Water Quality

Ground water quality will be affected if the losses were a result of seepage from ditches or leakage from pipelines. Whether the ground water quality would be diminished or improved depends on the quality of the irrigation water, the quality of the ground water, and any chemicals or nutrients in the soil that would be leached by the seepage/leakage.

Pollution is the end result of availability, detachment, and transport. Available contaminants in earthen ditches would include soil sterilants or herbicides used for weed control. In some situations, fertilizer is added to water being run through ditches to fields. Also, ground water movement from adjacent fields could place contaminants under a ditch or pipeline. Then, seepage/leakage would drive the contaminants deeper.

Normally it would be expected that achieving this OMO would reduce the potential for adverse effects on ground water quality. However, there are situations where water that seeps from distribution ditches is of much higher quality than the ground water.

Possible Effects on Surface Water Quality

Surface water quality would not normally be affected by this Objective. It would be expected that water delivered through the distribution system would be applied through an irrigation system before returning to any other natural water course. However, there may be cases where there is operational spill from a farm distribution system directly back to a natural surface water course. In these cases certain practices, such as lining ditches, could reduce potential contamination by reducing sediment loads in the spill.

4 CHAPTER

IP 1.00.01 Install Concrete Slip-form Ditches to Replace Earthen Ditches

Objective

Immediate reduction of losses to seepage and ditch-bank weeds. The amount of seepage reduction depends on the dimensions of the ditch, the amount of time the ditch carries water, and the type of soil. Excessive seepage can result in deep percolation that could transport pollutants to ground water. Excessive seepage may also impact yields by creating poor root zone conditions in fields adjacent to a ditch.

Description

Concrete slip-form ditches are constructed by pouring concrete into a moving form that slides inside a prepared earthen foundation. It is a widely used practice in some agricultural areas and there are many pre-manufactured control structures available for use in this type of conveyance structure. Importantly, there are simple and inexpensive flume designs that can be used for flow measurement.

This type of conveyance structure must be designed to ensure that sufficient water can be transported and that it will not crack, buckle, or slump. Critical design and construction factors include:

1. Use of correct cement mixes where there are excessive sulphates in the soil.

2. Proper combination of ditch bottom slope, surface roughness, and cross-sectional dimension to transport a desired water flow with sufficient freeboard and proper water velocities.

3. Proper foundation preparation to prevent settling. Note also that concrete-lined ditches should not be installed where there are high water tables.

There are companies that specialize in this type of construction. Generally, if an agricultural area is adapted to this type of conveyance system there will be at least one such company in the area.

Continual maintenance to prevent cracks in the lining is necessary to sustain the benefits of lining. In some soils and climates, winter freezing and subsequent thawing could cause the concrete to buckle.

SCS National Practice 320 addresses design and construction of permanent ditches. SCS Practice 430-A covers concrete lining while Practice 587 covers structures for water control. American Society of Agricultural Engineers Standard S289.1 also addresses concrete slip-form canal linings.

IP 1.00.02 - Convert Earthen Ditches to Pipelines or Gated Pipe

Objective

Immediate reduction of losses due to seepage, ditch-bank weeds, and surface evaporation. Pipelines also reduce some safety hazards and reduce the potential for contamination of irrigation supplies from wind drift of chemical applications.

Description

There are advantages and disadvantages to both ditches and pipelines. Generally a pipeline minimizes loss of water since there is no surface evaporation, seepage (assuming no leaks), or loss to weed use. In addition they are out of the way of farm tractors, provide more farm safety (no danger of drowning, slipping, or vehicular mishaps), do not serve as an entry or distribution point for weed seeds, and can transport water up hill as well as down. On the other hand, ditches are usually less expensive than pipelines to install and can transport more water than a pipeline for a given amount of water head, depending on the relative size of the pipeline and ditch.

Gated pipe is used as an alternative to the combination of open ditches and siphon tubes to introduce water into furrows or border strips. Gated pipe reduces seepage and surface evaporation losses and may result in increased control over the irrigation event. Gated pipe is commonly used with surge irrigation techniques.

Proper design and construction of pipelines is critical to continued high performance. Depth of burial, trench preparation, pipe handling, corrosion protection in the case of steel pipe, backfilling, and installation of thrust blocks, air vents, pressure reliefs, and vacuum reliefs are all important factors. Preventing water hammer is also a prime concern.

The American Society of Agricultural Engineers Standard S376.1 recommends sizing of pipelines to maintain water velocities below five feet per second. Higher velocities may be tolerated if sufficient consideration is given to controlling surge pressures and water hammer. However, the tradeoff between construction costs and operating costs should be analyzed to choose the right diameter. Note that as larger size pipe is used, capital costs go up but operating costs go down as it will take less pressure to move a given amount of water through the pipe. On the other hand, using smaller sizes reduces capital costs while increasing operating costs.

It is highly recommended that pipelines constructed of concrete, asbestos-cement, or steel be installed by experienced engineering/construction companies. Construction of PVC pipelines may appear to be simple enough for the individual to accomplish, and growers have installed their own pipelines in many cases. However, it is recommended that a competent pipeline engineering/construction company be retained even for this type of pipe material.

SCS National Practice 430-AA through HH addresses pipeline design and construction using a variety of materials. American Society of Agricultural Engineers Standard S376.1 is specific to thermoplastic pipelines. ASAE Standard S261.6 addresses nonreinforced concrete irrigation pipelines.

IP 1.00.03 - Install Flexible Membrane Linings in Earthen Ditches or Reservoirs

Objective

Eliminate water losses due to seepage while water is in an earthen ditch or reservoir. Depending on the specific installation, losses to ditch-bank weeds could also be eliminated.

Description

This is usually a less expensive method than slip-form concrete to seal an earthen ditch or reservoir. However, site preparation is critical since sharp rocks or other objects in the foundation may pierce the lining over time.

The grower may be able to install a temporary lining satisfactorily, provided manufacturer's recommendations for site preparation and construction are followed. A competent installer should be retained if the lining is to be permanent.

Care must be taken when cleaning ditches or reservoirs sealed with liners not to break the liner.

SCS National Practices 428B and 521-A cover use of flexible liners. American Society of Agricultural Engineers Engineering Practice EP340.2 also addresses flexible membrane liners.

IP 1.00.04 - Install Swelling Clays or Other Engineered Material in Earthen Ditches or Reservoirs

Objective

Reduce water losses due to seepage in an earthen ditch or reservoir.

Description

Certain clays will swell when wet. This swelling will minimize water movement through the clay. Bentonite clays are a commonly used material to seal earthen ditches and reservoirs. Care must be taken when cleaning ditches or reservoirs sealed with clays not to break the clay "cap."

If the lining is only temporary or semi-permanent the individual grower may be able to install it satisfactorily, provided manufacturer's recommendations for site preparation and construction are followed. If the lining is to be permanent, then a competent installer should be retained.

SCS National Practice 521-B through E covers the use of engineered materials for sealing earthen ditches and reservoirs.

IP 1.00.05 - Maintain Ditches and Pipelines to Prevent Leaks

Objective

Maintain effectiveness of the ditch or pipeline to transport water without losses due to leaks or seepage.

Description

Any lining material for ditches and reservoirs is subject to cracking or splitting due to freezing/thawing or “heaving” soils. Liners can also be breached by cleaning operations such as dredging to remove excess silt or aquatic vegetation. Depending on soil conditions under the lining, cracks can be a significant loss of water.

Pipeline maintenance should be minimal if the pipeline was designed and installed correctly. It is very important that sufficient thrust blocks, air vents, pressure reliefs, and vacuum reliefs be installed. Although construction may be done by the individual grower, a competent engineer should be retained to ensure a safe and reliable design.

One problem that can occur in pipelines or ditches is excessive siltation. This is a situation where water with a high sediment load is transported in the pipeline or ditch at low velocities. The low velocity allows the sediment to settle out of the water and eventually reduce the carrying capacity of the conduit. Siltation occurs many times in ditches in front of overflow control structures. Proper design and operation should minimize this problem.

OVERALL MANAGEMENT OBJECTIVE 2.00
IMPROVE IRRIGATION SYSTEM PERFORMANCE IN ORDER TO MINIMIZE DEEP PERCOLATION AND SURFACE RUNOFF

Explanation and Purpose

As discussed in Chapter 3, there are several possible fates (destinations) of applied irrigation water. Some water will immediately evaporate. Some will not infiltrate into the soil and will become surface runoff. Water that does infiltrate into the soil may remain in the root zone, available for plant uptake. If water infiltration is excessive, some will percolate below the root zone.

Water running off a field may carry sediments, dissolved nutrients or chemicals, or nutrients or chemicals that are adsorbed to the soil particles to surface waterbodies. Deep percolation is the transport mechanism for carrying dissolved nutrients or chemicals into ground water. Thus, reducing surface runoff and deep percolation reduces potential pollution through reduced detachment and transport.

Water flowing across soil is a detachment mechanism. Normally, the higher the velocity of water moving across the soil, the higher the potential for erosion. Increasing application efficiency with furrow/rill or border strip irrigation systems may involve an increase in water velocity. Thus, there is the chance that achieving this Objective will increase the potential for surface water quality contamination. It is important to realize that several Practices could have to be implemented simultaneously to positively reduce the contamination potential.

Distribution Uniformity and Application Efficiency

There are two measures of irrigation performance, distribution uniformity and application efficiency. Some of the Practices presented for this Objective are intended to increase uniformity. Increasing uniformity increases the potential application efficiency. Other Practices are intended to increase application efficiency directly.

Distribution uniformity is a measure of how evenly water soaks into the ground across a field during the irrigation. If eight inches of water soaks into the ground in one part of the field and only four inches in another part of the field, that is poor distribution uniformity. Distribution uniformity is expressed as a percentage between 0 and 100%. Although 100% distribution uniformity is theoretically possible, it is virtually impossible to attain in actual practice. Good distribution uniformity is critical for reducing deep percolation.

There are many measures of the efficiency of an irrigation system depending on the purpose of the efficiency measurement. Many times, “irrigation efficiency” (or as used by some authors, “application efficiency”) is used only to indicate how much of the applied water is stored in the root zone of the crop. This stored water is then available for crop water use, evapotranspiration. Crop water use is considered a beneficial use. However, this narrow definition does not consider that some deep percolation may be required to maintain a salt balance. This deep percolation, while not available for actual crop water use, is also a beneficial use.

Irrigation efficiency was defined by the American Society of Civil Engineers' On-Farm Irrigation Committee in 1978 as the ratio of the volume of water which is beneficially used to the volume of irrigation water applied. Beneficial uses may include crop evapotranspiration, deep percolation needed for leaching for salt control, crop cooling, frost control, and as an aid in certain cultural operations.

There are many specific mathematical definitions of efficiency in use. Differences in definitions are due primarily to:

1. Accounting for runoff and deep percolation.
2. Whether it is for an individual irrigation or an entire season.
3. Whether it is for an individual farm, irrigation project, or basin.

Many people will hold to a strict measure of efficiency considering only the beneficial use on the individual field. Others will classify reuse of any surface or sub-surface drainage by other farms as beneficial use. Some will ignore measurements of individual irrigations to focus on a seasonal efficiency. For the Manual, application efficiency is defined for each irrigation as:

$$\text{Application Efficiency} = \frac{\text{Applied water stored in the root zone or used for leaching}}{\text{Total water applied}} \times 100$$

Application efficiencies are also expressed as a percentage between 0 and 100%. A 100% application efficiency is not theoretically attainable due to immediate evaporation losses during irrigations. However, there could easily be close to 95% application efficiency if a crop is under-watered. In this case, assuming there was no deep percolation, all water applied and not immediately evaporated would be used by the crop.

Underwatering a crop will theoretically result in a high application efficiency. However, it may not be a very effective way of farming and could actually lead to an overall inefficient use of resources. This could be because of an inefficient use of fertilizer, a weak crop that is more susceptible to pest pressures, thus requiring additional chemical applications, or sub-standard yields that would require additional cropped acreage.

Note that the terms “irrigation efficiency” or “application efficiency” should not be confused with the term “water use efficiency” (WUE). Water use efficiency is generally a measure of yield per unit water applied.

Relationships Between Distribution Uniformity and Application Efficiency

Generally, the distribution uniformity of the irrigation system is the first concern. The reason for this is explained by the following four graphs. They are a profile view of two adjacent sprinklers in a field and the root zone under them. The spray patterns from the adjacent sprinklers must overlap to result in the same amount of water falling in all parts of the field. The horizontal, dashed line in the figures depicts the depth of the actual soil water deficit at irrigation. This is the amount of water that the grower would be trying to soak into the soil to satisfy crop water use requirements. The dotted-dashed line depicts the actual depth of water infiltrated during the irrigation. Deep percolation is indicated whenever the actual depth of irrigation (the dotted-dashed line) is below the soil water deficit line (the horizontal, dashed line). Conversely, under-irrigation is indicated whenever the actual depth of irrigation line is above the soil water deficit line. The depths multiplied by the area of a field indicate the volumes of water applied, stored, and percolated.

Figures 4-1 and 4-2 demonstrate that there must be good distribution uniformity before there can be good application efficiency, *if the crop is to be sufficiently watered.*

In Figure 4-1, the farmer has irrigated to sufficiently water the entire field. The poor distribution uniformity has resulted in excessive deep percolation. That is, the deep percolation was much more than would be needed to maintain a salt balance.

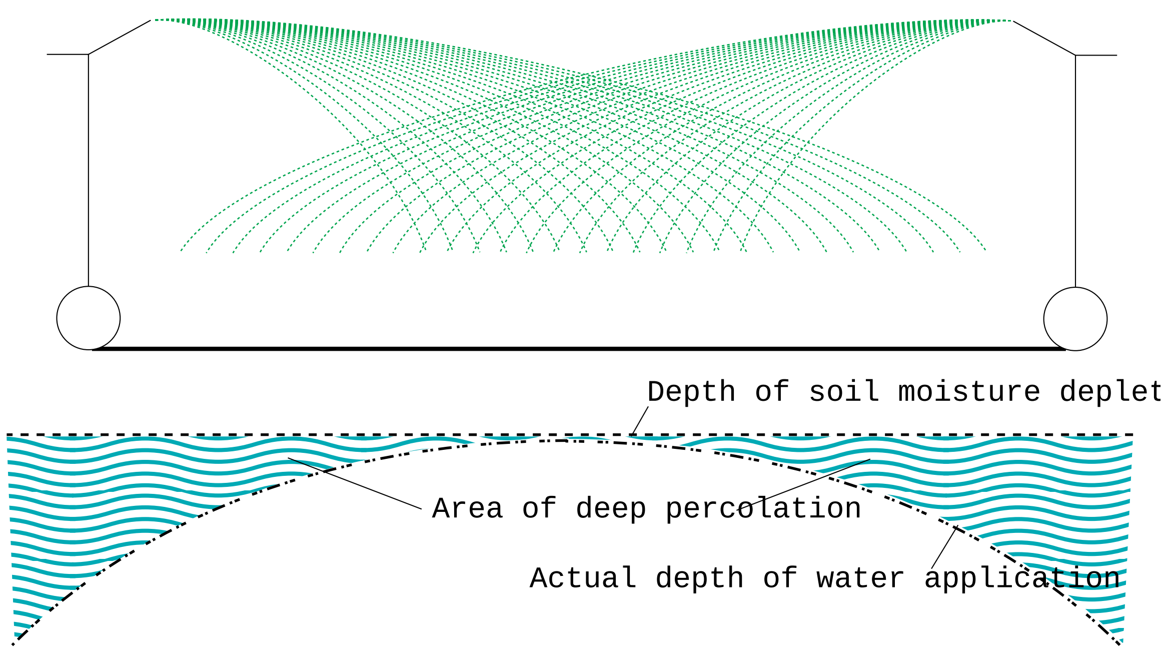


FIGURE 4-1. Depiction of irrigation resulting in poor distribution uniformity and excessive deep percolation

In Figure 4-2, the farmer has acted to prevent excessive deep percolation. Now part of the field remains under-irrigated. Under-irrigation usually results in a high irrigation application efficiency as most water applied is stored in the root zone, available for plant use. But it may not be an effective way of growing as the resulting water stress on the crop in some parts of the field will usually decrease yields. Also, there is the need for some deep percolation for leaching to maintain a salt balance. Note that the leaching must be uniform over a number of years to prevent areas of excessive salt accumulation.

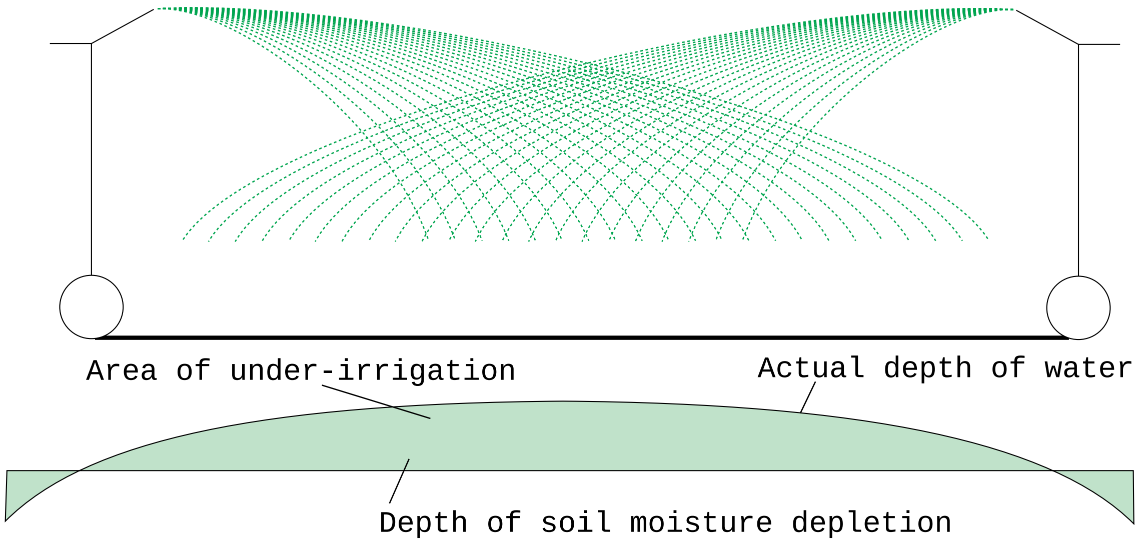


FIGURE 4-2. Depiction of irrigation resulting in poor distribution uniformity and insufficient irrigation in parts of the field

A second relationship is that good distribution uniformity is no guarantee of good application efficiency. Figures 4-3 and 4-4 show that a good distribution uniformity allows a good application efficiency, but the total amount of water applied must still be controlled.

Figure 4-3 depicts a good irrigation. There is a high distribution uniformity as indicated by the flatter infiltrated depth line (the dotted-dashed line). About the right amount of water was applied. There is little deep percolation (enough for salt control) and the entire field is wet sufficiently. It is assumed that surface runoff was minimal or collected for reuse.

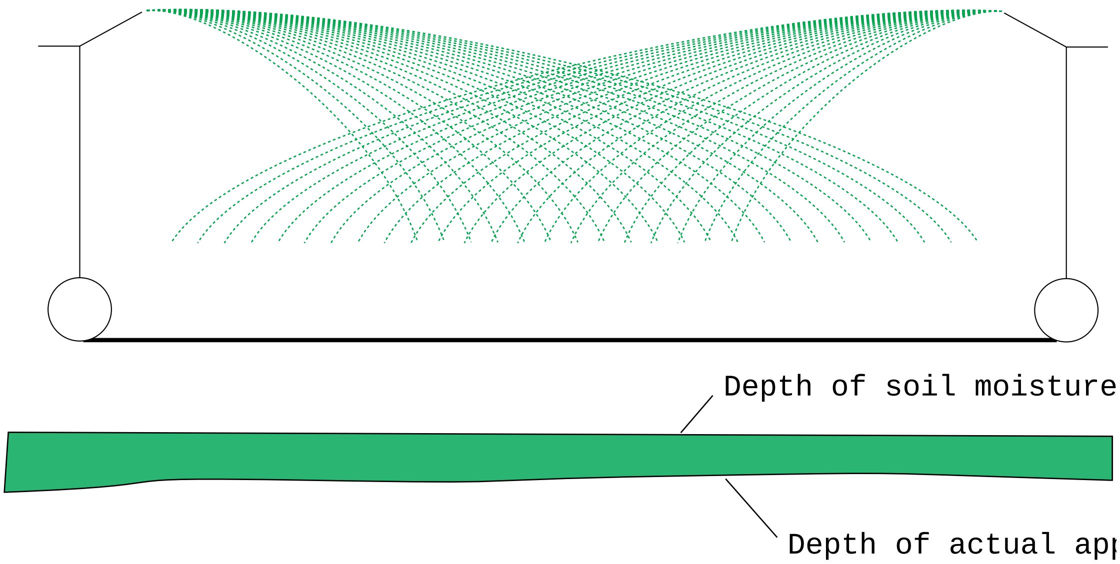


FIGURE 4-3. Depiction of an irrigation sufficiently watering the entire field with good distribution uniformity and application efficiency

Figure 4-4 depicts an irrigation with the same high distribution uniformity (same flat infiltrated water). However, twice as much water as needed was applied, resulting in a low application efficiency. Another practical example of this situation is the farmer who is using a well-designed and maintained micro-irrigation system. The hardware provides good distribution uniformity and the potential for high application efficiency. But, if the farmer runs the system twice as long as necessary, that potential is not realized.

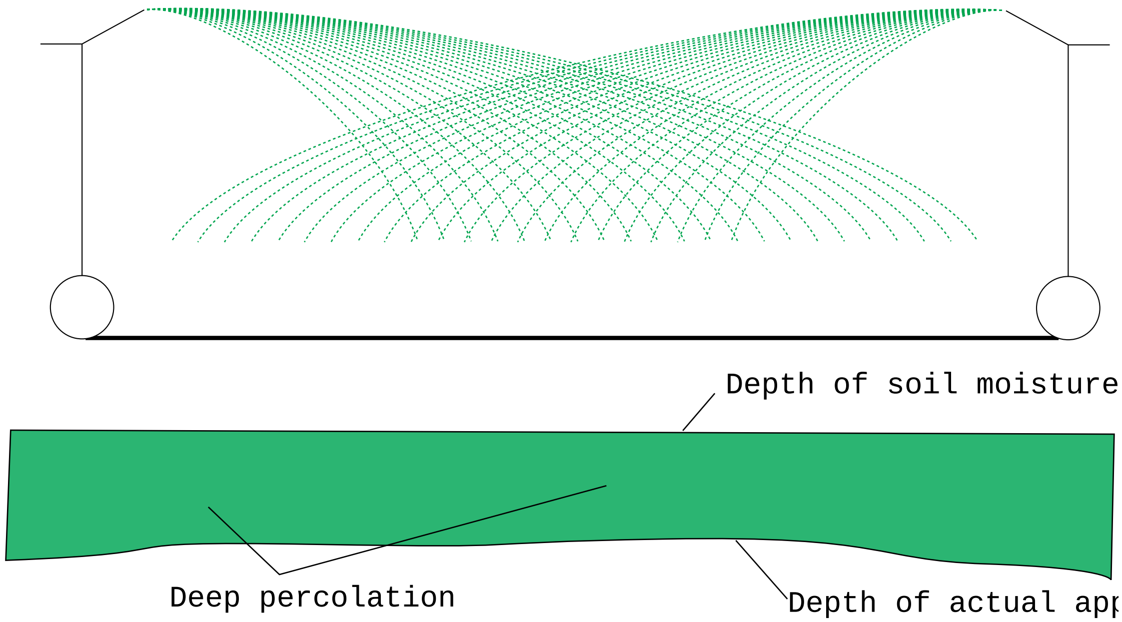


FIGURE 4-4. Depiction of irrigation resulting in good distribution uniformity but poor irrigation efficiency

In summary, Figures 4-1 through 4-4 demonstrate that:

1. Improved irrigation system hardware may result in higher distribution uniformity and also make it easier to achieve higher application efficiency.

2. But, achieving high application efficiency ultimately depends on the management of the system.

An important corollary to the preceding is that if the entire field was assumed to be sufficiently wet during an irrigation, including that water required for leaching, then the distribution uniformity is the upper limit of application efficiency. It then follows that the first concern when improving irrigation system performance is the distribution uniformity.

Efficient, Effective Irrigations

The goal is efficient, effective irrigations. Efficient irrigations make the best use of available water resources while minimizing negative impacts to water quality due to surface/sub-surface losses. Effective irrigations help do what is intended—produce a profitable crop. Efficient, effective irrigations are the result of knowing *when, how much, and how* to irrigate.

When to irrigate is an agronomic decision. Timing of irrigations should enhance the total cultural system. Commonly, irrigations are timed to avoid stress due to lack of soil water. In some cases, desired crop development will dictate some stress. In other situations, irrigations may be timed to aid fertilizer applications.

In any situation, the irrigator must also know *how much to irrigate.* Normally this is:

1. the amount of water required to refill the effective root zone of the plant,

2. plus required leaching for salt control,

3. plus unavoidable losses to deep percolation, surface runoff, or immediate evaporation.

Improving knowledge of how much to irrigate will involve some form of irrigation scheduling as discussed in Practice 2.01.05.

The irrigator must know *how to irrigate* so as to minimize unavoidable losses to immediate evaporation, deep percolation, and surface runoff. Note that it will be impossible to irrigate without some losses unless parts of the field are underwatered.

How to irrigate does not refer to the mechanics of setting up a booster pump or laying out sprinkler pipe. It refers to the ability to achieve good distribution uniformity while maintaining control over the total application. Controlling the total amount of water applied requires:

1. Water applications to be measured (IP 2.01.01).

2. Sufficient control to be present in the irrigation system, including hardware, labor to operate it when needed, and management to tell labor when to stop an irrigation (planning, IP 2.01.06).

3. Sufficient flexibility to be in the primary water supply (deep well, river/stream pump, or irrigation district turnout) so that the grower can turn the water on and off when needed.

Presentations of the Implementation Practices

The Practices for this Objective are presented in four sections. The first section presents Practices that are applicable to any irrigation system type. The other three sections pertain to specific irrigation system types. Section 2 is for furrow/rill systems, section 3 is for sprinkle systems, and section 4 is for micro-irrigation systems.

Within sections 2 through 4 are short discussions on how to get good distribution uniformity and how to control the total application using that particular type of irrigation system. The Practices that follow will first address distribution uniformity and then the control of the application.

Other Information Sources

There are several SCS National Practices that deal with overall issues of design, installation, and management of irrigation systems. These include:

1. Practice 441, covering micro-irrigation systems.
2. Practice 442, covering sprinkle systems.
3. Practice 443, covering surface (furrow/border strip systems).
4. Practice 447, covering tailwater recovery systems.
5. Practice 449, covering general irrigation water management.
6. Practice 587 covering water control structures.
7. Practice 610, covering salt management.

In addition, WSU Cooperative Extension has published many advisories concerning the different types of irrigation systems and management. For example, Drought Advisory EM4828 contains a detailed discussion of the factors involved in achieving high efficiency with surface irrigation systems. Issue 12 of *The Washington Irrigator* contains a discussion of distribution uniformity and the various factors involved in achieving good uniformity.

The American Society of Agricultural Engineers has various Standards and Engineering Practices that address design and management of on-farm irrigation systems. These will be noted in the various Implementation Practices as applicable.

Possible Effects on Water Diversions

Increasing overall application efficiency, by its definition, will reduce required water diversions to an individual farm unit. However, increasing on-farm application efficiency may not result in increased water supplies on a basin-wide basis. This is because of the possible reuse of both deep percolation and surface runoff from one farm by another.

If that deep percolation or surface runoff is reduced, the farm that was once dependent on it may draw from natural sources. Or, there may be legal ramifications if it can be proved that one farm became dependent on the deep percolation or runoff from another.

Possible Effects on Yields

Increasing system performance could very well lead to higher yields due to a number of reasons. This would be true even if all of the field was being sufficiently watered. Just improving distribution uniformity can result in the following:

1. In conjunction with proper set timing, deep percolation is reduced, which means less leaching of nitrogen fertilizer.

2. Improving uniformity can increase fertilizer use in those parts of a field that are underwatered due to non-uniform water application.

3. If fertilizers are being applied with the irrigation water (fertigation) then the uniformity of fertilizer application will increase.

4. All of the above contribute to a healthy crop that is able to utilize applied nutrients properly.

5. In addition, a healthy crop is less susceptible to diseases and insects, which means less need for applications of synthetic chemicals.

Possible Effects on Ground Water Quality

Generally, increasing irrigation system performance will minimize deep percolation. Deep percolation is the transport mechanism for movement of excess soluble nutrients and pesticides into ground water. Thus, adverse impacts on ground water quality by irrigated agriculture should be reduced by increasing irrigation performance.

And, as noted in the discussion of possible yield benefits, improved irrigation performance contributes to a crop that is less susceptible to diseases and insects. Thus, chemical applications may be reduced, which will reduce their availability.

There may not be a one-to-one reduction in impact due to reduction of deep percolation. This is due to a question of “load-flow” relationships. The amount of deep percolation may be reduced, but the concentration of the nutrient or pesticide may be increased depending on circumstances. For example, deep percolation may be reduced 50% but that may not mean the amount of chemical/ nutrient leaching is reduced 50%. Thus, achieving Overall Management Objectives 3.00 and 4.00 to reduce the availability of potential pollutants is essential to ensuring that adverse impacts are reduced or minimized.

Note that deep percolation, either from irrigation or rainfall, cannot be completely eliminated. The discussion in Chapter 3 concerning irrigated agriculture and salinity explained the need for a certain amount of leaching to maintain a salt balance in the root zone.

Possible Effects on Surface Water Quality

With sprinkle and trickle irrigation system types there should be little, if any, surface runoff. To the extent that implementing practices associated with these systems reduces or eliminates existing surface runoff, surface water quality will be protected.

Furrow/rill and border strip irrigation systems create surface runoff as a normal matter of operation. Thus, they have a built-in potential to increase the detachment process. And, if the surface runoff returns to a natural water course it becomes a transport mechanism as well. Depending on the current management, some of the Implementation Practices intended to increase distribution uniformity could increase the potential amount of surface runoff.

If a runoff-reuse system is installed (IP 2.02.11) surface runoff should stay on the individual farm. However, it is important to achieve Overall Management Objectives 3.00 and 4.00 to minimize the effects of the detachment process. That is, given that surface runoff will occur, minimize the amount of nutrients and chemicals that are available to be carried by that runoff. Finally, Objective 5.00 is important for managing any surface runoff that is produced.

Again, as noted in the discussion of possible yield benefits, improved irrigation performance contributes to a crop that is less susceptible to diseases and insects. Thus, chemical applications may be reduced.

SECTION 1 - PRACTICES FOR ALL IRRIGATION SYSTEM TYPES

The Implementation Practices in this section are actions that are applicable to any irrigation system. They should be part of any on-farm program for preventing contamination of surface and ground water.

IP 2.01.01 - Measure All Water Applications Accurately

Objective

Measure applied water so that knowledge of how much to irrigate, gained from some form of irrigation scheduling or just feeling the soil in the root zone, can be used properly.

Description

The basis for modern irrigation management is knowing how much water is being applied and where. Accurate measurement of water deliveries is essential. There are devices and techniques for use in open channels (ditches, streams, rivers) or pipelines.

These include:

1. Flumes, weirs, and orifice gates for streams, ditches, and canals.

2. Propeller flow meters and orifices for pipelines.

Main water delivery pumps should always have a flow meter installed. In addition to monitoring irrigation applications flow meters can serve as early warnings as to problems with a well or pump. Propeller flow meters can also measure total volume of water pumped as well as water flow.

A flow meter does not have to be a permanent installation. Depending on the configuration of the conveyance system, portable meters may be utilized. And, there are several types of flow meters available besides propeller types.

On pressurized systems (sprinkle, trickle) a flow meter in conjunction with a pressure gauge can indicate whether the system is performing as designed. Local irrigation supply companies are a source for flowmeters or information concerning manufacturers. Note that there are important restrictions concerning the installation of flow meters. Most important is that there must be clear, smooth flow into the metering device for an accurate measurement. Recommendations usually range from five to eight pipe diameters of smooth straight pipe upstream of a propeller meter and two to four pipe diameters clear downstream (refer to Figure 4-5). Follow manufacturer's recommendations whenever installing a flowmeter in either open channels or pipelines.

Meter gates for delivering water to a field or farm ditch come with factory calibration curves. Two simple measurements are all that are needed to estimate flow through a meter gate: (1) the head at the gate and (2) the amount of gate opening.

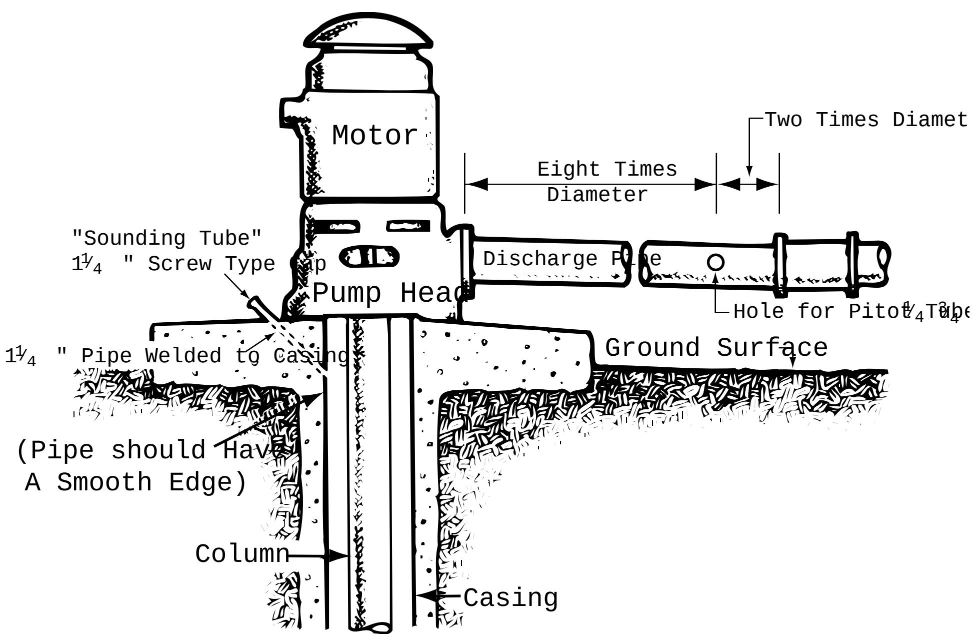


FIGURE 4-5. Schematic of water well showing recommended configuration of discharge piping in order to test flow accurately (flow tested by pitot tube) - after Pacific Gas & Electric Company publication 62-8953

Low-cost flume designs, such as the Replogle Flume shown in Figure 4-6, have been developed for use in concrete lined ditches. USDA Farmer's Bulletin 2268, *Constructing Simple Measuring Flumes for Irrigation Canals,* contains design and construction information for the Replogle flume. SCS offices will also have information on flume design and construction. WSU Extension publication C0912, *Determining the Gross Amount of Water Applied-Surface Irrigation*, contains more information on measuring water applications.

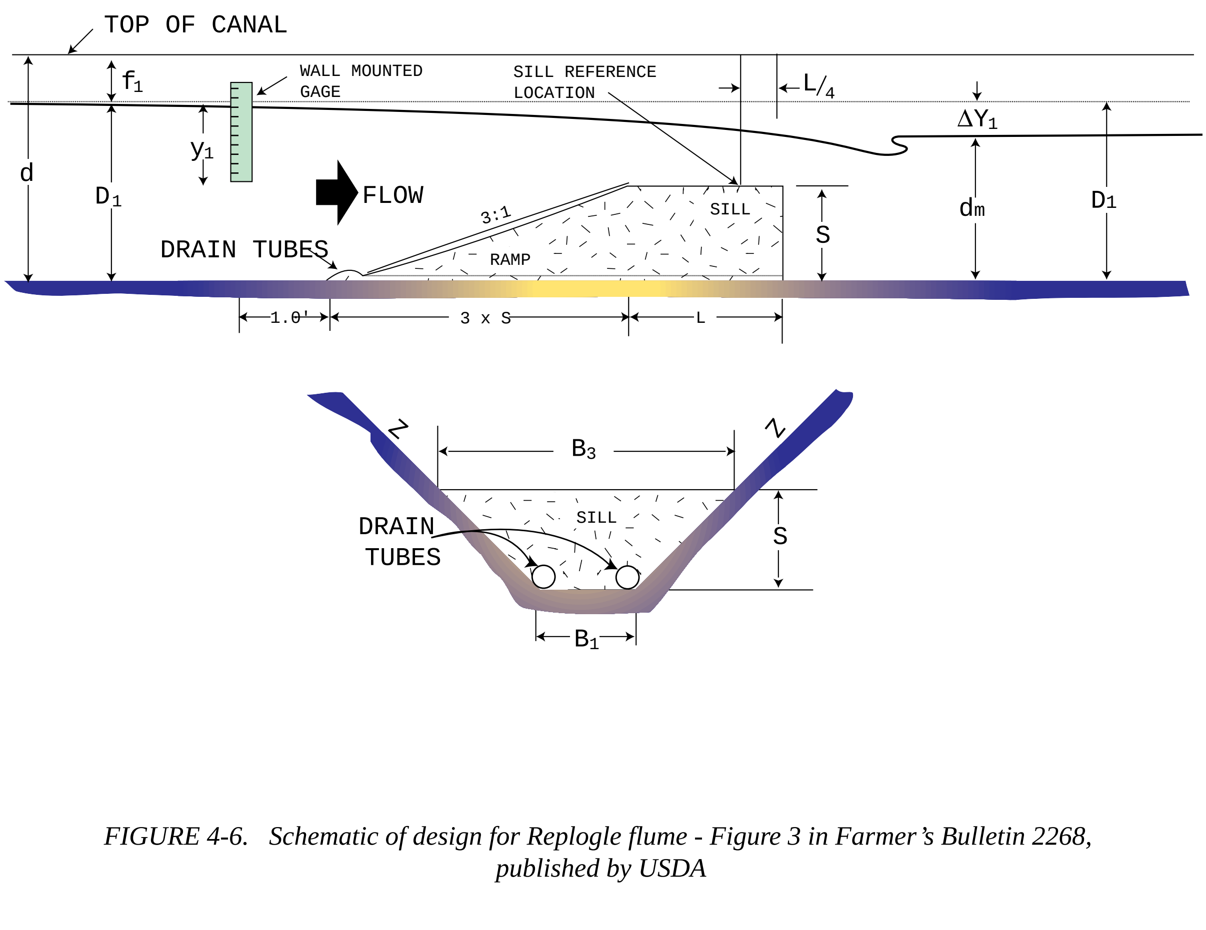


FIGURE 4-6. Schematic of design for Replogle flume - Figure 3 in Farmer's Bulletin 2268, published by USDA

4 CHAPTER

IP 2.01.02 - Monitor Pumping Plant Efficiency

Objective

Maintain pressure and flow into an irrigation system as designed while maximizing energy use efficiency. The distribution uniformity and thus, potential application efficiency, of many irrigation systems are partially dependent on maintaining design flow and pressure from the pumping plant.

Description

Many irrigation systems are partially dependent on a pumping plant maintaining the correct water flow and pressure for good distribution uniformity. This is especially critical in sprinkle and trickle systems. However, insufficient or fluctuating flows may also affect furrow and border strip systems as well. If the pump performance should deteriorate this could decrease the uniformity and efficiency of the system.

Pumping plants should always have a flow meter and a pressure gauge installed.
The grower should know the design operating condition of the pump, that is, the design combination of flow and pressure. If the flow or pressure during operation are not as designed then something may be wrong with the pumping plant. In the case of sprinkle or trickle irrigation systems, the system may not be set up or being operated correctly, or emission devices or nozzles may be worn or clogged.

Pacific Northwest Extension publication PNW285, *Pumping Plant Efficiencies*, discusses how to test for pumping plant efficiency as well as providing tips on how to minimize pressure losses in a system. Pumping plant efficiency tests may be available through pump companies or private consultants.

During an efficiency test, the water horsepower output of the pump (a factor of the combination of flow and total dynamic head) will be compared to the input horsepower. Measurements that are needed include:

1. Well lift - pumping water level.

2. Well column losses.

3. Pump discharge pressure.

4. Pump flow.

5. Power into the pumping plant (either gallons per hour of fuel or kilowatt-hours).

An example pump test report is seen in Figure 4-7.

PUMP TEST

Test No.: 911624
Record #: 70

Pump No.: #1
Test Date: 05-June-91

Operator/Owner:
Address:
City:

Pumping plant location: PRESSURE AREA

PG&E location No.: 94556 Meter No.: 159036

Pump make: LAYNE Serial No.: 6740

Motor Make: NO NAME PLATE Serial No.: NA
Horsepower: 40
Motor Efficiency: 88.0 %

PUMP TEST REPORT

Datum=c/l discharge pipe	WIDE OPEN	15 PSI DISCHARGE	SHUT OFF
Static Water Level, Feet	81.4	81.4	81.4
PUMPING WATER LEVEL, feet	97.4	90.6	81.4
Drawdown, feet (dd)	16.0	9.2	0.0
Discharge pressure, psi	2.0	15.0	28
Discharge pressure, feet	4.6	34.7	64.7
TOTAL DYNAMIC HEAD, feet	102.0	125.3	146.1
Avg. disch. pipe velocity, fps	4.03	2.69	0
CAPACITY, gpm	651	434	0
YIELD OF WELL, gpm/ft. dd	41	47	NA
Water pumped per day, ac-ft	2.88	1.92	0.00
Measured speed, rpm	1770	1770	1770
Kilowatt input, kw	27.0	24.2	16.0
Horsepower input, hp	36.2	32.4	21.4
Kilowatt hours/unit pumped	225	302	NA
OVERALL PLANT EFFICIENCY,%	46.3	42.4	NA
Motor load, % full load	79.7	71.2	47.0
ENERGY COST, $/ac-ft	24.80	33.25	NA

Pump tested by: TFR/MSR

Test witnessed by: WG

FIGURE 4-7. Example pump test report (note the three operating conditions of wide open discharge, 15 pounds per square inch discharge, and no discharge)

IP 2.01.03 - Evaluate the Irrigation System Using SCS or WSU Cooperative Extension Procedures

Objective

This practice has three major objectives:

1. Ensure that the irrigation system hardware is in good operating condition.

2. Ensure that the irrigation system design is matched to the site conditions.

3. Indicate where system management can be improved so that distribution uniformity and overall potential application efficiency is increased.

Description

Evaluation of an irrigation system involves several aspects: 1) the overall condition of the system, 2) whether essential components are in place, and 3) how the design and management of the system work together to achieve high or low distribution uniformities and application efficiencies. In many cases the condition of the system directly affects the performance.

Pacific Northwest Extension publication PNW293, *Walk-Through Irrigation Systems Analysis,* contains a checklist that can be used to "walk through" the irrigation system, checking on the overall condition and whether vital components, such as pressure gauges or flow meters, are in place. The publication contains sections for suction systems on booster pumps and deep wells, pumps in general, electric motors and service, pipelines, sprinkler laterals, and sprinkler heads. Growers wishing to do their own evaluation should obtain a copy of PNW293 and perform the "walk-through." Even if the irrigation system is a furrow or border strip system, some of the checklist will be applicable.

Two Drought Advisory bulletins from WSU Cooperative Extension, *Irrigation System Evaluation* (EM4822) and *Set-Move and Permanent Sprinkle Irrigation Systems* (EM4832), contain information on how to evaluate the operating performance of irrigation systems. For example, an evaluation of a sprinkle system will include checks of pipe pressure at several spots in the system. If the pressures are too far apart then this indicates poor pressure uniformity, which may count against the overall distribution uniformity of the system.

The SCS has also developed evaluation procedures for testing the distribution uniformity that results from an irrigation. Evaluations may be available through SCS, local Conservation Districts, or local consultants.

The American Society of Agricultural Engineers has several published standards and practices for evaluating systems. These include:

1. S298.1 - Procedure for Sprinkler Testing and Performance Reporting.
2. EP419 - Evaluation of Furrow Irrigation Systems.
3. S346 - Test Procedure for Determining the Uniformity of Water Distribution of Center Pivot, Corner Pivot, and Moving Lateral Irrigation Machines Equipped with Spray or Sprinkler Nozzles.

IP 2.01.04 - Know Required Leaching Fractions to Maintain Salt Balances

Objective

Maintain the viability of irrigated agriculture while minimizing required deep percolation.

Description

All irrigation water contains salts. Thus, as irrigations proceed, salt is added to the soil. There are other sources of salts in the root zone as well. Essentially, the plant will take up pure water, leaving the salts behind. Over time, with no other management action, these salts will build up in the soil to the level at which yields are impacted or cropping options are decreased.

The only way to maintain a suitable salt balance in the root zone is through leaching, the creation of intentional deep percolation to carry salts out of the root zone. However, leaching should be the minimum necessary and the amount of required leaching varies with the irrigation water quality, soil conditions, and desired cropping rotations.

The irrigation water supply should be tested for total salts, adjusted SAR, and critical salts such as boron, calcium, magnesium, and sodium. Consult a qualified agronomist for recommendations on required leaching fractions or contact the local WSU Cooperative Extension office. Table 3-1 in Chapter 3 of the Manual contains guidelines for interpreting water quality tests.

Be aware of the other problems excess or imbalanced salts can cause:

1. Low soil permeability.
2. Specific crop toxicities.
3. Irrigation system corrosion.
4. Disposal of required leaching water.

There are several equations in use for determining required leaching ratios. One commonly used was developed by Rhodes, et al., and is presented in FAO 29 *Water Quality for Agriculture* (Westcott and Ayers). It states:

$$LF = \frac{ECe}{(5 * ECe) - ECiw} \times 100$$

where:

LF = that percentage of applied water that must be deep percolation

ECe = the electrical conductivity of the average saturation extract from the root zone - this number will usually be assumed as the maximum salinity allowable before yield reductions will be expected. These “yield reduction threshold salinities” are listed in a number of publications. Local agronomic consultants should know the values for crops grown in their areas.

ECiw = the electrical conductivity of the irrigation water

SCS National Practice 610 addresses leaching for salt control.

IP 2.01.05 - Use Irrigation Scheduling as an Aid in Deciding When and How Much to Irrigate

Objective

Irrigation scheduling techniques can aid in improving overall application efficiency by either improving the timing of irrigations, more closely estimating the correct amount of water to apply during the irrigations, or both. Thus, implementing irrigation scheduling would normally tend to reduce water diversions.

However, in those cases where a crop was proved to be under-watered, diversions may actually be increased. Note that this does not mean that application efficiencies were necessarily reduced.

Description

Irrigation scheduling is the general name given to a number of different techniques. All of these techniques will help the irrigator in deciding when to irrigate, how much water to apply with the irrigation, or both. Generally, some method is used to measure or predict the soil or plant water content. At some pre-determined water content an irrigation is indicated. Some form of irrigation scheduling is applicable to any combination of crop and irrigation system.

Application efficiency can be improved either because individual applications are reduced or, in extreme cases, some irrigations avoided entirely. This Practice should be used in conjunction with IP 2.01.03, *Irrigation System Evaluation*, so that the increased knowledge of how much to irrigate can be utilized properly.

There are two major families of irrigation scheduling techniques. One is generally called "checkbook" or "water budget." With checkbook scheduling, the irrigation manager first defines the depth or volume of root zone to manage. He/she then attempts to identify, measure, and predict all water going into and out of this root zone. A common water budget equation is:

$$D_2 = D_1 + ETc + DEEP - IRR - RAIN + UP$$

where:

- D_2 = root zone depletion at the end of a day
- D_1 = root zone depletion at the start of a day
- ETc = crop evapotranspiration for the day
- DEEP = deep percolation out of the root zone for the day
- IRR = irrigation water added to the root zone that day
- RAIN = effective rainfall for the day (that portion of the gross rainfall that infiltrates)
- UP = upwards percolation of water into the root zone from a high water table

These factors are seen in Figure 4-8, a schematic of the crop root zone identifying the various types of water moving into and out of it.

All variables are defined in terms of inches of water. An irrigation is called for when the resulting total soil water, or soil water depletion, is predicted to reach some predetermined level, the "management allowed depletion" (refer to the discussion in Chapter 3 regarding soil-water-plant relationships). Checkbook irrigation scheduling will result in an estimate of both the timing and amount of irrigations.

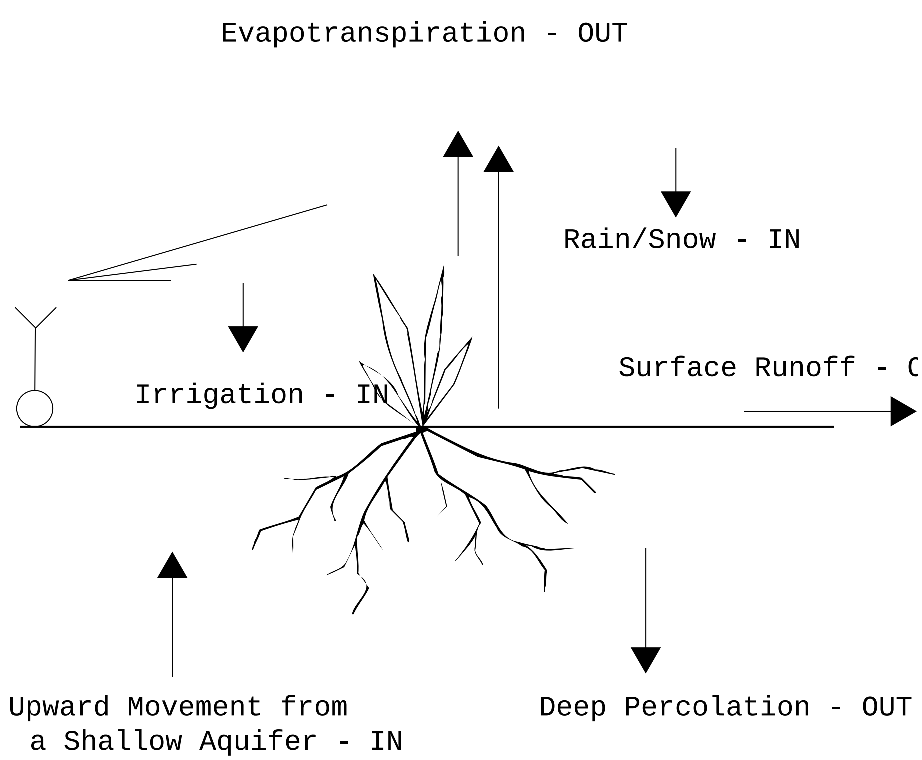


FIGURE 4-8. Schematic indicating the different categories of water coming into and going out of the effective crop root zone

Although the previous equation seems simple, checkbook irrigation scheduling can be complex and computers are often used with this method. The method depends on science to predict the soil water level, especially when predicting daily crop evapotranspiration (crop water use). However, the accuracy of water budget scheduling in field use relies heavily on periodic field checks of actual soil water content to allow continual adjustment of the computer models.

Common names given to the other major family of irrigation scheduling are “graphical,” “bottom-line,” or “moisture monitoring.” The general technique is to:

1. Choose some method of measuring soil or plant water,
2. Make these measurements on a rather frequent basis,
3. Plot the measurements with time,
4. Use the trend of measurements, or the individual measurement itself, to judge when to irrigate, how much to irrigate, or both.

Water measurements can be:

1. Gravimetric and volumetric - these are measurements of the actual soil water content. They can be done using the gravimetric method, a neutron probe, reflectometer, or by simply using experience to judge the look and feel of soil samples. This type of measurement can be calibrated to provide estimates of water available to the plant or water depleted from the soil. Measurements of soil water depletion are especially helpful to farmers as they are the “how much” to irrigate. That is, the soil water depletion is generally the amount of water that an irrigation is attempting to replace.

   The “feel” method of estimating soil water content is the process of taking small samples of soil from various depths in the root zone and then comparing the color and feel to a chart of descriptions. The descriptions on the chart are keyed to either soil water depletion or soil water content. Table 4-1 was taken from the USDA-SCS pamphlet, *Estimating Soil Moisture by Feel and Appearance*, that describes how to use the method. Note that this pamphlet contains color pictures of sandy loams, loams, and clay loam soils at various water contents. Although not as accurate as using a neutron probe or reflectometer, the feel method is fast, flexible, and inexpensive. Farmers can quickly become adept at estimating soil water deficits with reasonable accuracy.

   The gravimetric method entails obtaining a soil sample of known volume, weighing the sample wet, drying the sample, then weighing it again. The difference in weight is the water lost to drying. The data are then converted to volume of water per volume of soil, or inches of water per inch of soil.

2. Measurements of soil water tension - most commonly done with gypsum blocks or tensiometers. These indicate stress on a plant and thus, are useful in deciding when to irrigate. But there must be some relationship established, or another technique in use, to indicate the soil water depletion, which is the “how much” to irrigate.

TABLE 4-1. Guide for Estimating Soil Moisture Condition - taken from *Estimating Soil Moisture by Feel and Appearance*, published by SCS

GUIDE FOR ESTIMATING SOIL MOISTURE CONDITIONS

Dominant Texture	**Fine Sand and Loamy Fine Sand**	**Sandy Loam, Fine Sandy Loam**	**Sandy Clay Loam and Loam**	**Clay, Clay Loam or Silty Clay Loam**
Available Water Capacity (Inches/Foot)	0.6 - 1.2	1.3 - 1.7	1.5 - 2.1	1.6 - 2.4
Available Soil Moisture	Soil moisture deficit in inches per foot when the feel and appearance of the soil is as described.			
0 - 25 percent	Dry, will hold together if not disturbed. Loose sand grains on fingers.	Dry, forms a very weak aggregated soil grains ball, break from ball.	Dry, soil aggregations break away easily, no moisture staining on fingers.	Dry, soil aggregations easily separate, hard clods crumble with applied pressure.
	1.2 - 0.7	1.7 - 1.1	2.1 - 1.4	2.4 - 1.6
25 - 50 percent	Slightly moist, forms weak ball with well defined finger marks. Light coating of loose and aggregated sand grains on fingers.	Slightly moist, forms a weak ball with defined finger marks few aggregated soil grains break away, darkened color, very light water staining.	Slightly moist, forms a weak ball with rough surfaces, darkened color, moisture staining on fingers.	Slightly moist to moist, forms a weak ball, very few soil aggregations break away, no water stains. Clods flatten with applied pressure.
	0.7 - 0.5	1.1 - 0.8	1.4 - 0.9	1.6 - 1.1
50 - 75 percent	Moist, forms a weak ball loose and aggregated sand grains remain on fingers, darkened water staining.	Moist, forms ball with very few aggregated soil grains breaking away, light water staining, darkened color.	Moist, forms firm ball well defined finger marks, irregular soil/water water coating on fingers, darkened color, pliable.	Moist, forms smooth ball with defined finger marks, little or no granules remain on fingers. Pliable, ribbons between thumb and forefinger.
	0.5 - 0.2	0.8 - 0.4	0.9 - 0.5	1.1 - 0.6
75 - 100 percent	Wet, forms a weak ball, loose and aggregated sand grains form uneven coating on fingers.	Wet, forms ball, free water appears on soil surface when squeezed or shaken, irregular soil/water coating on fingers.	Wet, forms soft ball, light to heavy soil/water coating on fingers, soil may glisten after squeezing or shaking.	Wet, forms soft ball, soil may glisten following squeezing or shaking, light to heavy soil/water coating on fingers, easily ribbons.
	0.2 - 0.0	0.4 - 0.0	0.5 - 0.0	0.6 - 0.0
At Field Capacity (100 percent)	Wet, forms a weak ball, free water glistens briefly on soil surface when shaken, wet outline on hand after squeezing.	Wet, forms soft ball, free water appears briefly on soil surface when squeezed or shaken, irregular soil/water coating on fingers.	Wet, forms soft ball soil pat with water glistening on surface after squeezing or shaking. Thick soil coating on fingers.	Wet, forms very soft soil pat, thick soil/water coating on fingers, soil glistens, slick and sticky, will not ribbon.
	0.0	0.0	0.0	0.0

Figure 4-9 is an example graph of a series of tensiometer measurements in a trickle irrigated orchard. When the trend of measurements started at the begining of July, indicating that the soil was drying out, the number of operating hours per week was increased. After the increase, the measurements dropped again to a stable and satisfactory level.

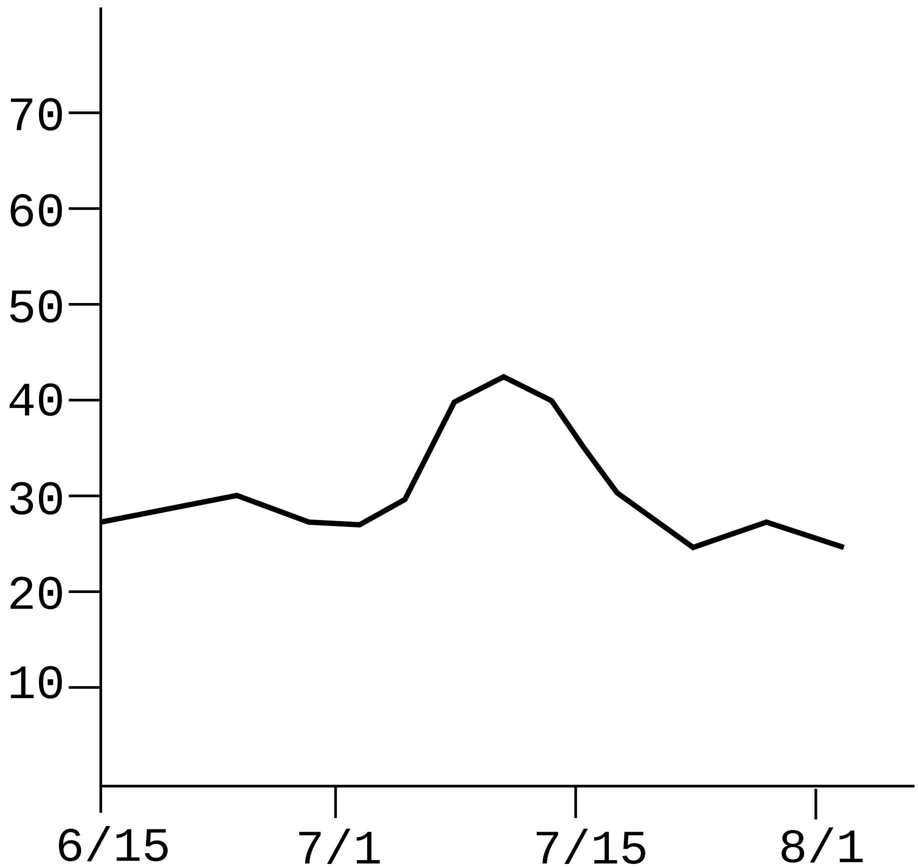


FIGURE 4-9. Example graph of tensiometer readings used to guide irrigations

3. Measurements of plant water tension - using the leaf pressure chamber. The pressure chamber is a direct measurement of stress on a plant and thus, useful in deciding when to irrigate. But, there must be some relationship established, or another technique in use, to indicate the soil water depletion, which is the "how much to irrigate."

4. Measurement of a surrogate for plant stress - a common technique would be infrared thermometry which measures the difference between plant leaf temperature and air temperature. A calculated "Crop Water Stress Indicator" will indicate the level of stress on a plant and thus, can be used to decide when to irrigate. But, there must be some relationship established, or another technique in use, to indicate the soil water depletion, which is the "how much to irrigate."

Pacific Northwest Extension publication PNW288, *Irrigation Scheduling,* and WSU Cooperative Extension publications EB1304, *Simple Irrigation Schedule Using Pan Evaporation*, EM4825, *WSU Drought Advisory: Scientific Irrigation Scheduling,* and EB1513, *Irrigation Requirements for Washington: Estimates and Methodology,* offer more complete discussions of irrigation scheduling. Several Drought Advisories from WSU Cooperative Extension also contain information useful for irrigation scheduling systems. These include Tree Fruits (March 1988), Vegetable Crops (April1988), Mint Irrigation Management (March 28, 1988), and Visual Crop Moisture Stress Symptoms (March 1988). Issue 11 (Fall 1989) of *The Washington Irrigator* also contains a discussion of irrigation scheduling. SCS National Practice 449 addresses general irrigation water management.

In addition, Washington State University Cooperative Extension has developed PAWS, Public Agricultural Weather System. PAWS is a valuable source for irrigation management information. It consists of a network of standardized, calibrated weather stations placed in strategic agricultural production areas. The data from these weather stations are stored in computers and available to users of the service. More importantly PAWS calculates a daily estimate of a reference evapotranspiration. This reference ET is essential for checkbook irrigation scheduling. WSU Cooperative Extension Bulletin 1547, a PAWS user manual, is available from any Cooperative Extension office.

The PAWS network includes data from the Agri-Met system, a Northwest-wide network of weather stations and irrigation scheduling information developed and operated by the Bureau of Reclamation. The Bureau's Pacific Northwest Regional Water Conservation Center in Boise, Idaho, has more information on Agri-Met and its services to growers.

Checkbook irrigation scheduling can be complex to start up. Obtain and read the Cooperative Extension literature cited above. It is best to utilize the services of a competent and experienced agriculturalist when first starting irrigation scheduling. The local Conservation District, Soil Conservation Service, or WSU Cooperative Extension office can also provide aid.

Graphical methods of irrigation scheduling are simpler to start up but take some experience to develop the calibration needed for effective use. Again, it is highly recommended that experienced consultants be called on when first starting an irrigation scheduling system.

IP 2.01.06 - Practice Total Planning of Individual Irrigations

Objective

Manage the irrigation system and each irrigation objectively to increase efficiency and develop benchmarks on which to base improvements.

Description

Total planning for individual irrigations involves the following steps:

1. Determine when to irrigate - this is an agronomic decision based on how the crop is to be managed. The use of soil or plant moisture measuring devices such as tensiometers, gypsum blocks, and leaf pressure chambers can be valuable aids in deciding when to irrigate. Irrigations are usually scheduled to prevent crop stress. However, sometimes crop stress is desirable.

2. Determine how much to irrigate - the soil water deficit is the amount of water that is needed to wet the soil in the effective root zone back to field capacity. This can be determined by using some form of water budget type of irrigation scheduling. A simpler method is to use a soil sampler and feel the soil taken from different depths in the root zone (refer to IP 2.01.05). For micro-irrigation systems or other high frequency irrigation management, the amount of water to apply will be based on the daily crop water use rates.

   The "how much" to irrigate also includes water required for leaching to maintain a salt balance.

3. Determine an initial strategy based on system design or past performance (the "how to irrigate").

   Furrow/Border Strips - The initial strategy for a furrow or border strip irrigation system involves the stream size into the furrow or border and length of set. For a furrow system there may also need to be decisions made concerning a possible cutback. If using surge flow there will have to be an initial strategy concerning the flow rates, length of pulses, and number of pulses (refer to IP 2.02.03). An equation that can be used for planning is:

$$\text{INCHES} = \frac{\text{GPM} \times \text{HOURS} \times 96.3}{\text{FURROW LENGTH} \times \text{FURROW SPACING}} \times \text{AE}$$

   where:

   INCHES = net amount of water infiltrated in inches
   GPM = furrow flow rate in gallons per minute
   FURROW LENGTH = furrow length in feet
   FURROW SPACING = furrow spacing in feet
   AE = expected application efficiency as a decimal (i.e., 70% efficiency = .7)

   When using the above equation, the initial strategy is to run GPM as a flow for HOURS amount of time. The INCHES found using the equation should be compared with the estimated soil water deficit. If they are not equal then another strategy should be chosen.

There are some important assumptions in the above equation:

1. Every furrow has water running in it. If every other furrow has running water then the FURROW SPACING used in the equation would be twice the actual furrow spacing.

2. The GPM flow chosen will result in an acceptable advance ratio. That is, the flow will wet the furrow in an acceptably short amount of time in relation to the total set time.

3. The assumed AE is close to the final result. It is important that the grower consider the disposition of runoff.

If a cutback flow is going to be used, the equation is modified as:

$$\text{INCHES} = \frac{(\text{GPM}_1 \times \text{HOURS}_1 \times 96.3) + (\text{GPM}_2 \times \text{HOURS}_2 \times 96.3)}{\text{FURROW LENGTH} \times \text{FURROW SPACING}} \times \text{AE}$$

where:

INCHES = net amount of water infiltrated in inches
GPM_1 = initial furrow flow rate in gallons per minute
HOURS_1 = time that initial flow in place
GPM_2 = cutback furrow flow rate in gallons per minute
HOURS_2 = time that cutback flow in place
FURROW LENGTH = furrow length in feet
FURROW SPACING = furrow spacing in feet
AE = expected application efficiency as a decimal (i.e., 70% efficiency = .7)

The above equation can also be used for border strips by substituting BORDER LENGTH and BORDER WIDTH for FURROW LENGTH and FURROW SPACING.

Sprinkle - Hand-line and side-roll sprinklers have an application rate that is measured in terms of inches of water applied per hour. Knowing this application rate, expected application efficiency, and the soil water depletion at irrigation allows an easy computation of indicated set time using the equation:

SET TIME = SWD / (AE x AR)

where:

SET TIME = the indicated set time in hours
SWD = soil water deficit (including leaching requirements) in inches
AE = expected irrigation efficiency as a decimal
AR = application rate of the system in inches per hour

Example: assume the following:

- application rate (AR) = .2 inch/hour
- overall application efficiency (AE) expected is 75%
- soil water depletion (SWD) at irrigation is 3 inches

SET TIME = SWD / (AE x AR)
= 3 in / (.75 x .2 in/hr)
= 20 hours

It is often desirable for sprinkler sets to be multiples of 12 or 24 hours, making it convenient for labor to change sets. In the above example, if the set was started at 6:00 A.M., then the set would have to be changed at 2:00 A.M. Another way to use the equation is to first assume a 12- or 24-hour set, or whatever is desirable, and then determine the soil water depletion that the set will satisfy.

Using the previous example, assume the following:
- desired 23-hour sets (1 hour to change pipe positions)
- overall application efficiency of 75%
- application rate of .2 inch/hour

Now, solving for the soil water depletion at the time of irrigation:

SWD = SET TIME x AE x AR
= 24 x .75 x .2
= 3.6 inches

Thus, the farmer would wait until the soil water depletion was 3.6 inches before putting on the 23-hour set. This assumes that the 3.6-inch soil water depletion will not adversely affect crop development.

There are other methods for determining a strategy for center pivots and micro-irrigation systems. WSU Cooperative Extension publication EB1305, *Sprinkler Irrigation - Application Rates and Depths*, contains a detailed discussion on planning irrigations with sprinkle systems.

4. React to the results - the initial irrigation sets should be monitored closely to see if the strategy chosen is appropriate. The grower might have to react to unforseen circumstances.

5. Maintain records - most growers keep detailed records of farming operations and irrigation management should be no different. The soil water deficit at irrigation, the condition of the furrow, border strip, or field surface, the climate, the strategy used, and results should all be noted.

SCS National Practice 449 addresses general irrigation water management while Practice 610 covers leaching for salt control.

IP 2.01.07 - Use Two Irrigation Systems in Special Situations (sprinklers for pre-irrigations then furrows; portable gated pipe to reduce furrow lengths for pre-irrigations; sprinklers to germinate crops irrigated by micro-irrigation; over-tree sprinkler for cooling/frost control with undertree for irrigation)

Objective

Ensure that an appropriate irrigation system type is used throughout the season. An appropriate system type will allow the highest application efficiency possible consistent with overall farm economics.

Description

The term "dual irrigation systems" may be applied to a number of situations. Casual observations or a formal irrigation system evaluation (IP 2.01.03) may indicate that the one irrigation system in use is very inefficient at certain times in the season due to soil, crop, or climatic conditions. Thus, another type of irrigation system, or a temporary modification to the current system may be in order during these periods. Two of the more common situations would be:

1. A hand-line or solid-set sprinkle system and a furrow/rill or border strip system used on the same field in the same season. In this case the sprinkler system is used for pre-irrigations, germination, and possibly early, light, seasonal irrigations. Sprinkle systems allow better control of the total water application. This may be required by the frequent, light applications during germination. Also, some soils will have very high infiltration rates early in a season. The sprinkle system maintains high application efficiency in a situation where total water applications would be hard to control with the furrow/rill system.

2. Temporary use of portable gated pipe to reduce the run length of a furrow/rill irrigation system. Again, when soil infiltration rates are high, or smaller water applications are required, shorter furrow lengths make it easier to maintain acceptable application efficiencies.

In both of the situations described above, the portable pipe, either sprinkler or gated pipe, is removed at some time during the season and irrigations are continued using the regular furrow/rill or border strip system.

IP 2.01.08 - Consider Changing the Irrigation System Type

Objective

Ensure that an appropriate irrigation system type, enabling sufficiently good application efficiency, has been chosen for the site.

Description

An irrigation system is only as good as the management of that system. However, some system types are more adapted to a particular situation than others. It may be that site conditions will prevent good irrigation performance with one irrigation system type. For example, it may be difficult to irrigate efficiently with furrows on a steep, rocky soil. Or, excessive wind conditions will place a limit on potential efficiency with sprinkle systems. In such cases consideration should be given to changing the irrigation system type. The final decision should be based on a complete economic analysis.

It can be a difficult and expensive decision to change system types. The current irrigation system operation should be evaluated first to see if there are changes that could be made to improve performance (IP 2.01.03). If performance is poor, even with the best management possible, other systems should be evaluated for adaptability.

Contact the local WSU Cooperative Extension or SCS offices for advice and assistance. Local agronomic consultants, irrigation supply centers, and agricultural engineers will also know which systems are best adapted to specific situations.

IP 2.01.09 - Use Aerial Photography to Identify Patterns that Indicate Problems with Irrigation/Drainage Management

Objective

Early identification of crop development problems, some of which may be due to poor irrigation and drainage management.

Description

Aerial photography can be an aid in identifying overall problems in agriculture. Soil streaks, weed infestations, areas of insect pressure or plant disease, and irrigation and drainage problems may be readily indicated by aerial observation. Modern techniques involve the use of infrared film and computer enhancement to increase the usefulness of aerial photography. Information about available aerial photography services can be found in local phone books or by contacting WSU Cooperative Extension or the SCS.

SECTION 2 - PRACTICES FOR SURFACE (FURROW/RILL, BORDER STRIP) IRRIGATION SYSTEMS

Drought Advisory EM4828, *Surface Irrigation Systems,* published by WSU Cooperative Extension is a discussion of achieving good distribution uniformity and application efficiency with surface irrigation systems.

There are two variables that control how much water infiltrates during an irrigation using a surface irrigation system, 1) the infiltration rate of the soil and 2) the opportunity time. The infiltration rate is how fast water will soak into a soil. Infiltration rates usually change throughout a season due to irrigations and cultivations and normally decrease continuously throughout an irrigation (although most soils will reach what is known as a “basic intake rate” at some point in the irrigation).

Opportunity time is the amount of time that water is on the surface of the soil at a particular point. If water is running in a furrow for 24 hours, then the top of the furrow has had 24 hours of opportunity time. The bottom of the furrow has had something less than 24 hours because it takes time for water to travel from the top of the furrow to the bottom.

There are three aspects of overall distribution uniformity with furrow/rill irrigation systems: 1) down-row uniformity, 2) cross-row uniformity, and 3) soils variability. They are depicted in Figures 4-10, 11, and 12.

Down-row uniformity

Down-row uniformity refers to the difference in infiltration from the head to end of the furrow. As previously stated, the head of a furrow will always have more opportunity time than the end of a furrow. The difference in infiltrated water from the head of the furrow to the end depends on the actual difference in opportunity time and the pattern of infiltration rate of the soil. The effects of poor down-row uniformity are diagrammed in Figure 4-10.

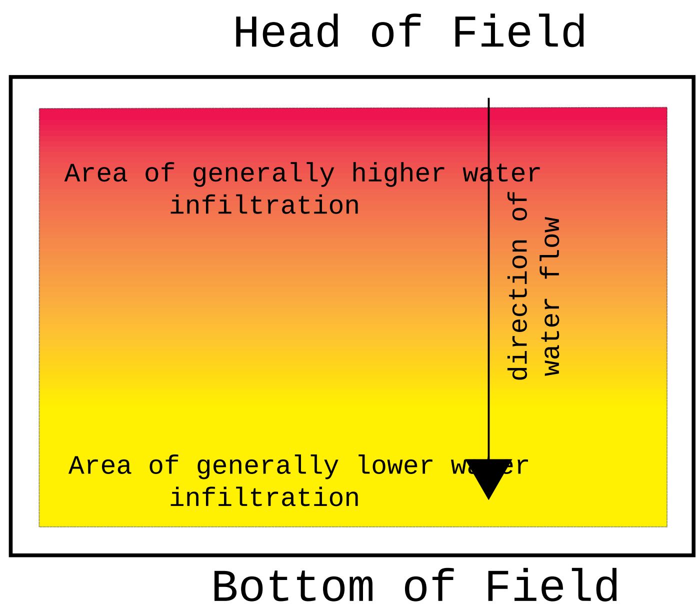


FIGURE 4-10. Schematic of effects of poor down-row uniformity during a furrow irrigation

Improving down-row uniformity is a matter of having a fast enough water advance. That is, when water is first turned into the furrow, it must travel sufficiently quickly down the furrow to equalize the opportunity times between the top of the furrow and the bottom to some degree.

Recommendations for water advance are sometimes given in terms of an “advance ratio.” The advance ratio is found by dividing the “advance time” by the total set time. The advance time is the amount of time necessary for water to go from the top of the furrow to the bottom when irrigation first starts. For example, if the time of advance is 6 hours and the total set time is 24 hours, the advance ratio is 6/24 = 1/4.

It is usually recommended that water advance to the end of a furrow in about 1/4 to 1/3 of the total set time with coarse soils, in about 1/3 to 1/2 of the total set time with medium loams, and 1/2 or greater with finer textured soils such as clays and clay loams. Thus, given a 24-hour set, it would be recommended that water advance to the end of the furrow in about 6 to 8 hours with a coarse soil, in 8 to 12 hours with a medium soil, and 12 hours or more in a heavy clay.

Note that the opportunity times at the top of a furrow and the bottom of a furrow will never be the same since it takes time for the water to travel down the furrow. However, infiltration rates decrease with time during an irrigation. Thus, if the opportunity times are equalized to some degree, the difference in total infiltration between the top and the bottom of a furrow will be acceptably small. And, as the recommended advance ratios above indicate, the difference in opportunity times from top to bottom of a furrow can be larger with a heavier soil than they are in a coarse soil for acceptable uniformity.

Common practices to improve down-row uniformity include increasing furrow flow rates, cutting the length of furrows, and using surge-flow techniques. All of these are aimed at reducing the difference in opportunity times between the top of the furrow and the bottom.

Achieving good down-row uniformity involves the potential for significant amounts of surface runoff. Assuming that the grower does not want to lose this runoff, it can be controlled by using cutback flows (IP 2.02.10), a runoff reuse system (2.02.11), surge-flow techniques (IP 2.02.03), or some combination.

Cross-row uniformity

Cross-row uniformity refers to the difference in infiltration from furrow to furrow. Differences in overall infiltration can occur due to differences in infiltration rates or differences in opportunity time.

Usually, tractor tires do not run in every row of a furrow irrigated field. Thus, some furrows are compacted by the tractor tires and some are not and there will be different infiltration rates in those furrows. Additionally, as a tractor makes a turn in a field, a “guess row” is created that may have a different infiltration rate from either the compacted or the uncompacted rows. A schematic diagram showing the effects of poor cross-row uniformity due to compaction from tire tractors is seen in Figure 4-11.

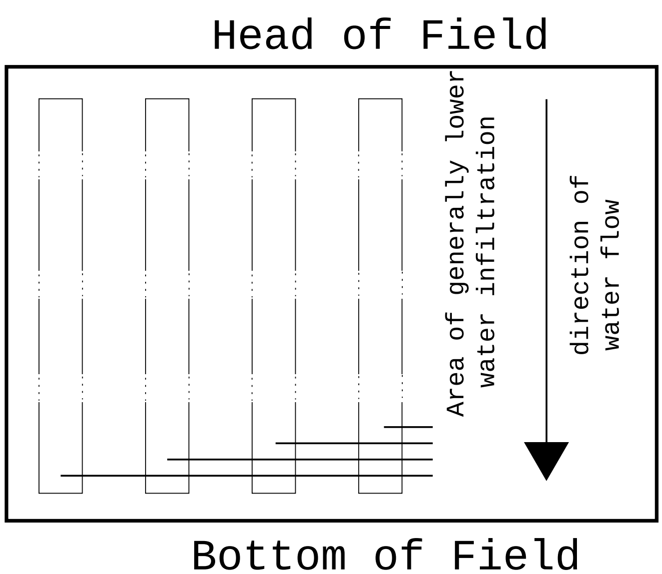


FIGURE 4-11. Schematic diagram showing effects of poor cross-row uniformity due to compaction from tractor tires

It may be difficult to alleviate this type of problem. Some techniques that have been used include 1) driving a tractor with no tool bar through a field in the uncompacted furrows and 2) irrigating in two sets. When irrigating in two sets, one set would be in the compacted furrows with one management and the other set would be in the uncompacted furrows with another management. For example, shorter sets with larger furrow flows would be used in the uncompacted furrows and longer sets with smaller furrow flows in the compacted furrows.

The opportunity time in each furrow will be affected by the irrigator's ability to set the same or correct amount of flow into each furrow if trying to account for infiltration rate differences.

1. Use the same size siphon tubes, or the same size gated pipe openings.

2. Recognize head-flow relationships with siphon tubes and change tube settings as heads in the supply bay change.

3. Try not to split the flow from one gated pipe opening or siphon tube between two or more furrows.

4. Use the same valve opening for pipeline outlets.

Soil variability

Soils variability refers to fields that have different types of soils in them. Different types of soil have different infiltration rates, thus even if opportunity times could be equalized throughout a field there would be different amounts of water infiltrated. Figure 4-12 depicts a field with sand streaks in it.

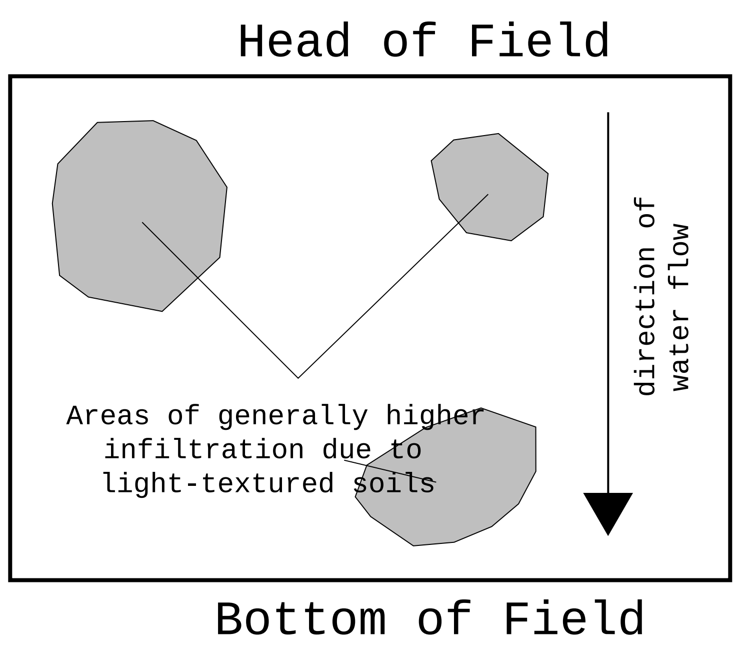


FIGURE 4-12. Poor distribution uniformity due to variable soils in a field

Soil variability may be something that the grower just has to live with. On the other hand, depending on the patterns of variability it may be possible to change set management as the irrigation progresses. For example, given that a sandy streak in a field is generally in the direction of the furrow, shorter sets with larger furrow flows may be used as the irrigation progresses through the sandy area.

Another type of soil and topography variability are high and low spots in the field. Laser-controlled land leveling (IP 2.02.08) is in common use and can be used periodically to "touch up" a field.

Border strips

The above discussion of down-row, cross-row, and soil variability was directed primarily at furrow/rill irrigation systems. These are all concerns with border strips also. Cross-"strip" uniformity is not affected as much by differences in infiltration rates due to the width of the strips. However, it is still imperative that the same flow be set into each strip.

It is important to note that irrigation management of border strips is different from furrows for one important reason. When water is turned off in a furrow, it recedes relatively quickly. That is, water runs off the furrow relatively quickly. With a border strip, however, the hydraulics of the wide flow path and friction due to a crop create a large volume of water on the surface of the strip. This requires a significant "recession" time to run off or infiltrate after the inflow is shut off. The recession time in border strips can be very useful for equalizing the opportunity time from the top of the strip to the bottom.

Advance ratios are not used for recommendations concerning flows into a border strip. Also, surface runoff should normally be much less with a border strip than with a furrow. Down-row uniformity with a border strip is a matter of equalizing the effects of the advance rate of the water during irrigation and the recession time after the water is turned off. System evaluations of border strips will identify the balance between the advance rate and the recession rate and are very helpful in improving performance.

IP 2.02.01 - Increase Furrow Flows to Maximum Non-Erosive Streamsize if Water Advance is Too Slow

Objective

Achieve an appropriate advance time for water during the initial wetting phase of a furrow irrigation. This will give good down-row uniformity.

Description

As previously explained, a good down-row uniformity is the result of sufficiently fast water advance during the initial wetting of the furrow. Depending on the length of run, type of soil, condition of furrow, and land slope, this may or may not require the maximum non-erosive stream size. The smallest stream size necessary to achieve good advance speed should be used.

Advance ratios in fine-textured soils should be in the range of 1/2. That is, the initial water advance over the full length of the furrow should occur in about 1/2 the time of the total set. The recommended advance ratio for coarse-textured soils is about 1/4 to 1/3. For medium soils the advance ratio can be in the range of 1/3 to 1/2.

IP 2.02.02 - Use Torpedoes to Form a Firm, Obstruction Free Channel for Furrow Flow

Objective

Improve down-row uniformity by increasing speed of water advance during the initial wetting phase.

Description

Depending on the soil type, newly listed or cultivated furrows may have a cloddy, hydraulically rough surface. This Practice consists of using some type of implement to form a slicked or unobstructed channel in furrows. Although in some soils there may be significant sub-surface compaction, the intention is to reduce surface obstructions.

The results of this practice can be either an increase in advance rate for a given furrow flow, or an equalizing of soil infiltration rates between adjacent furrows, or both. The smoothing of the furrow surface, along with some decrease in water infiltration rates due to surface compaction, will allow faster advance rates. This in turn will result in better distribution uniformity.

An inherent problem in furrow irrigation systems is the different compactions in furrows due to the presence of tractor traffic. Normally, tractor traffic is confined to the same furrows for each field pass so as to maintain bed alignment. The weight of the tractor will result in high compaction in some furrows. This results in different infiltration rates between the compacted and uncompacted furrows. Using a furrow slicker or press may modify the infiltration rates so as to make them more uniform among the furrows. This modification of rates could result in higher distribution uniformities.

Excessive soil compaction is to be avoided. In those soils where compaction is a problem, lighter weight implements can be used so as to only reduce the surface roughness of the furrows. Also, soil water content during cultivations is a critical factor in determining resulting compaction. Cultivations on soil at or near field capacity are to be avoided whenever possible.

The local Cooperative Extension agent or SCS office can show growers how to make torpedoes out of scrap pipe, old compressed gas bottles, or some other suitable material.

IP 2.02.03 - Use Surge-Flow Techniques

Objective

Surge is usually used to improve down-row uniformity but may also reduce surface runoff.

Description

"Surge flow" is the practice of applying water to a furrow in pulses rather than with a continuous flow. That is, water will be turned into the furrow for a time, then stopped. After some time, water is then re-applied, then stopped again. The pulses continue until the furrow has been completely wetted (water advances to the end of the furrow). The pulses may or may not continue even after the full furrow becomes wet. The actual number and length of pulses, as well as the water flow and total set time, depend on the site-specific situation.

It is common for the initial pulsing flow rates to be greater than the final, steady flow. In this manner, some applications of surge flow result in a concurrent cut-back flow system (see IP 2.02.10). For example, one type of implementation includes using a specialized "surge-valve" in conjunction with gated pipe. The surge-valve is usually a TEE-type valve connected to the gated pipe extending to either side of the valve. During the irrigation, the water supply will be directed to the gated pipe on one side or the other of the surge-valve, depending on which furrows are being pulsed. The water supply is split between the gated pipe on both sides of the surge-valve for continuous flow until the end of irrigation after the furrows are completely wet. This gives an automatic 50% cutback in individual furrow flows. (Note that the irrigator still has to make sure that the pipe outlets are flowing equal amounts of water.)

Figure 4-13 is a schematic showing the distance of water advance at the end of each of three surges. The surge valve is in the middle feeding water to gated pipe on either side. Water is turned to first one side (Sets 1, 3, and 5), then the other (Sets 2, 4, and 6) during the surging of the irrigation. A the end of the surges, about 2:00 A.M., the valve will turn water to both sides until the end of the set.

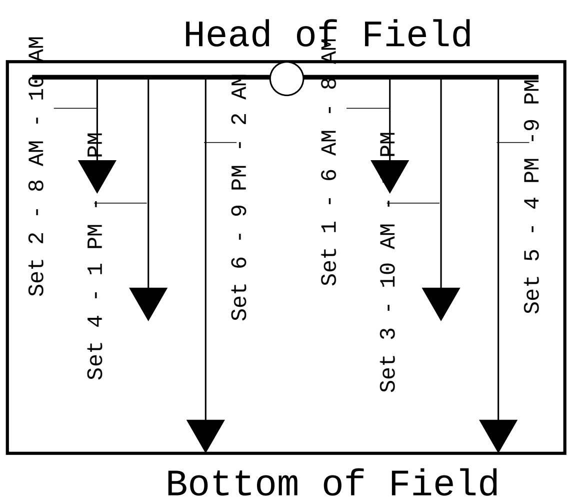


FIGURE 4-13. Schematic of a surge irrigation showing water advance at the end of each of three surges

Surge flow can improve distribution uniformity by reducing the total on-time needed to wet a furrow. On-time is the time that water is flowing in the furrow. Reducing the amount of on-time needed to wet the furrow will decrease the difference in soak times between the top and bottom of the furrow. This should result in improved application efficiency in conjunction with proper set timing.

However, the surging effect may lower infiltration rates too much. Surge can make it difficult to infiltrate enough water during irrigations to satisfy the soil water deficit if applied incorrectly. Surge is usually most effective on coarse-textured soils with very high infiltration rates. Surge may also create more erosion due to increased flow rates. Placing straw mulch in furrows can stabilize erosive soils (IP 5.01.03).

WSU Cooperative Extension published a Drought Advisory, EM4826, *Surge Flow Surface Irrigation* (March 1988). It contains a more detailed discussion of surge flow techniques.

The local Cooperative Extension or SCS office will have information on what schedule of pulses work best in a given area. Local irrigation hardware suppliers who distribute specialized surge valves may also have information and suggestions on best combinations of on-flow timing and number of pulses.

IP 2.02.04 - Decrease the Length of Furrow Runs

Objective

To reduce the difference in opportunity time between the top and bottom of the furrow so as to increase down-row uniformity. Reducing furrow run lengths is done to allow a sufficiently fast advance without resorting to an erosive stream size.

Description

A suitable speed of water advance during initial wetting may not be achievable without using an erosive stream size due to some combination of furrow length, furrow condition, soil type, and land slope. One option is to try surge flow irrigation (IP 2.02.03). Another option is to decrease the length of the furrow. The time of advance is automatically reduced in relation to the total set time by decreasing the length of the furrow.

For example, assume that it takes a 24-hour irrigation set to infiltrate the desired amount of water. Using a furrow length of 1,500 feet requires 16 hours of advance time. Thus, the advance ratio is 16/24 = .67. This would be considered too high for normal soils. By cutting the furrow in half, the advance time is reduced to 6 hours. Now the advance ratio is 6/24 = .25. This is actually a little low. In some cases, the furrow flow may be decreased slightly as the furrow length is reduced.

The decrease in furrow length may be permanent, or it may be temporary by using gated pipe or dirt ditches. Temporary reductions may be satisfactory for situations where the infiltration rates of the soil are very high at the start of a season due to cultivations and field preparation.

IP 2.02.05 - Install a Suitable Field Gradient Using Laser-Controlled Landgrading Where Topsoil Depth Allows

Objective

Ensure an appropriate grade for the field length and soil characteristics in order to use surface irrigation systems efficiently.

Description

Efficient surface irrigation requires the right combination of flow, field slope, furrow/border strip length, and soil characteristics. A limiting factor may be too steep or too flat a field gradient in relation to the soil characteristics. If topsoil depth allows, make sure that an appropriate gradient is installed.

SCS National Practices 464 and 466 address land grading and smoothing.

IP 2.02.06 - Irrigate a Field in Two Cycles, One Cycle With Water in the Compacted Furrows, One in the Uncompacted Furrows

Objective

Improve cross-row uniformity in a manner that is easy for labor to implement - by using two, or more, combinations of flow rate and set time in separate cycles of irrigation through a field.

Description

Some furrows will be compacted by tractor traffic and some will not under normal conditions with annual crops. Thus, adjacent furrows may have different infiltration rates. These different infiltration rates should indicate different management strategies to achieve the same results, correct amounts of water infiltrated with good uniformity. This means shorter sets with larger stream sizes used in uncompacted furrows versus longer sets with smaller stream sizes in compacted furrows. This can be difficult and confusing for labor to accomplish if the field is irrigated normally, running every furrow with water in the same irrigation cycle.

This Practice is to irrigate the field in two cycles. The first cycle runs water only in the compacted furrows using a single combination of furrow flow and set time. Then as all compacted furrows in the field are finished, another irrigation cycle is immediately started with water run in the uncompacted furrows. Again there will be a single, albeit different, strategy (probably larger flows for shorter sets) in use.

IP 2.02.07 - Drive a Tractor With No Tools in the Uncompacted Rows, or Use a Short Shank in Compacted Rows, to Equalize the Overall Infiltration Rates in Adjacent Furrows

Objective

Equalize the infiltration rates from furrow to furrow so as to improve the cross-row distribution uniformity.

Description

Because tractor tires do not run in each furrow the infiltration rate of adjacent furrows may not be equal. Thus, even if opportunity times were even there would be different amounts of water infiltrated from furrow to furrow. One method to combat this entails trying to equalize the infiltration rates by driving a tractor with no tools in the furrows that are normally uncompacted.

The soil water content at the time of compaction will be critical. Too much water and excessive compaction will occur. Too little water and there may not be any compacting effect. Note, however, that the tractor tires will always act the same as a torpedo in creating a firm, clod-free channel for water to run in.

Another method is to use a short shank in the rows where tractor tires run. It is critical to not rough the furrow too much.

IP 2.02.08 - Use Laser-Controlled Land Grading to Take Out High and Low Spots in a Field

Objective

Remove high and low spots in a field that could impede the smooth advance of water down a furrow or border strip or create areas of excess soil moisture.

Description

One aspect of soil variability might be considered to be high and low spots in the field. These can impede the smooth advance of water down a furrow or border strip and also create areas of excess water infiltration where low spots exist. Laser-controlled land leveling is a fast, accurate method to reduce the amount of high and low spots in a field. Many growers will periodically “touch up” their fields to ensure uniform grades.

SCS National Practices 464 and 466 address land grading and smoothing.

IP 2.02.09 - Rip Hardpans and Compacted Soil Layers to Improve Infiltration Rates

Objective

Increase infiltration rates and lower erosion.

Description

Soil texture and structure partially govern infiltration rates. Fields with very low infiltration rates can be hard to irrigate efficiently as excessive surface runoff may be generated. Ripping, chiseling, or some other form of subsoiling can improve infiltration rates. This can reduce erosion and help in increasing overall application efficiency.

IMPORTANT!!! Note that increased infiltration rates will increase the likelihood of deep percolation. The grower must maintain control of the total water application at all times.

SCS National Practice 324 addresses chiseling and subsoiling to improve infiltration rates.

IP 2.02.10 - Use Cutback Furrow Flows to Reduce Surface Runoff

Objective

Reduce the amount of surface runoff during a furrow irrigation.

Description

Correct operation of furrow/rill irrigation systems entails:

1. Wetting the furrow in an appropriately short time period

2. Then allowing water to run in the fully wet furrow until sufficient water has infiltrated at all points along the furrow.

Regardless of the amount of time taken to wet a furrow, once it is fully wet runoff commences and must be managed. IP 2.02.11 discusses the installation of runoff reuse systems as one form of management. An optional Practice is a “cutback” furrow flow.

A cutback furrow flow occurs when the average furrow flow is reduced some time after the entire furrow is wetted. This reduced furrow flow will result in reduced surface runoff. For example, the initial furrow flow may be 8 gallons per minute (GPM) so as to wet the furrow in an acceptably short time period. The large initial flow may then be reduced to 4 GPM once significant runoff starts.

There are several ways a cutback operation can be implemented. One way is with the use of specialized surge valves as described in IP 2.02.03. Another way when using siphon tubes would be to use two or more tubes during the initial wetting phase, then pull one or more tubes for the rest of the irrigation. Gated pipe openings can be larger during initial wetting and then closed down.

Note that with siphon tubes or gated pipe as just described, a new set will have to be started as the cutback is implemented. Or, the excess irrigation water supply will have to be directed to another field or decreased entirely.

IP 2.02.11 - Install Runoff-Reuse Systems

Objective

Improve overall on-farm application efficiency by gathering and reusing surface runoff on the farm generating the runoff.

Description

The purpose of this Practice is to collect all the tailwater from a field and recycle it back to the same field, or another field on the same farm, for reuse. The Practice is normally associated with furrow/border strip irrigation systems. It may also be useful where low soil infiltration rates or rolling terrain, or both, produce significant runoff with sprinkle systems.

Since tailwater that might normally leave the farming unit is collected and re-used, the overall on-farm application efficiency should be improved with this Practice. Another factor in its use is that it provides management of the increased runoff that would occur if faster water advance was desired in a furrow irrigation system. (Faster water advance usually results in better distribution uniformity, which can lead to higher application efficiency as long as the increased runoff is managed.) This Practice may be considered as an alternative to, or in conjunction with, IP 2.02.10 - Use Cutback Flows, and also IP 2.02.03 - Use Surge Flow Techniques.

If an appropriate design is used, the runoff reuse system may also act as a sedimentation pit, allowing sediments to settle out before the water is reused. Some systems will use two pits. Trash and sediment that is brought in with the runoff will settle out or float on the surface in the first pit. Clean water only flows into the second pit and is pumped back for reuse.

If tailwater is to be used on another field, check for adverse reactions due to transferred chemicals, fertilizers, or diseases.

SCS National Practice 447 covers design and installation of tailwater recovery systems. American Society of Agricultural Engineers practice EP408.1 also addresses runoff return system design and installation.

IP 2.02.12 - Reduce Furrow Flows to Minimum Necessary to Ensure Down-row Uniformity if Excess Runoff is a Problem

Objective

Minimize surface runoff from a furrow irrigation system while maintaining acceptable down-row uniformity.

Description

Furrow irrigation involves runoff. The faster the advance of water down the furrow in the initial wetting phase, the more runoff there will be, assuming that there is no cutback flow used. Furrow flows should be reduced as much as possible while still maintaining an acceptable advance ratio if runoff (or soil erosion) is a problem. If at that point there is still too much runoff, consider using either surge flow (IP 2.02.03) or a cutback furrow flow (IP 2.02.10), or installing a runoff reuse system (IP 2.02.11). Spreading straw in furrows will also help to slow water advance and improve infiltration.

IP 2.02.13 - Control the Total Application of Water

Objective

Assuming distribution uniformity is acceptable, implementing this Practice will reduce deep percolation to a minimum. The amount and disposition of surface runoff depends on the specific management (surge flow, cutback, advance ratios) and whether runoff reuse systems are used.

Description

This Practice requires four things:

1. The grower knows how much water is supposed to be applied. Some form of irrigation scheduling (IP 2.01.05) should be used, even if it is using the feel method. The “how much” to apply is the soil water deficit in the effective root zone along with any required leaching water.

2. The water application is being measured (IP 2.01.01). Although a soil probe or shovel can be used to judge the amount of water infiltrated during an irrigation, modern irrigation managers utilize water measurement devices.

3. There are sufficient control structures in the irrigation system to control the total application.

4. There is sufficient flexibility in the water supply to allow it to be turned on and off as desired. A well provides that flexibility as the grower can turn it on and off as desired. Water supplied by irrigation districts may not have this flexibility.

SCS National Practice 449 addresses general irrigation water management. Practice 587 covers water control structures.

IP 2.02.14 - Apply Water Only in Every Other Furrow

Objective

Reduce deep percolation by reducing the amount of wet soil surface during an irrigation.

Description

In some soils, or at certain times of the season, infiltration rates are high enough that it is difficult to control the total application of water given other constraints. These other constraints might include labor availability or lack of flexibility in the primary water supply (the requirement to run irrigation district water in 24-hour sets for example). Reducing the amount of wetted soil surface by running water in every other furrow will reduce the total application of water per irrigation set, assuming the same set time. This will help in matching the amount of infiltrated water to the soil water depletion at irrigation.

The type of soil and the furrow spacing must be appropriate for this technique to be effective without reducing yields. If used on a light-textured soil, or with too large a furrow spacing, it is likely that not all areas of the field will be wet. The light-textured soil will not spread water laterally far enough to provide full wetting of the field.

SECTION 3 - PRACTICES FOR SPRINKLE IRRIGATION SYSTEMS

With sprinkle irrigation systems the amount of water infiltrated depends on the system design and the amount of opportunity time. With standard hand-line or side-roll sprinkle systems, the amount of opportunity time is the set time since water is piped to the place of application. With center pivots and linear move sprinkle systems, the opportunity time changes with the percentage-timer setting as the machine is either speeded up or slowed down.

Center pivot sprinklers introduce another complication. Inherent in the system design is the fact that the soil at the outer reaches of the span will always have less opportunity time than the soil near the center of the span. This is because as the span rotates around the “center pivot,” the outer reaches of the span must travel much faster than the inner reaches as they must travel a much farther distance for each revolution. As explained below, this also introduces some important exceptions to the goal of application rate uniformity.

An important assumption regarding management of sprinkle irrigation systems is that the application rate of the system is always lower than the infiltration rate of the soil. That is, the soil is infiltrating all the water that is being applied by the irrigation system at all times during the irrigation. This may not always be true, again, especially near the outer reaches of a center pivot system.

When the application rate becomes larger than the infiltration rate, runoff will occur. Something is wrong if there is excessive runoff from a sprinkle irrigation no matter what type of system is being used. Either the system design is inappropriate for the field or field conditions, or the system is being run too long or at the wrong irrigation timing.

Infiltration rates and application rates are described in terms of inches per hour. That is, application and infiltration rates refer to a depth of water that is either applied or infiltrated per unit of time. It is important to realize two important facts:

1. At any point in a sprinkle system the application rate usually will remain constant.

2. The infiltration rate of soil will be constantly changing no matter how little the change.

Thus, although the infiltration rate of a soil may be described as .5 inch/hour, that does not mean that the infiltration rate will be equal to .5 inch/hour *for one hour.* It may infiltrate water at the *rate* of 1 inch/hour for 10 minutes, at the *rate* of .75 inch/hour for another 10 minutes, etc. The average infiltration rate for the whole may be .5 inch/hour. But again, for any one time frame, it may be more or less.

Thus, even though the application rate of a center pivot system may be 1 inch/hour at the outer reaches of the span, and the soil's infiltration rate may be described as .5 inch/hour, there may not be excessive runoff because the center pivot passes over any one part of the soil in 20 minutes. And in that 20 minutes the soil's instantaneous infiltration rate may be at or near 1 inch/hour. Thus, there will not be excessive runoff.

Disregarding the special case of center pivot machines for a moment, there are three aspects of overall distribution uniformity with sprinkle systems: 1) pressure uniformity, 2) device uniformity, and 3) wind effects.

Pressure uniformity

The flow of water through an individual sprinkler or sprayer depends on the pressure at the device and the size and type of opening. Pressure uniformity refers to how uniform the pressure is throughout a sprinkle system. It is usually practically and economically unfeasible to design piping systems for 100% pressure uniformity. There will be some pressure variance even if pressure regulators are used (commonly in situations involving large changes in elevation). Competent and experienced irrigation engineers/specialists should be retained to design all sprinkle irrigation systems.

Device uniformity

If different devices are used at different locations, the flow of water at those locations will be different, even if the pressure was 100% uniform throughout a piping system. Commonly, device uniformity refers to having the same sprinkler or spray device with the same nozzle size at all positions in the irrigation system. Note also that it is important that the nozzles are not worn.

Device uniformity is not a concern in some center pivot designs as different size devices will be used at different positions on the span. However, the devices that are used should be maintained in good operating condition.

Wind effects

Wind can have the largest effect on distribution uniformity with sprinkle irrigation systems. Water is sprayed through the air with these systems and excessive wind will move the water droplets while they are in the air. Thus, the water droplets will not fall in patterns as planned. Spray patterns from adjacent sprinklers are intended to overlap to some degree. The measure of how well the patterns overlap as designed is referred to as "overlap uniformity" or "catch-can uniformity" (since the uniformity is measured with a grid of cans to see how much water falls in different locations between sprinklers).

Center pivots as exceptions

Center pivot machines may be exceptions to both device and pressure uniformity as described above. This is due to the decrease in opportunity time as distance from the center pivot increases. As the opportunity time decreases, the application rate must increase so as to maintain the same total application at all points in the field. For example, at a point 100 feet away from the pivot, the opportunity time may be 1 hour. That is, water from sprinklers strikes the soil at this point for one hour for every revolution. On the other hand, the soil at a point 800 feet away will only receive water for about 7.5 minutes. Thus, if the total application was to be .25 inch, the application rate at the near point would have to average .25 inch/hour and the application rate at the far point would have to average 2 inches/hour.

The difference in application rates may be achieved by:

1. Varying spacing of sprinklers while the nozzle size is held constant.

2. Holding sprinkler spacing constant while the sprinkler head and nozzle size are varied.

3. Some combination of the above, along with pressure regulation.

Thus, device pressure uniformity may or may not be a factor depending on the design. However, all devices should be in good operating condition and the whole system maintained so as to deliver design performance.

IP 2.03.01 - Have an Irrigation Engineer/Specialist Check Hand-Line and Side-Roll Sprinkle Field Layouts to Ensure Correct Combinations of Spacing, Operating Pressure, Sprinkler Head, and Nozzle Size/Type

Objective

Ensure proper overlap of adjacent sprinkler patterns by utilizing the correct combination of spacing, sprinkler head, nozzle size, and operating pressure.

Description

Sprinkle systems require proper overlapping of spray patterns from adjacent sprinklers for good distribution uniformity. A correct overlap is the result of a correct combination of sprinkler spacing, operating pressure, sprinkler head, and nozzle size. Manufacturers will make recommendations concerning their products. Experienced irrigation engineers/ specialists will combine these recommendations with experience with local conditions to design efficient sprinkle systems.

There are two dimensions to the sprinkler spacing with hand-line and side-roll sprinkle systems, the spacing down the lateral and the move spacing. With center pivots and linear moving sprinkle machines there is theoretically only one dimension, the spacing along the pipeline.

IP 2.03.02 - Have a Competent and Experienced Irrigation Engineer/Specialist Check Field Layouts for Flow Uniformity - Use Flow Control Nozzles, Pressure Regulators as Necessary

Objective

Minimize the difference in flow from sprinkler to sprinkler.

Description

Flow uniformity means that the same amount of water is flowing from each sprinkler head. It is the result of good pressure uniformity and good device uniformity. Assuming that the same sprinkler head, nozzle, and nozzle type are used at each location, and assuming that they are in good condition (device uniformity), flow uniformity is a matter maintaining of a certain pressure uniformity. That is, the water pressure in the system should be nearly the same at all points.

It is practically and economically impossible to design, install, and maintain a system at 100% pressure uniformity. However, competent engineers/specialists can design a system where the pressure at each sprinkler will not vary beyond reasonable limits. Commonly desired pressure differences are less than 15-20%. Pressure regulators or flow control nozzles may be required in situations involving extreme elevation changes or long pipeline runs.

With some center pivot designs different sprinklers will be specified for different flows depending on their position on the span. In other design types, only the spacing of the sprinklers is changed.

IP 2.03.03 - Maintain Sprinkle Systems in Good Operating Condition

Objective

Maximize potential application efficiency by maintaining the sprinkle system so that it operates as designed.

Description

An important aspect of uniformity with sprinkle systems is device uniformity. Every sprinkler device should be the same, they should be in good operating condition, and nozzles should not be worn. Regular inspections for obvious equipment failures should take place. Nozzles should be checked for wear at least once a year.

Leaks in above ground piping can be a significant loss of water. The system should be periodically inspected for leaky pipeline or riser gaskets or automatic drain valves if a side-roll system. Deep percolation from leaking pipes could leach nutrients or chemicals to ground water.

Pressures should be checked in a sprinkle system regularly. This can be an early indication of problems with a pump or could indicate a malfunctioning or incorrectly set valve. Correct system pressures are essential for efficient operation of sprinkle systems.

Pacific Northwest Extension publication PNW239, *How to Calculate Manure Application Rates in the Pacific Northwest*, contains a checklist for sprinkle irrigation systems.

IP 2.03.04 - Use the "Lateral Offset" Technique with Hand-Line, Side-Roll, or "Big Gun" Field Sprinklers to Improve Overlap Uniformity

Objective

Improve overlap uniformity with sprinkle systems by moving the wet and dry spots that result from wind, large sprinkler spacings, or possibly use of low pressure sprinkler heads, around a field. This will improve the seasonal distribution uniformity, thus the potential application efficiency.

Description

Sprinkle systems depend on the overlapping spray patterns from adjacent sprinklers to create good distribution uniformity. Wind will distort normal spray patterns and thus decrease uniformity. Switching to low pressure sprinkler heads/nozzles in order to lower energy costs may also change patterns, especially if the original sprinkler spacings are retained. One method to combat these effects with hand-line or side-roll systems is to utilize the offset lateral technique. This technique is discussed in detail in Pacific Northwest Extension publication PNW286, *Offsets for Stationary Sprinkler Systems.*

The actual technique involves placing the lateral lines in alternating positions, “offset,” from one irrigation to another. Note that the distance between laterals remains the same from irrigation to irrigation. The spacing of the alternating position is one-half a lateral move. The laterals may be in the normal mainline position, next to risers, for one irrigation. A swing-line is used at each lateral to allow placement halfway between mainline risers for the next irrigation. The intention is that any wet and dry spots will be moved around the field as the laterals are placed in the alternating positions.

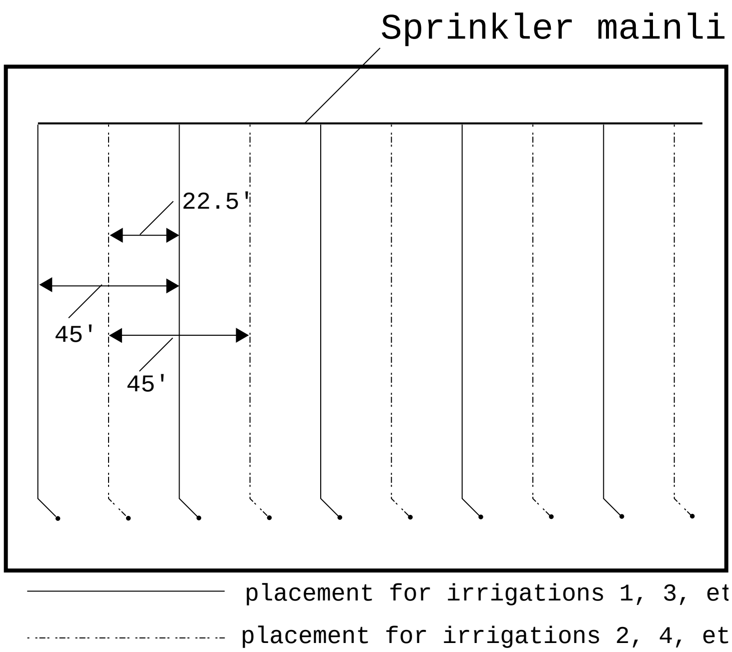


FIGURE 4-14. Schematic of lateral offsetting - laterals are placed in positions indicated by solid line for irrigations 1, 3, etc., in positions indicated by dashed lines for irrigations 2, 4, etc.

IP 2.03.05 - Operate in Low-Wind Situations if Possible

Objective

Reduce detrimental effects of wind on overlap uniformities. Also, this will reduce wind drift of chemicals during chemigation and could lower water losses due to immediate evaporation during the application.

Description

This practice is another option for dealing with excess wind. It simply entails operating the system during periods of low wind.

IP 2.03.06 - Modify Hand-Line and Side-Roll Sprinkle System Layouts to Smaller Spacings and Lower Pressures if Wind is a Problem

Objective

Reduce the detrimental effects of wind on overlap uniformities by reducing the distance water travels in the air and also creating larger droplets.

Description

This practice is another option for dealing with excess wind. Note that it will result in higher labor costs as it entails more moves of the laterals. Lower pressures in a sprinkle system equipped with standard nozzles will generally create larger water droplets and lessen the distance water travels. The larger droplets are less likely to be moved around by wind. The shorter lateral moves compensate for the smaller patterns.

IP 2.03.07 - Ensure That Center Pivot Sprinkler/Nozzle Packages Are Matched to the Infiltration Rate of the Soil

Objective

Reduce transport of sediment and other potential pollutants to surface water supplies.

Description

The nature of center pivot sprinkle systems is such that the application rate of water varies over the span of the pivot. That is, the application rates under the pivot near the center are much lower than the rates under the span near the end. This is because the field area covered by the outside portions of the center pivot are much greater than those covered by the inside. And, since the pivot will cover those areas in the same amount of time (one revolution), the amount of water applied per hour must be much greater at the outer reaches of a pivot.

This is a particular problem for irrigation system designers. They must design a system that will supply the required amount of water to maintain the crop but do so while not creating excess runoff due to too high an application rate. The purpose of this Practice is to ensure a design is used that is matched to the particular field, not just a standard package.

IP 2.03.08 - Minimize Surface Runoff from Sprinkle-Irrigated Fields

Objective

Reduce transport of sediment and other potential pollutants to surface water supplies.

Description

The application rate of a sprinkle system must be lower than the infiltration rate of the soil at all times during an irrigation or runoff will occur. Runoff should be minimal with a sprinkle system. If runoff is a problem:

1. Have people experienced both with irrigation systems and soils check the application rate of the system versus the infiltration rate of the soil at all times during an irrigation. Modify the application rate of the sprinkle system if appropriate to do so. Options for doing this include lowering system pressure or changing to a smaller nozzle size. Overlap uniformities must be maintained. Note IP 2.03.07 concerning the design of center pivots.

2. Check to see if there is a soil structure or water/soil chemistry problem. Chemical amendments may be needed to improve soil structure.

3. Ensure that the system is not causing excessive surface crusting from too large water droplets. Large droplets cause the soil structure to deteriorate at the field surface. This causes a thin layer of crusted soil to form which has lower than normal infiltration rates.

4. Run shorter sets (if possible) while fully watering the crop.

5. Use tillage practices which increase the soil's infiltration rate (including "dammer-dikers" as explained in IP 2.03.09). A dammer-diker creates many small reservoirs in the field so that runoff stays on the field and is available for infiltration. Incorporating organic matter over a number of years can improve infiltration rates.

6. The amount of water applied through center pivots per irrigation is dependent on the percentage timer. The total application at any one timer setting should be known. If runoff is known to occur at some setting or below, this should be known by all people charged with the pivot's operation.

Pacific Northwest Extension publication PNW287, *Irrigation Runoff Control Strategies,* (January 1986) discusses the problem of excess application rates in detail and gives more options for corrective action.

IMPORTANT!!! Increasing the infiltration rate may also increase the danger of creating excess deep percolation. The irrigation manager must be able to control the total application of water.

IP 2.03.09 - Use Reservoir Tillage (Dammer/Diker) Techniques with Sprinkle Systems to Reduce Field Runoff

Objective

Reduce transport of sediment and other potential pollutants to surface water supplies.

Description

Dammer/dikers create small reservoirs at even intervals in the field to help retain excess water application from sprinkle systems. This management practice is applicable to sprinkle systems on any soil type. It may be especially beneficial for fine-textured soils, or even coarse soils if on steep slopes. This method was developed primarily to reduce excessive runoff and soil erosion by increasing infiltration opportunity time.

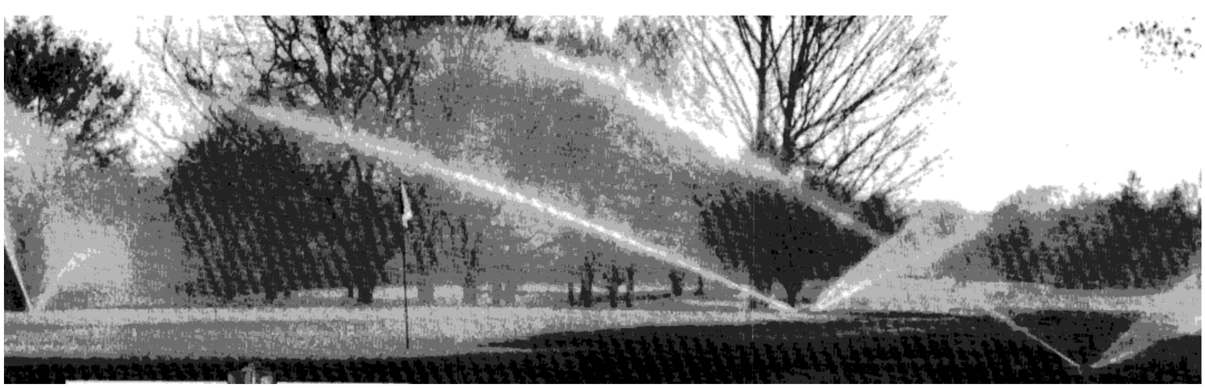
Pacific Northwest Extension publication PNW287, *Irrigation Runoff Control Strategies,* (January 1986) discusses the problem of excess application rates in detail and gives more options for corrective action. Bonneville Power Administration publication DOW/BP-21925-9, *Reservoir Tillage for Controlling Runoff and Saving Energy,* published October 1985, also discusses the use and results of reservoir tillage techniques.

IMPORTANT!!! Because this method can result in increased infiltration volumes, there is an increased risk of deep percolation. The irrigation manager must control the total application of water at all times.

IP 2.03.10 - Install Runoff-Reuse Systems (see IP 2.02.11)

Objective

Reduce transport of sediment and other potential pollutants to surface water supplies.



SECTION 4 - PRACTICES FOR MICRO-IRRIGATION SYSTEMS

The term "micro-irrigation" refers to drip, trickle, sprayer, fogger, or mini-sprinkle systems using devices with extremely small openings and typically operating at less pressure than sprinkle systems.

However, as with sprinkle irrigation systems, the amount of water infiltrated depends on the system design and the amount of opportunity time. With micro-irrigation systems the amount of opportunity time is the set time.

There are only two aspects of overall distribution uniformity with micro-irrigation systems: 1) pressure uniformity and 2) device uniformity. Wind effects are not important for distribution uniformity since micro-irrigation systems generally do not depend on any overlap of water application from adjacent emission devices. But note that micro-irrigation systems are usually run much more frequently than most sprinkle irrigation systems and consistently high winds can reduce overall application efficiencies by increasing immediate evaporation during irrigations.

Pressure uniformity

The flow of water through an emitter, be it a standard dripper, drip tape, sprayer, or mini-sprinkler, depends on the pressure at the device and the size and type of opening. Pressure uniformity refers to how uniform the pressure is throughout a sprinkle system. It is practically and economically infeasible to design piping systems for 100% pressure uniformity. Even if pressure regulators are used (commonly in situations involving large changes in elevation), there will be some pressure variance. Competent and experienced irrigation engineers/specialists should be retained to design all micro-irrigation systems.

Device uniformity

If different devices are used at different locations, the flow of water at those locations will be different, even if the pressure was 100% uniform throughout a piping system. Commonly, device uniformity refers to having the same type and size of dripper, drip tape, sprayer, or mini-sprinkler or spray device at all positions in the irrigation system. Note also that it is important that the emission devices are not worn or clogged.

American Society of Agricultural Engineers Engineering Practice EP 405.1 addresses design and installation of micro-irrigation systems.

IP 2.04.01 - Consult Experienced Agronomists/Engineers to Ensure that the Appropriate Volume of Soil is Being Wet by the System Design

Objective

Ensure correct volume and pattern of soil wetting to minimize surface runoff and deep percolation. This will also increase fertilizer-use efficiency. Note that the primary benefit will be to ensure proper crop development.

Description

A major defining characteristic of micro-irrigation systems is that not all of the soil volume in a field is wet. An important agronomic consideration when designing micro systems is how much of the root zone should be wet to ensure proper crop development. The correct *volume of water* may be delivered to the plant. But if the correct *volume of soil* is not wet, or not wet in the correct pattern, crop development may suffer. And, there may be surface runoff or excess deep percolation if water is too concentrated. Crop development could suffer also, which would reduce fertilizer-use efficiency or leave the crop susceptible to insects or disease. This, in turn, could require increased pesticide applications.

IP 2.04.02 - Have a Competent and Experienced Irrigation Engineer/Specialist Check the Design for Emission Uniformity (pressure uniformity, correct pressure for the device) - Use Pressure Regulators and Pressure Compensating Emitters as Necessary

Objective

Minimize the difference in flow from emission devices.

Description

Emission uniformity means that the same amount of water is flowing from each emission device. It is the result of good pressure uniformity and good device uniformity. It is practically and economically impossible to design, install, and maintain a system at 100% pressure uniformity. However, competent engineers/specialists can design a system where the pressure at each lateral inlet will not vary beyond reasonable limits. Pressure regulators or pressure-compensating emission devices may be required in situations involving extreme elevation changes or long pipeline runs.

Device uniformity is critical with micro-irrigation systems because of the very small passages which can vary due to manufacturing tolerances. Irrigation system designers work with what is known as the “manufacturer’s coefficient of variation” which is a measure of device uniformity as manufactured. The lower this coefficient, the more uniform the device.

Finally, different emission devices have different relationships defining how flow through the device varies with a change in pressure. Flow through emission devices is generally described by the equation:

$$Q = k \times H^x$$

where:

Q = flow through the device
k = some constant number depending on the device
H = pressure at the device
x = an "exponent," depending on the device

The key fact is that the larger the exponent ("x" in the equation above), the larger the variance in the flow with a variance in pressure. So-called "pressure compensating" emitters commonly have exponents equal to .4 or less. A "laminar-flow" emitter has an exponent that is close to 1.00. The laminar flow emitter is much more sensitive to pressure differences in the system than a pressure compensating emitter. (The advantage of laminar flow emitters are that they usually have larger openings and thus, are less susceptible to clogging. Also, they are usually, but not always, less expensive than a pressure compensating design.)

Always have a competent and experienced engineer/specialist design micro-irrigation systems.

IP 2.04.03 - Have the Irrigation Water Analyzed to Enable Design of an Adequate System of Water Treatment and Filtration

Objective

Ensure continued good performance from the system by preventing clogging of emission devices.

Description

Once a micro-irrigation system has been designed and installed, ensuring a clean water supply into the system becomes critical to efficient operation. Clogging of emission devices is the single, biggest concern of managers. Clogging reduces distribution uniformity and requires that the system be run longer to compensate. This may increase surface runoff or deep percolation due to the non-uniformity of clogging.

Even with a clean water supply into a system, clogging may occur due to algal or bacterial growths, or chemical precipitates. Thus, keeping a micro-irrigation system "clean" can involve water treatment as well as water filtration.

It is most important that the water filtration/treatment system be designed *before* operation of the system begins. This requires a complete chemical analysis of the water supply to identify factors such as pH, carbonates, bicarbonates, and iron. Controlling pH can be very important to prevent precipitates from forming in the system. In some cases, water temperature may be a factor.

If the water filtration/treatment system requires some type of water amendment, be aware of requirements when utilizing chemigation (IP 4.02.05).

There are several types of filtration devices available. Which is chosen depends on several factors including the type of water, type of emission device, and crop value. These include:

1. Sand separators - use centrifugal force to separate larger sand particles from the water. They are not effective in removing organics or smaller particles of silt and clay.

2. Cylindrical screen filters - can be made to remove much finer silts and clays than a sand separator but are not always effective in removing organics. Organics have a tendency to be extruded through the screen under pressure. Regular back-flushing to remove debris is essential.

3. Sand media filters - are enclosed sand beds in which water is forced through pressure. They are effective in removing organics but care must be taken to see that they do not become too clogged with the contaminants that they removed. Regular back-flushing, with correct flows, is essential.

4. Overflow screen filters - the water supply is poured over fine screen mesh. The screen effectively removes most debris and organics as the water is not under pressure. Also, the back-flush operation is continual with these filters.

Note that some foreign material will get through any practical agricultural filter system. Thus, periodic flushing of pipelines and driplines is an essential part of system maintenance.

IP 2.04.04 - Have a Chemical Analysis of Irrigation Water/Fertilizer/Other Additives to Ensure Compatibility and Prevent Clogging of the System

Objective

Prevent clogging of emission devices when utilizing fertigation or chemigation.

Description

One of the great advantages of micro-irrigation is the ability to control both the placement and amount of fertilizers and other chemicals. Fertigation and chemigation is widely practiced with micro systems. However, due to the small passages in the emission devices and the flow characteristics of the piping systems, incorrect combinations of particular nutrients/chemicals and irrigation water may cause clogging of the system.

Fertilizer and chemical dealers in an area with significant micro-irrigated acreage should know which formulations will work and which will not. Also, contact local WSU Cooperative Extension personnel for information.

Do not take chances with clogging a micro-irrigation system. When in doubt, contact a reputable laboratory to run tests of chemical/nutrient/water combinations *at the pressure and temperatures within the system.*

IP 2.04.05 - Practice Good Maintenance Procedures to Ensure That the System Performs as Designed

Objective

Maintain design emission uniformity, thus potential application efficiency.

Description

Design of micro-irrigation systems many times involves the use of pressure regulating valves. These valves must be set correctly and maintained. Pressure gauges that are installed at strategic points in the system can identify problems with pressure regulation or with the pumping plant.

Even with the best of maintenance, filtration, and chemical treatments, some clogging may occur. In these cases, emission devices will be replaced. Or, it may be a situation where as the crop develops, additional emitters are added to the system. It is essential that the devices at each plant have the same operating characteristics. That is, they will emit the same flow for a given pressure.

One of the tradeoffs in using micro-irrigation systems is that labor for maintenance increases. The system should be regularly inspected for leaks and clogged or worn emission devices. A flow meter at the pump and pressure gauges at strategic spots in the system can help indicate when problems are developing.

The best filtration will not remove fine silts and clays. These sediments may settle out in the piping system at points of low flow velocity. Periodic flushing of all pipelines in the system is needed to make sure that the sedimentation does not build up to harmful levels.

OVERALL MANAGEMENT OBJECTIVE 3.00 MANAGE FERTILIZER PROGRAM SO AS TO MINIMIZE EXCESS NUTRIENTS AVAILABLE FOR DETACHMENT AND TRANSPORT

Explanation and Purpose

This Objective seeks to minimize the amount of fertilizer in or on the soil that would be available for detachment and transport. That is, if there is deep percolation or surface runoff from irrigations or rainfall, the potential pollution is reduced due to reduced availability of the polluting substance. Achieving this Objective should not result in yield reductions due to decreased nutrient availability to the crop.

Fertilizers may be manufactured compounds, manures, food processing by-products or other agricultural wastes, or crop residues that are purposely left in the field. The purpose of fertilizer applications is to supplement nutrients already in the soil.

The Practices presented in this Objective are arranged in three sections. Section 1 contains overall good Practices. Section 2 pertains to the amount and timing of fertilizer applications. Section 3 addresses how the material is applied. In many cases, fertilizer applications are like irrigations, they should be done uniformly (the same amount of material on all parts of the field), and with control. However, there are situations where soil or crop conditions dictate that variable amounts of fertilizer be applied in different parts of a field.

Growers should understand the basic processes in the utilization of the various types of fertilizer material applied. Chapter 3 includes discussions of nitrogen and phosphorous fertilizers. In addition, WSU Cooperative Extension bulletin EB1722, *How Fertilizers and Plant Nutrients Affect Ground Water Quality,* (published January 1993) contains a detailed discussion of common plant nutrients, their pollution potential, and sound management practices to reduce that potential.

Fertigation is the practice of applying fertilizers by injecting them directly into the stream of irrigation water. It is a specific term used to describe the general practice of chemigation. Fertigation/ chemigation is an effective and convenient method for applying fertilizers and other chemicals, and safe for the environment when utilized properly. Pacific Northwest Extension publication PNW360, *Chemigation in the Pacific Northwest,* (January 1992) contains detailed information concerning the proper implementation of chemigation. It is important to also note that WAC 16-200-742 contains regulations governing fertigation. The discussion of Practice 3.03.10 below details requirements for chemigation systems as wellas important factors to consider for the effective application of the technique.

Possible Effects on Water Diversions

It would not be expected that achieving this Objective would have a large effect on required water diversions. However, depending on the existing situation, improved nutrient management could increase crop yields to the point where crop evapotranspiration increases and more water is required for irrigation.

Possible Effects on Crop Yields

Depending on the situation, improved fertilizer management could improve yields, quality, or both. Again, it is not the intent of this Objective to reduce crop yields by reducing fertilizer applications. However, note IP 3.02.07 which seeks to set realistic yield goals. In some cases, maximum economic yields (i.e., most profitable yields) are less than the maximum obtainable yields.

Possible Effects on Ground Water Quality

Especially when considering nitrogen sources, achieving this Objective should reduce adverse impacts on ground water quality. Leaching of nitrogen in the form of nitrate-N is a major problem. Note that achieving Objective 2.00, improved irrigation performance, is also essential since deep percolation from excess irrigations is a prime factor in the transport process.

Possible Effects on Surface Water Quality

The direct pollution of surface water by fertilizers is due to both the availability of the fertilizer and the detachment/transport of the fertilizer through surface runoff. Although reducing available fertilizer is important, reducing surface runoff by achieving Objective 2.00 will probably have more of an effect.

Note also that ground water can return to surface water supplies. Thus, by improving ground water quality as previously discussed, there may be beneficial effects on surface water quality as well.

SECTION 1 - OVERALL GOOD PRACTICES

IP 3.01.01 - Assess the Risk of Contamination of Ground and Surface Water Due to Fertilizer/Chemical Leaching or Runoff

Objective

Use fertilizer formulations that are minimally susceptible to leaching considering the soil on which they are used.

Description

Some combinations of soil and fertilizer are more susceptible to leaching than others. The *Washington State Water Quality Guide* contains a section that explains the development of a Leaching Index. The Leaching Index "allows for evaluation of the potential for contaminating the ground water with soluble nutrients." The major concern is nitrate-nitrogen leaching through lighter soils.

The Soil Conservation Service also has developed a method for estimating the potential for phosphorus losses. This includes losses of soluble phosphorus as well as material that is adsorbed to soil particles. Note, the current edition of the *Washington State Water Quality Guide* states, ". . . The key to preventing agriculturally applied phosphorus from becoming an environmental problem is to prevent erosion."

The Washington State Water Quality Guide also lists important questions to be answered when considering the fertilizer/pesticide program. These include:

1. What is the sensitivity of the surface/ground water resource? Is it a sole source aquifer for drinking water? What about contact recreation?

2. Will surface water or wind drift losses affect adjacent field or aquatic vegetation?

3. Where is the nearest water well in relation to application points?

4. If ground water is a concern, how deep is the aquifer and what type of geologic structures are present from the surface to the aquifer? That is, are there confining (fine clays or bedrock) layers that could provide additional protection from leached chemicals?

IP 3.01.02 - Consider Conservation Tillage Methods to Reduce Erosion

Objective

Reduce sedimentation that in itself is pollution, but that is also a transport mechanism for those nutrients that adsorb tightly to soil particles.

Discussion

Conservation tillage options include mulch tillage, ridge tillage, strip tillage, and no till. These are all intended to leave crop residues in the field to some extent to reduce erosion. Other conservation practices to consider include farming on contours on highly sloped fields and cover crops. Overall Management Objective 5.00 contains lists of Practices to reduce erosion.

IMPORTANT!!! Note that practices which reduce erosion generally also increase infiltration rates. Be aware of the potential for increased leaching when reducing erosion. The grower should always maintain control of applications of irrigation water.

IP 3.01.03 - Consider Cropping Patterns That Include Deep-Rooted Crops to Scavenge Residual Fertilizer

Objective

Utilize soluble fertilizers that have been leached deeper in the root zone.

Description

Even with the best management of fertilizer applications, an unexpected rainfall or a mistake in irrigation management can push soluble fertilizers below the root zone, especially with shallow-rooted crops. Deep-rooted crops in the crop rotation, if feasible, can use this fertilizer.

If feasible and economic, follow shallow-rooted crops with deeper-rooted crops in the cropping rotation. Continue to sample soil and plant tissue and water quality (IPs 3.02.01, 3.02.02, and 3.02.03) to ensure that proper nutrient levels are maintained.

IP 3.01.04 - Maintain Records of All Soil, Tissue, and Water Tests, Cropping Rotations, Yields, and Applications (dates, material, method, results)

Objective

General improvements in the fertilizer program over time.

Description

Records of the fertilizer program can be used in conjunction with small scale on-farm field trials to fine-tune the program. It may or may not reduce the total amount of fertilizer applied but may improve the timing and efficiency of use while reducing the amount lost to leaching and surface runoff.

SECTION 2 - DO NOT APPLY NUTRIENTS IN EXCESS OF NEEDS

IP 3.02.01 - Analyze Fields for Residual Nutrients

Objective

Account for available nutrients already in the soil when planning applications for a new crop.

Description

Soil tests before field preparation will indicate current available nutrients in the soil, in what form, and at what depth. Note that proper sampling techniques should be followed so that a representative sample of the field is taken. This means an appropriate number of samples taken from random spots in the field. The depth of sampling is also critical and may vary depending on the crop.

It is normally recommended that soil testing be done before planting. Testing for nitrogen in season can be done either by soil or plant tissue analysis. Make sure the method is applicable to the cropping situation.

Contact a reputable agricultural laboratory for testing. Either contract with their technicians for the sampling or follow their directions in obtaining the samples yourself.

IP 3.02.02 - Analyze Irrigation Water for Nitrogen Content

Objective

Account for available nutrients in the irrigation water supply when planning fertilizer applications.

Description

Especially when the water supply is a well, irrigation water may contain significant amounts of nitrate-nitrogen. This can be a "free" supply of fertilizer.

Contact a reputable agricultural laboratory for testing. Either contract with their technicians for the sampling or follow their directions in obtaining the samples yourself.

Table 4-2 was prepared by the Franklin Conservation District. It shows the total pounds of nitrogen applied per acre for various depths of irrigation water containing various concentrations of nitrate-nitrogen.

TABLE 4-2. Pounds of nitrogen applied per acre due to nitrate-N in irrigation water[1]

NITRATE N (ppm)	ACRE-INCHES OF WATER APPLIED PER ACRE DURING GROWING SEASON										
	24	26	28	30	32	34	36	38	40	42	44
30	163	177	191	204	218	232	245	259	272	286	300
28	153	165	178	191	203	216	229	242	254	267	280
26	142	153	165	177	189	201	212	224	236	248	260
24	131	142	153	163	174	185	196	207	218	229	240
22	120	130	140	150	160	170	180	190	200	210	220
20	109	118	127	136	145	154	163	173	182	191	200
18	98	106	114	123	131	139	147	155	163	172	180
16	87	94	102	109	116	123	131	138	145	153	160
14	76	83	89	95	102	108	114	121	127	133	140
12	65	71	76	82	87	93	98	104	109	114	120
10	54	59	64	68	73	77	82	86	91	95	100
8	44	47	51	54	58	62	65	69	73	76	80
6	33	35	38	41	44	46	49	52	54	57	60
4	22	24	25	27	29	31	33	35	36	38	40

[1] Developed by Franklin Conservation District, Pasco, WA

IP 3.02.03 - Analyze Plant Tissue to Identify Nutrient Requirements

Objective

Reduce excess applications of fertilizer by obtaining more information on how much is actually in the plant and needed.

Description

Plant tissue analyses can identify how much nutrient is actually in the plant. This will lead to more accurate recommendations on further applications and can also serve as a guide to all applications in succeeding crop years. As with soil sampling, proper procedures need to be followed to ensure a representative sample of the field.

It is important to consider the crop, whether an annual or perennial, condition, and growth stage when interpreting results.

IP 3.02.04 - Test Manure or Other Waste Materials for Nutrient Content

Objective

Account for available fertilizer in manure or sludge applications when planning fertilizer applications.

Description

Manuring, or other waste disposal, should be considered a fertilization procedure, not just a disposal procedure. Manure and other wastes can contain varying amounts of nutrients. For accurate management and control of the fertilizer program, all materials to be applied should be tested for actual nutrient content so that additional applications of commercial fertilizer are appropriate.

Other concerns when using manure or other wastes on a regular basis include:

1. The rate of mineralization of the waste. That is, how fast the organic nitrogen is converted to the ammonium (NH_4) form, which is available to the plant.

2. The salt content. Dairy and feedlot manures can contain salt concentrations of 50,000 to 100,000 ppm. Large, regular applications to the same field could cause salt injury or excessive leaching of salts to ground water. It may be beneficial not to apply manure too close to planting as crops are most susceptible to salt injury during germination and early seedling stages.

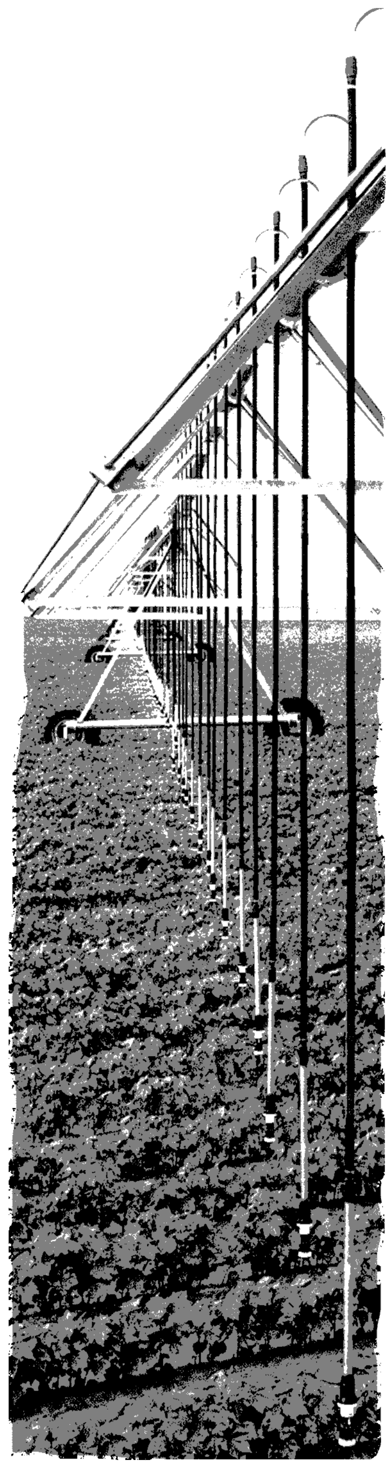
3. Weed seeds. It is often recommended that only well-aged manures be used. This is because the heat generated in manure stockpiles can reduce the viability of weed seeds.

4. Toxic materials content. Sewage sludge can sometimes contain heavy metals and other toxic materials. Sludge applications are regulated. Contact your local health department.

Contact a reputable agricultural laboratory for testing. Either contract with their technicians for the sampling or follow their directions in obtaining the samples yourself.

Table 4-3 from WSU Cooperative Extension bulletin EB1719, *Animal Manure Data Sheet*, (Revised May 1994) lists the amount of fertilizer nutrients in fresh manure per animal. Note that not all of the nutrients are available to the plant.

Pacific Northwest Extension bulletin PNW239, *How to Calculate Manure Application Rates in the Pacific Northwest*, is available as an aid in the proper use of manure. It is being replaced by a computer model, *Manure Nutrient Balancer.*



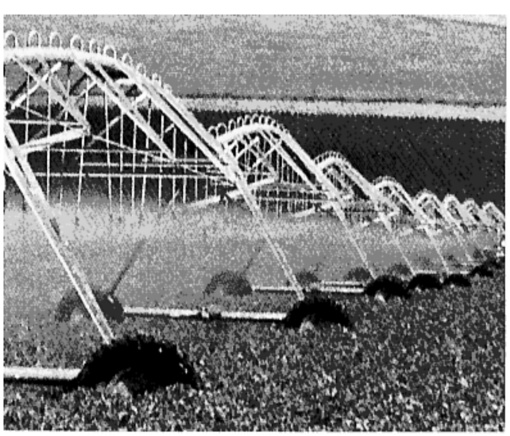


Table 4-3a. Livestock manure production and properties

Source: Hermanson, R.E. and P.K. Kalita. Rev. May 1994. *Animal Manure Data Sheet.* WSU-CE EB1719.

		Wet Raw Manure[a]					BOD[b]	COD[c]	Total Solids		Volatile Solids
Animal	Weight,lb	lb/day	ton/yr	gal/day	cu.ft/day	MC,[d] %	lb/day	lb/day	lb/day	ton/yr	lb/day
Dairy Cow	1400	120	22	14.3	1.9	87	2.2	15.4	16.8	3.0	14.0
Dairy Heifer	1000	86	15.7	10.2	1.4	87	1.6	11.0	12.0	2.2	10.0
Beef Stocker	500	29	5.3	3.5	0.5	88	0.8	3.9	4.3	0.78	3.6
Beef Feeder[e]	1000	58	11[e]	6.9	1.0	88	1.6	7.8	8.5	1.55	7.2
Beef Cow		63	11.5	7.5	1.0	88	1.7	8.5	9.2	1.68	7.8
Horse	1000	51	9.3	6.0	0.8	80	1.7		15.0	2.70	10.0
Nursery Pig	35	2.9	0.54	0.35	0.047	91	0.11	0.29	0.39	0.07	0.30
Growing Pig	65	5.5	1.00	0.65	0.089	91	0.20	0.55	0.72	0.13	0.55
Finishing Pig	150	12.6	2.30	1.50	0.20	91	0.47	1.26	1.65	0.30	1.28
	200	16.8	3.07	2.00	0.27	91	0.62	1.68	2.20	0.40	1.70
Gestating Sow*	275	11.6	2.11	1.38	0.19	91	0.43	1.16	1.51	0.28	1.17
Sow and Litter	375	31.5	5.75	3.75	0.51	91	1.16	3.15	4.13	0.75	3.19
Boar*	350	14.7	2.68	1.75	0.24	91	0.54	1.47	1.93	0.35	1.49
Sheep Feeder	100	4	0.73	0.48	0.06	75	0.12	1.10	1.10	0.20	0.92
Laying Hen	4	0.26	0.047	0.030	0.004	75	0.013	0.044	0.064	0.012	0.048
Broiler	2	0.17	0.031	0.020	0.003	75	0.002	0.032	0.044	0.008	0.034

[a] Bulk density of raw manure is about 32 cu ft/ton, or 62 lb/cu ft, or 8.4 lb/gal with no flushing or wash water
[b] Five-day biochemical oxygen demand
[c] Chemical oxygen demand
[d] Moisture content
[e] Evaporation and decomposition reduce feedlot manure in dry climates to 1 to 2 tons of 50% moisture content manure for a 150- to 180- day feeding period.
* For gestating sows and boars that are limit fed, the Midwest Plan Service recommends using hog feeder data prorated according to weight and divided by 2.

Table 4-3b. Fertilizer nutrients in fresh manure[a]

Source: Hermanson, R.E. and P.K. Kalita. Rev. May 1994. *Animal Manure Data Sheet.* WSU-CE EB1719.

		Total Nitrogen		Phosphate[b]		Potash[c]	
Animal	Weight,lb	lb/day	lb/yr	lb/day	lb/yr	lb/day	lb/yr
Dairy Cow	1400	0.63	230	0.302	110	0.490	179
Dairy Heifer	1000	0.45	164	0.216	79	0.350	128
Beef Stocker	500	0.17	62	0.106	39	0.126	46
Beef Feeder	1000	0.34	124	0.211	77	0.252	92
Beef Cow		0.36	131	0.221	81	0.266	97
Horse	1000	0.30	110	0.162	59	0.301	110
Nursery pig	35	0.018	6.6	0.0144	5.3	0.012	4.5
Growing pig	65	0.033	12	0.0268	9.8	0.023	8.3
Finishing pig	150	0.079	29	0.063	23	0.052	19
	200	0.104	38	0.082	30	0.071	26
Gestating sow*	275	0.071	26	0.057	21	0.049	18
Sow and litter	375	0.195	71	0.156	57	0.131	48
Boar*	350	0.091	33	0.072	26	0.061	22
Sheep Feeder	100	0.042	15	0.020	7.3	0.039	14
Laying Hen	4	0.0033	1.2	0.0028	1.0	0.0014	0.53
Laying Hen							
Broiler	2	0.0022	0.80	0.0014	0.50	0.0009	0.35

[a] Manure fertilizer elements are not completely available to plants.

[b] $P = 0.436\ P_2O_5$

[c] $K = 0.830\ K_2O$

* For gestating sows and boars that are limit fed, the Midwest Plan Service recommends using hog feeder data prorated according to weight and divided by 2.

IP 3.02.05 - Apply Seasonal Fertilizer Requirements with Multiple Applications

Objective

Reduce amount of nutrients available for detachment and transport through leaching or surface runoff.

Description

This practice seeks to reduce the amount of nutrients available for leaching or runoff by reducing the amount of nutrients in the root zone at any one time. Depending on the crop there may be yield and quality benefits either because of not over-fertilizing at any one time during the season or because of improved nutrient availability during latter parts of the season.

The economics of this Practice include the cost of multiple applications versus the savings in unavoidable nitrogen losses due to leaching, denitrification, or volatilization, and the possible yield and quality benefits.

The multiple applications should be done with guidance from soil, plant, and material testing as per IPs 3.02.01, 3.02.02, 3.02.03, and 3.02.04. Multiple applications are only beneficial if the applications are not excessive.

IP 3.02.06 - Use Slow-Release Nitrogen Fertilizers

Objective

Reduce amount of nitrate-nitrogen in the root zone.

Description

Nitrification converts nitrogen in the ammonium form (NH_4^+) to the nitrate form (NO_3^-). The nitrate form is highly soluble and moves readily with soil water. Thus, it is highly susceptible to leaching. Slow-release fertilizers release nitrogen slowly to the root zone at a rate closer to the rate of plant utilization. Hence, the amount of nitrate-nitrogen available for leaching is reduced.

There are several factors that may affect the actual rate of nitrogen released. These include soil temperature and soil water content. The rate of release must match crop requirements.

The effectiveness of this practice depends on site conditions and type of crop. Conditions contributing to effective use are a light soil and a crop that requires relatively low concentrations of nitrogen over a long period of time.

IP 3.02.07 - Develop Realistic Yield Goals

Objective

Reduce overapplication of fertilizer to produce yields that are either not attainable or not economical.

Description

Adequate fertilizer is just one part of a successful cropping program. Given that enough nutrients are available to the crop there may be other "weak links" in the program that will limit yields. These include the insect control program, irrigation management, field preparation, harvest procedures, and handling of the crop after harvest. If these components cannot be improved, make sure that excess fertilizer is not being applied uselessly. Also, maximizing yields may not maximize farm income as increased inputs may not pay for themselves in enough increased yields.

Bonneville Power Administration publication DOE/BP-21925-11, *Optimum Energy Efficiency,* (published February 1988), addresses the question of net returns to the acre at various production levels from the standpoint of energy usage.

SECTION 3 - APPLY FERTILIZER PROPERLY (NOTE APPLICABLE WAC REQUIREMENTS)

IP 3.03.01 - Calibrate Application Equipment Including Manure Spreaders to Apply the Proper and Known Amount

Objective

Make sure that the exact amount desired is applied.

Description

The application equipment should be calibrated to apply a known amount of fertilizer uniformly across the equipment's application path. Most application equipment comes with instructions and calibration charts from the manufacturer. However, for accuracy, testing should be done in the field.

This Practice is also applicable to manure spreaders. Manuring should be viewed as a fertilization technique as well as manure disposal. Manure should be tested for fertilizer content as per IP 3.02.04. Knowing how much is being applied with the manure spreader will indicate how much fertilizer, especially nitrogen, is being applied with the manure.

IP 3.03.02 - Use the Appropriate Application Technique (chemigation, broadcast, banding, foliar) for the Particular Situation

Objective

Achieve maximum efficiency from applied nutrients.

Description

Different combinations of crop, soil, nutrient, climatic conditions, and growth stage call for using different application techniques. For example, phosphorus does not move very far in the soil and should be applied close to the point of plant uptake. This would indicate that a banding or side-dress method be used.

Nitrogen fertilizer applied in multiple applications may be banded below the seed at planting, then side-dressed at mid-growth, then water-run until the end of the season. This will match the point of application to the root zone development.

IP 3.03.03 - Schedule Fertilizer Applications to Avoid Periods of Irrigation for Leaching for Salt Control, Plant Cooling, or Frost Control

Objective

Reduce the transport of fertilizers from the field due to leaching or excess surface runoff.

Description

Depending on soil water content at the time of water application for leaching, plant cooling, or frost control, there may be excessive deep percolation, surface runoff, or both. Thus, if fertilizer is available for transport, the likelihood of this transport is increased.

IP 3.03.04 - Avoid Wind Drift During Applications

Objective

Reduce transport of fertilizer off the field through wind effects.

Description

Wind drift can occur with applications through the irrigation system if sprinkling, or through aerial applications. Do not use these methods on windy days.

IP 3.03.05 - Incorporate Surface-Applied Fertilizers Immediately to Reduce Any Volatilization

Objective

Reduce direct loss of nitrogen fertilizer to air as ammonium gas.

Description

Volatilization is the direct loss of nitrogen via ammonium gas. It occurs when urea or ammonium containing fertilizers are applied to the surface of alkaline soils. Manure, especially poultry and veal calf manure, is an example of such a fertilizer. These types of fertilizers should be mechanically incorporated as soon as possible after application.

IP 3.03.06 - Use Nitrification Inhibitors in Combination with Applications of Ammoniacal Forms

Objective

Reduce the amount of nitrate-nitrogen in the root zone.

Description

As explained in Chapter 3 of the Manual, nitrification is the conversion of the ammonium form (NH_4^+) of nitrogen fertilizer to the nitrate form (NO_3^-). The problem with this conversion is that the nitrate form is highly soluble and thus subject to leaching. Nitrification inhibitors are chemicals that slow the nitrification process, allowing the plant to take up nitrogen in the ammonium form. This will reduce the amount of nitrate-nitrogen, which is highly susceptible to leaching, in the root zone.

Nitrogen Fertilizer Management in Arizona, a publication of the College of Agriculture, University of Arizona (#191025, May 1991), lists the following general guidelines for use of nitrification inhibitors:

1. Thoroughly mix or dry coat ammonium fertilizers with the inhibitor. Use a compatible formulation when mixing inhibitor with fluid nitrogen materials.

2. Apply treated ammonium fertilizers in a sub-surface band, injection, or side-dressing. Avoid broadcast or water-run applications.

3. Carefully follow use guidelines and application rates recommended by the manufacturer.

4. Avoid mid- to late-season applications of inhibitor-treated materials which would remain unavailable to the crop during the period of maximum nitrogen uptake.

5. Excessive nitrogen applications will offset the benefits of the inhibitors. Carefully match nitrogen fertilizer rate with plant needs.

IP 3.03.07 - Ensure Uniformity of Application With Manure

Objective

Prevent overapplication of manure in parts of a field.

Description

Depending on the source and timing of manure applications, the whole field may be treated at one time or in stages as the manure becomes available. It is important that no part of the field receive excessive amounts of manure.

IP 3.03.08 - Do Not Apply Manure to Frozen Ground, Especially Sloping Fields

Objective

Reduce surface runoff of nutrients.

Description

Manure is produced all year. In some cases, it may be necessary to provide for enough manure storage so that it does not have to be applied to frozen ground in the winter. With frozen ground the nutrients may stay on the surface and be available for transport via surface runoff with spring rains or snow melt.

IP 3.03.09 - Analyze Irrigation Water for Compatibility With Any Fertilizer to be Applied Via Fertigation

Objective

Maintain irrigation system performance when practicing fertigation.

Description

Some combinations of fertilizer and irrigation water chemistry may have the potential to decrease irrigation system performance, primarily through clogging. Whenever fertigation is practiced, the uniformity and control of the irrigation system is critical to applying the correct amount of fertilizer uniformly. This Practice is essential if micro-irrigation systems are in use.

Also, nitrogen losses from volatilization may be excessive if ammonia forms are used for fertigation and the irrigation water is alkaline with high bicarbonates.

IP 3.03.10 - Use Fertigation Properly and According to Regulations

Objective

Prevent direct contamination of water supplies during the fertigation process and apply fertilizers uniformly and effectively via the process.

Description

Fertigation is the application of fertilizers to a field by injecting them directly into the irrigation water as the water is being applied. WAC 16-200-742 contains regulations governing the practice, specifically the type of equipment that must be in place to prevent back siphonage of fertilizer into a well or other water source. Figure 4.15 shows a recommended layout for direct injection of nutrients or chemicals into irrigation pipelines. The following components are part of the system:

1. Backflow prevention device (check valve) in water line upstream of fertilizer injection - this prevents reverse flows from the irrigation system down a well or other water source.
2. Vacuum relief valve - prevents a vacuum from forming upstream of the check valve.
3. Backflow prevention device (automatic, quick-closing check valve) in fertilizer feed line - prevents reverse flows of water or fertilizer into the fertilizer storage tank.
4. Normally closed, solenoid-operated valve located on the intake side of the injection pump to prevent fertilizer flow during irrigation system shutdown.
5. Electrical interlock for injection systems using electric-driven fertilizer pumps - this ensures that the injection pump will shut down if the irrigation pump does.
6. Low pressure drain valve - to drain water from the pipe between the check valve and the water source, including any leakage past the check valve.

Reputable fertilizer and chemical dealers should be able to provide the type of equipment shown in Figure 4-15. If in doubt, contact your local Cooperative Extension office or the Washington Department of Agriculture for advice.

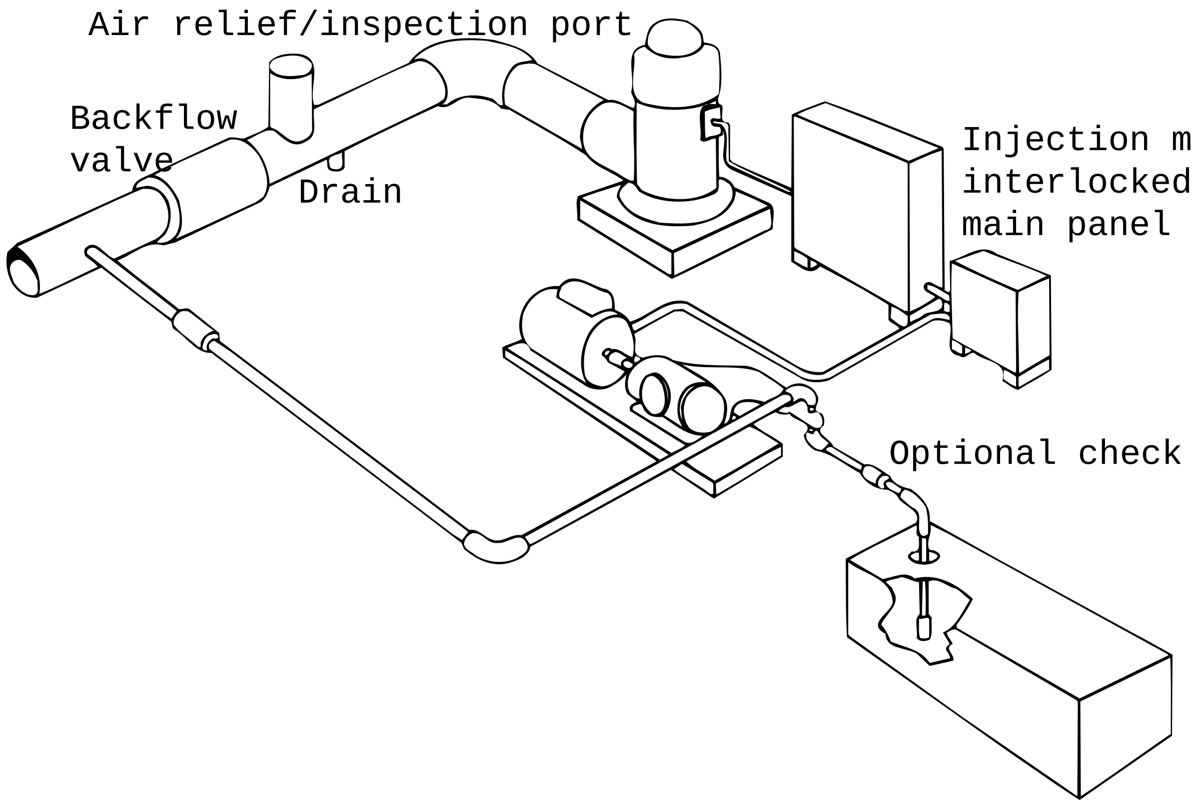


FIGURE 4-15. Schematic of fertigation system meeting minimum requirements for antipollution devices (taken from PNW360, Chemigation in the Pacific Northwest, by W.L. Trimmer, Tom Ley, G. Clough, and D. Larsen)

Other important factors to consider when fertigating include:

1. Distribution uniformity of the irrigation is critical for uniform application of the fertilizer. Refer to Objective 2.00 for Practices that improve irrigation system performance.

2. Surface irrigation systems generally produce surface runoff. Make sure that any surface runoff during fertigation is picked up and reused on the field being treated or a similar field that is also being treated. Consider the amount and distribution of any surface runoff.

3. Fertilizers which are subject to rapid degradation in wet, warm soil conditions have not been generally successful when applied via fertigation.

4. Do not fertigate during windy periods if using a sprinkle irrigation system. This may also be an important factor if using a mini-sprinkler system in orchards with little canopy cover.

5. Make sure the combination of fertilizers and water will not produce clogging if using a micro-irrigation system.

6. Know how much water is needed to refill the root zone during the irrigation and plan the fertilizer application accordingly. Over-irrigation during fertigation not only wastes water but could result in leaching of the fertilizer below the root zone.

7. If applying another chemical with the fertilizer, note that a chemical label will contain a notice such as, “Do not apply this product through any type of irrigation system,” if the chemical is not intended for chemigation.

8. The type of injection device is critical depending on the type of irrigation system being used. Some devices will inject at a relatively uniform rate throughout the irrigation, some will not. Be aware of which type is being used and which type is required by the situation. Uniform injection rates are required for furrow/rill, border strip, center pivot, and linear move sprinkle irrigation systems.

9. Fertigation may not be suitable for use on fields that are very susceptible to runoff (steep slopes and/or low infiltration rates).

10. Be aware of the requirements for flushing the irrigation system after fertigation.

11. Irrigation systems should be monitored much more closely during fertigation, continuously if possible.

OVERALL MANAGEMENT OBJECTIVE 4.00 MANAGE CROP PROTECTION PROGRAM SO AS TO MINIMIZE CHEMICAL RESIDUES AVAILABLE FOR TRANSPORT

Explanation and Purpose

The crop protection program includes those actions to prevent weeds, insects, or plant diseases from impacting crop yield or quality. Management actions include tillage, crop rotations, introduction/protection of beneficial insects, and application of chemicals.

A major Practice for achieving this Objective is to use Integrated Pest Management (IPM) techniques. This is a collection of management actions that seek to reduce the overall use of synthetic chemicals. Many of the specific Implementation Practices that are listed separately are considered parts of a comprehensive IPM program (i.e., effective scouting for proper timing of chemicals, use of natural bio-controls). It should be recognized that even if the use of a material is justified and correct, contamination could occur anyway due to unforeseen rains or winds.

The Practices presented in this section are arranged in two sections. The first section includes overall good practices. Section 2 pertains to the actual application practices, emphasizing uniformity and control.

Chemigation is the practice of applying chemicals by injecting them directly into the stream of irrigation water. It is an effective and convenient method for applying chemicals and safe for the environment when used properly. Pacific Northwest Extension publication PNW360, *Chemigation in the Pacific Northwest,* (January 1992) contains detailed information concerning the proper implementation of chemigation. It is important to also note that WAC 16-228-232 contains regulations governing the practice. The discussion of Practice 4.02.05 below details requirements for chemigation systems as well as important factors to consider for effective application of the technique.

WSU Cooperative Extension bulletins EB1644, *Protecting Ground Water from Pesticide Contamination,* (published November 1991) and EB1543, *Pesticide Movement in Soils-Ground Water Protection,* (published October 1989) contain detailed discussions of ground water pollution via pesticides and how to prevent it.

SECTION 1 - OVERALL GOOD PRACTICES

IP 4.01.01 - Assess the Risk of Contamination of Ground and Surface Waters due to Chemical Leaching and Runoff

Objective

Use chemical formulations that are minimally susceptible to leaching and runoff considering the soil they are used on.

Description

Some combinations of soil and chemical are more susceptible to leaching and runoff than others. The *Washington State Water Quality Guide* contains ratings of leaching and runoff potential for chemicals. It also provides a method for determining potential leaching and runoff for specific soils. If a soil/chemical combination is found to be susceptible to leaching or erosion, either another combination should be sought or special care taken in the use of the material.

Particular factors that affect potential contamination of ground water are listed in WSU Cooperative Extension bulletin EB1543, *Pesticide Movement in Soils-Ground Water Protection,* (published October 1989) as:

1. Rate and method of application. Excessive and improper applications must be avoided.

2. Pesticide persistence and mobility. Some chemicals will persist longer than others. Some are more mobile then others, either because of their solubility or their adsorptive ability.

3. Soil permeability and organic matter content. More permeable soils are susceptible to leaching of nutrients and chemicals. Organics tend to tie up chemicals and prevent them from leaching.

4. Frequency and timing of rainfall and irrigations. Unexpected rainfall or excessive irrigations can cause excessive deep percolation, surface runoff, or both. These are prime transport mechanisms for moving chemicals to surface and ground water bodies.

5. Depth to ground water. The deeper the aquifer, the more chance that the pesticide will either convert to a less harmful form or be tied up by organics or clay soils layers.

IP 4.01.02 - Practice Integrated Pest Management Techniques Where Applicable

Objective

Reduce overall chemical use and retain effectiveness of currently available chemicals.

Description

Integrated Pest Management (IPM) means different things to different people. Generally though, IPM seeks to reduce the use of synthetic chemicals. It does this by creating a pest control strategy that incorporates biological, cultural, physical, genetic, narrow spectrum, and low-toxic chemical tactics as appropriate. Some important aspects of IPM include:

1. Improved crop rotations - to encourage beneficial predators, improve soil tilth, and suppress weeds.

2. Improved tillage practices - timing and type of tillage can reduce pest habitat and control weeds. Reduction in the overall number of tractor trips across a field could also reduce compaction and/or erosion.

3. Avoidance of overuse of synthetic chemicals that could cause resistance - if chemicals have to be used it is desirable to rotate the type of chemical to prevent build-up of resistance in the targeted pest.

4. Maintenance of beneficial populations - it is desirable to use beneficial insects to control populations of non-beneficial insects. In some cases, beneficial insects are reared in artificial environments and then released in targeted agricultural areas. Note that use of chemical controls often will destroy beneficial populations at the same time.

5. Use of pest-resistant crop varieties.

6. Improved field sampling - this seeks to more accurately determine when chemical use is actually warranted. Sampling involves direct counting, trapping, and sweeping. Aerial photography may also be helpful.

7. Modified planting/harvesting schedules to disrupt insect populations.

8. Trap crops - this is the planting of small areas to plants that attract pests from the main crop.

IP 4.01.03 - Schedule Applications for Maximum Effectiveness

Objective

Ensure that chemicals are applied at the right time for maximum effectiveness.

Description

Make sure that pest populations are at an economic threshold before applying chemicals. Try to match the spray to emerging generations.

Use scientifically proven scouting techniques and ensure that the data is used with locally calibrated population dynamics models. Also, note Practice 4.02.03 for avoiding periods just before irrigations.

IP 4.01.04 - Maintain Records of All Chemicals Bought and Applied as well as Scouts and Individual Applications (dates, material, method, crop, results)

Objective

General improvements in the crop protection program over time.

Description

Records of the crop protection program can be used in conjunction with small-scale on-farm field trials to fine-tune the program. These may or may not reduce the total amount of chemical applied but may improve the timing and efficiency of use while reducing the amount lost to leaching and surface runoff. Records should also include the amount of chemical in storage and number and type of containers for disposal.

The Washington Pesticide Application Act addresses pesticide use in the state. It requires that specific information be recorded regarding application of pesticides to more than one acre of land.

IP 4.01.05 - Read and Follow All Label Instructions

Objective

Legal use of chemical as intended.

Description

A chemical's label defines how that chemical can be used and on what crops. It contains such information as the maximum dosage, concentration, and frequency of use, the targeted pest, weed, or disease, and what other chemicals or fertilizers the chemical can be mixed with. It will state if the chemical can be used in a chemigation system. Importantly it lists precautions for worker and applicator safety. It is illegal to use a chemical in a manner that violates label requirements. The label may also contain information regarding the chemical's potential as a contaminant.

IP 4.01.06 - Transport and Store Chemicals Properly

Objective

Prevent chemical spills during transport or storage.

Description

Even small spills of concentrated pesticides can be a substantial threat to surface and ground water. Proper transportation of chemicals involves appropriate loading, stacking, and restraint, inspection for punctured or leaking containers, and carrying spill cleanup materials in case of an accident. Note that the transporting vehicle must be labeled properly and proper authorities notified for transport of extremely dangerous materials.

Chemicals should be stored so that there is no possibility of spills or loss due to weather, theft, or unauthorized access. WSU Cooperative Extension bulletin EB1644, *Protecting Ground Water from Pesticide Contamination*, (published November 1991) includes the following precautions:

1. Provide for secure storage, out of reach of children, livestock, pets, and irresponsible people.

2. Category 1 poisons should be in a locked and posted enclosure.

3. Storage should be at least 100 feet from water sources or wells, preferably down slope from them.

4. Storage facilities should be cool, well-ventilated, and fire resistant.

5. Storage facilities should have a concrete floor and concrete curbing around them. The floor should slope to a leak-proof sump for easy cleanup in case of a spill.

6. Mixing/loading/rinsing facilities should be nearby if feasible.

7. Equip the facility with cleanup materials.

8. Inventory and monitor chemicals periodically to discover spills and cleanup.

IP 4.01.07 - Mix and Load Pesticides Properly

Objective

Minimize chemical spills during mixing and loading of pesticides.

Discussion

WSU Cooperative Extension bulletin EB1730, *Pesticide Mixing and Loading Options to Protect Water Quality,* (published December 1992) contains a detailed discussion concerning the proper procedures and precautions for mixing and loading pesticides. Important information from that bulletin follows.

Although some pesticide formulations are dusts or granules, most require some sort of carrier to dilute and spread the chemical. Usually this carrier is water. Many small spills in the same mixing and loading location can build up over the years to become a serious hazard. The more important considerations for preventing this are:

1. Use anti-siphon devices whenever using water directly from wells for mixing or loading. Back siphonage of material back into a well is to be avoided at all cost.

2. Mix and load material in the field where it is to be applied if possible. This will prevent concentration of many small spills in the same location. Try not to mix and load in the same location every time and dispose of containers promptly and properly.

3. Use impermeable (concrete) loading pads when mixing and loading around farmsteads and water sources.

4. Use nurse tanks to supply water for mixing and rinsing of equipment so that mixing, loading, and rinsing can be done away from water sources.

5. Measure chemicals carefully. Using more chemical than the label requirements is illegal and usually provides no more pest control than correct rates.

IP 4.01.08 - Store and Dispose of Used Containers Properly

Objective

Prevent contamination during disposal of containers.

Description

Used containers are still dangerous due to residues. Follow instructions for disposal of containers. Containers should be triple-rinsed immediately at a safe rinse site. Make sure that the rinse water is disposed of properly, preferably to use for mixing of future applications of that chemical. Know which containers must be transported to hazardous waste facilities.

The Washington State Department of Agriculture maintains a Waste Pesticide Program. This program provides for safe disposal of unusable or prohibited pesticides. It is operated at no cost to the participating farmers. Participating farmers must pre-register with the Department of Agriculture to be notified of collection dates and sites. Interested farmers should contact the Department of Agriculture's Pesticide Management Division in Olympia.

IP 4.01.09 - Maintain Equipment Properly to Reduce Spills or Leaks and Clean Properly After Use

Objective

Reduce unintentional chemical spills during mixing, loading, application, and cleaning.

Description

Check all hoses, gauges, nozzles, and piping to make sure there are no leaks. Make sure screens are clean and pumps operate correctly.

IP 4.01.10 - Clean Equipment Properly After Use

Objective

Reduce unintentional chemical spills during equipment cleaning.

Description

WSU Cooperative Extension bulletin EB1644 , *Protecting Ground Water from Pesticide Contamination,* (published November 1991) lists the following precautions when cleaning equipment:

1. Perform an initial rinse at the application site using clean water.

2. Rinse and clean application equipment after each use unless the same chemical is to be used again.

3. Follow chemical label instructions for cleaning if a listed chemical.

4. Do not wash equipment near wellheads, ditches, streams, or other water sources.

5. Construct a safe cleaning site that will minimize the chance for chemical spills.

IP 4.01.11 - Consider Conservation Tillage Methods to Reduce Erosion

Objective

Reduce sedimentation that in itself is a contaminant, but is also a transport mechanism for those chemicals that adsorb tightly to soil particles.

Discussion

Conservation tillage options include mulch tillage, ridge tillage, strip tillage, and no till. These are all intended to leave crop residues in the field to some extent so as to reduce erosion. Other conservation practices to consider include farming on contours on steeply sloped fields and cover crops. Overall Management Objective 5.0 contains a list of Practices to reduce erosion.

IMPORTANT!!! Practices which reduce erosion generally also increase infiltration rates. Be aware of the potential for increased leaching when reducing erosion.

SECTION 2 - APPLY CHEMICALS PROPERLY (NOTE APPLICABLE WAC REQUIREMENTS)

IP 4.02.01 - Calibrate Application Equipment

Objective

Make sure the amount desired is applied uniformly in the field.

Description

The application equipment should be calibrated so as to apply a known amount of chemical uniformly across the equipment's application path. Most application equipment comes with instructions and calibration charts from the manufacturer. However, for accuracy, testing should be done in the field.

IP 4.02.02 - Use the Appropriate Application Technique (chemigation, broadcast, air, ground application)

Description

The goal is safe and effective application of chemicals. Obviously, an air application in a high wind is neither very safe nor effective. Soil incorporation of chemicals should be avoided unless required for effective use.

IP 4.02.03 - Schedule Chemical Applications to Avoid Periods of Irrigation for Leaching for Salt Control, Plant Cooling, or Frost Control

Objective

Reduce the transport of chemicals off the field due to leaching or excess surface runoff.

Description

Depending on the soil water content at the time of water application for leaching, plant cooling, or frost control, there may be excessive leaching, surface runoff, or both. Thus, if chemical is available for transport, the likelihood of this transport is increased.

Also, if a chemical doesn't need water for activation it is best to delay irrigations to one or two days after an application to avoid surface runoff or leaching of the chemical.

IP 4.02.04 - Analyze Irrigation Water for Compatibility With Any Chemicals to be Applied Via Chemigation

Objective

Maintain irrigation system performance when practicing chemigation.

Description

Some combinations of chemicals and irrigation water may have the potential to decrease irrigation system performance, primarily through clogging. Whenever chemigation is practiced, the uniformity and control of the irrigation system is critical to applying the correct amount of chemical uniformly.

Note also that incompatible water and chemical combinations could result in decreased efficiency of the chemical.

IP 4.02.05 - Use Chemigation Properly and According to Regulations

Objective

Prevent direct contamination of water supplies during the chemigation process and apply chemicals uniformly and effectively via the process.

Description

Chemigation is the application of chemicals to a field by injecting them directly into the irrigation water as the water is being applied. WAC 16-228-232 contains regulations governing the practice, specifically the type of equipment that must be in place to prevent back siphonage of chemical into a well or other water source. Figure 4-16 shows a recommended layout for direct injection of nutrients or chemicals into irrigation pipelines. The following components are part of the system:

1. Backflow prevention device (check valve) in water line upstream of chemical injection - this prevents reverse flows from the irrigation system down a well or other water source.

2. Vacuum relief valve - prevents a vacuum from forming upstream of the check valve.

3. Backflow prevention device (automatic, quick-closing check valve) in chemical feed line - prevents reverse flows of water or chemical into the chemical storage tank.

4. Normally closed, solenoid-operated valve located on the intake side of the injection pump to prevent chemical flow during irrigation system shutdown.

5. Electrical interlock for injection systems using electric-driven chemical pumps - this ensures that the chemical injection pump will shut down if the irrigation pump does.

6. Low pressure drain valve - to drain water from the pipe between the check valve and the water source, including any leakage past the check valve.

Most reputable fertilizer and chemical dealers should be able to provide the type of equipment shown in Figure 4-16. If in doubt, contact your local Cooperative Extension office or the Department of Agriculture for advice.

Other important factors to consider when chemigating include:

1. Distribution uniformity of irrigation is critical for even application of the chemical. Refer to Objective 2.00 for Practices that improve irrigation system performance.

2. Surface irrigation systems generally produce surface runoff. Make sure that any surface runoff during chemigation is picked up and reused on the field being treated or a similar field that is also being treated. Consider the amount and distribution of any surface runoff.

3. Chemicals which are subject to rapid degradation in wet, warm soil conditions have not been generally successful when applied via chemigation.

4. Do not chemigate during windy periods if using a sprinkle irrigation system. This may also be an important factor if using a mini-sprinkler system in orchards with little canopy cover.

5. Make sure the combination of chemicals and water will not produce clogging if using a micro-irrigation system.

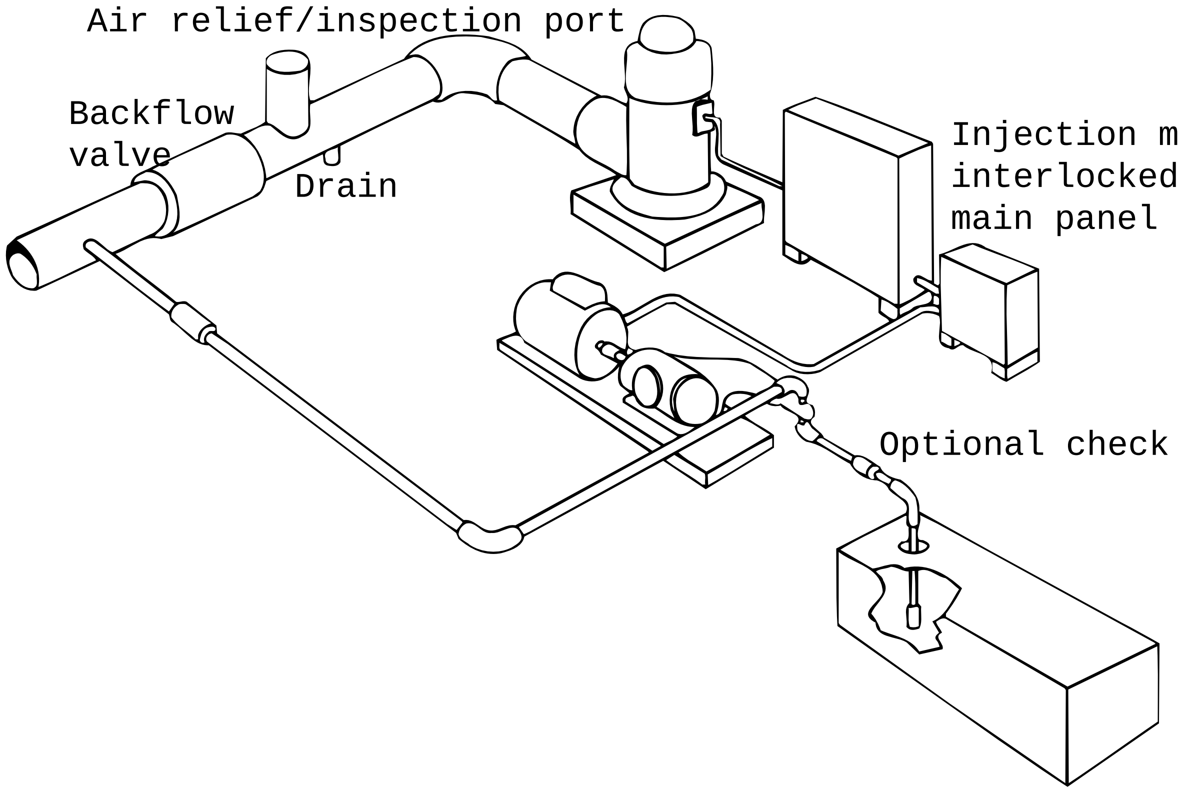


FIGURE 4-16. Schematic of chemigation system meeting minimum requirements for antipollution devices (taken from PNW360, Chemigation in the Pacific Northwest, by W.L. Trimmer, Tom Ley, G. Clough, and D. Larsen)

6. Know how much water is needed to refill the root zone during the irrigation and plan the chemical application accordingly. Over-irrigation during chemigation not only wastes water but could result in leaching of the chemical below the root zone.

7. A chemical label will contain a notice such as, "Do not apply this product through any type of irrigation system," if the chemical is not intended for chemigation.

8. The type of injection device is critical depending on the type of irrigation system being used. Some devices will inject at a relatively uniform rate throughout the irrigation, some will not. Be aware of which type is being used and which type is required by the situation.

9. Chemigation may not be suitable for use on fields that are very susceptible to runoff (steep slopes and/or low infiltration rates).

10. Be aware of the requirements for flushing the irrigation system after chemigation.

11. Irrigation systems should be monitored much more closely during chemigation, continuously if possible.

OVERALL MANAGEMENT OBJECTIVE 5.00 REDUCE CONTAMINATION OF SURFACE WATER FROM SEDIMENTATION

Explanation and Purpose

There will be some surface runoff associated with some irrigation system types, primarily furrow/rill and border strip systems. Surface runoff creates the potential for contamination from sedimentation. Not only are sediments a contaminant themselves, they may carry adsorbed chemicals with them. This Objective seeks to:

1. Reduce the detachment action of surface runoff, that is, reduce erosion.

2. Reduce sediment loads in any surface runoff that is returned to surface water supplies.

IMPORTANT!!! Practices which reduce erosion and sediment loads generally also increase infiltration rates or the total infiltration of water. Be aware of the potential for ground water contamination through increased leaching of nutrients or chemicals when reducing erosion. Water applications must always be controlled carefully. Try to account for expected rains. Achieving Objectives 3.00 and 4.00 will reduce the availability of soluble nutrients and chemicals.

Possible Effects on Water Diversions

Normally, achieving this objective should have no effect on required water diversions since it does not address irrigation system performance. However, if infiltration rates are increased and water applications are not controlled, overall irrigation efficiency may decrease.

It should be noted that improved infiltration rates may actually increase irrigation performance. An example would be where improved infiltration reduced losses due to surface runoff under a center pivot.

Possible Effects on Crop Yields

Achieving this objective should have no effect on crop yields as it does not address either irrigation, or in-field fertilizer or pesticide management. However, if infiltration rates are increased and deep percolation increases as a result, some fertilizer might be lost. This lost fertilizer could impact crop yields.

Possible Effects on Ground Water Quality

Increasing infiltration rates as a way of reducing the velocity and volume of surface runoff may result in increased deep percolation without good management of irrigations. Increased deep percolation increases the chance of nutrients or chemicals to be leached to aquifers. Also, if sedimentation pits are installed in highly permeable soils there could be increased leaching of contaminated water under the pit. Thus, there is the chance that achieving this Objective could negatively impact ground water quality.

Possible Effects on Surface Water Quality

Achieving this Objective should reduce the amount of sedimentation in any surface runoff that reaches natural water bodies. Not only is reduced sedimentation beneficial, this would also mean that any transportation of adsorbed chemicals is also reduced.

SECTION 1 - REDUCE CONTAMINATION OF SURFACE RUNOFF

IP 5.01.01 - Use Cover Crops on Unprotected, Easily Erodible Soils

Objective

The primary objective is reduction of erosion but improvements in infiltration rates and nitrogen fixation (if a legume is used) may be additional benefits.

Description

A cover crop is any crop grown to produce dense ground cover between the main agronomic crop. The intentions may include stabilization of erodible soils, improvement of soil infiltration rates, nitrogen fixation or retention, or some combination of the three.

This management practice is applicable to any irrigation system and soil type. It is especially beneficial to sprinkle irrigation systems on soils that are easily eroded by wind or water. A prime application is growing a cover crop between rows in vineyards or orchards.

Cover crops should be chosen that are compatible with the general cultural system. It is especially important to consider what insects or weeds the potential cover crop may be a host for. Cover crops may also change the nutrient cycle by releasing or using nitrogen at different times of the year.

SCS National Practices 327 and 340 address establishment of cover and green manure crops for soil stabilization and improvement.

IP 5.01.02 - Manage Crop Residues to Reduce Surface Water Contamination

Objective

Improve soil structure and increase infiltration rates by providing adequate organic residue from the cropping rotation.

Description

This management practice is applicable to any type irrigation system and soil type, but is especially beneficial to sprinkle irrigation systems on easily erodible soils. This Practice consists of including high residue crops, corn and small grains for example, in a cropping rotation. The organic matter from these crops stays on or near the soil surface and is effective in increasing infiltration rates and reducing erosion and runoff.

SCS National Practices 328 and 344 address cropping rotations and the use of crop residues. Practice 354 defines delayed seedbed preparation to reduce erosion.

IP 5.01.03 - Install Straw Mulching in Furrows

Objective

Stabilize erosive soils and allow larger flows to be used in furrows to achieve good down-row distribution uniformity.

Description

This Practice is similar to IP 5.01.02 but is primarily aimed at furrow/rill irrigation systems on easily erodible soils. It is especially recommended where erosive streams would be needed to achieve sufficiently fast water advance. It has been particularly noted for use with surge irrigation techniques.

SCS National Practice 484 addresses mulching as a means of reducing erosion.

IP 5.01.04 - Use Reduced Tillage (Paraplow) Cultural Systems

Objective

Increase infiltration rates to reduce surface runoff.

Description

This management practice is applicable to any type irrigation system and soil type, but may be especially beneficial to low intake and easily eroded soils. This method was developed primarily to reduce excessive runoff and soil erosion by increasing water infiltration, maintaining crop residues, and reducing soil compaction due to repeated tillage operations.

SCS National Practice 329 addresses conservation tillage systems. A criterion for a conservation (reduced) tillage system is that 30% of the field be covered by plant residue after planting.

IP 5.01.05 - Use Pressed (Slicked) Furrows with Furrow/Rill Irrigation Systems

Objective

Reduce the roughness and possibly the infiltration rate of the furrow so that smaller non-erosive streams can be used to achieve the same advance speed.

Description

Depending on the soil type, newly listed or cultivated furrows may have a cloddy, hydraulically rough surface. This Practice consists of using some type of implement to form a slicked or unobstructed channel in furrows. Although in some soils there may be significant subsurface compaction, the intention is to reduce surface obstructions. Slicking the furrow will reduce the amount of erosion of small clods left by cultural practices.

Refer to IP 2.02.07 for possible beneficial effects on distribution uniformity.

IP 5.01.06 - Perform Land Grading to Optimize Furrow/Rill Gradients to Reduce Soil Erosion

Objective

Ensure an appropriate grade for the field length and soil characteristics in order to use surface irrigation systems efficiently without causing soil erosion.

Description

Efficient surface irrigation requires the right combination of flow, field slope, furrow/ border strip length, and soil characteristics. Too steep a gradient will cause excess velocities in the furrow and increase potential erosion. If topsoil depth allows, make sure that an appropriate gradient is installed.

SCS National Practices 464 and 466 address land grading and smoothing.

IP 5.01.07 - Install Tailwater Drop Structures

Objective

Reduce erosion in tailwater ditches by reducing natural gradients with the use of control structures.

Description

Tailwater drops are applicable whenever existing land gradients result in erosive water velocities in open ditch tailwater collection systems. Drops can be used to break an excessively sloped tailwater ditch into a series of non-erosive grades. Or, one or more drop structures can be placed at selected areas where there are sharp elevation changes.

A tailwater drop allows the use of a non-erosive gradient in the tailwater ditch. Drop structures, constructed so as to be non-erosive, are installed in the tailwater ditch as necessary to account for the terrain’s natural change in elevation.

This management practice is primarily applicable to furrow irrigation systems where significant amounts of tailwater are produced. However, it can apply to the management of runoff from any type system. This method does not improve application efficiency or distribution uniformity, but it can improve the quality of the tailwater entering other surface waters.

SCS National Practice 410 addresses the design of what are also called grade stabilization structures.

IP 5.01.08 - Install Buried Tailwater Drops and Collection Pipes

Objective

Eliminate sedimentation from high velocity flows in tailwater systems.

Description

This Practice consists of installing a buried pipe system at the end of a field to gather and direct tailwater flows. The Practice can improve the quality of the tailwater re-entering surface waters by reducing or eliminating erosion losses caused by open ditch tailwater collection systems. This method should be applied anytime the soils are erodible or when tailwater velocities in open ditch systems increase the risk of soil erosion.

SECTION 2 - MANAGE SURFACE RUNOFF TO MINIMIZE CONTAMINATION POTENTIAL

IP 5.02.01 - Install Sedimentation Pits

Objective

Collect all of the tailwater from a furrow irrigation system and allow time for sediment to settle out of solution.

Description

Sediment pits are intended to temporarily store surface runoff. The runoff continues to flow through the pit to its final destination but the pit is designed so the runoff is in the pit for a sufficient amount of time and flows at such a low velocity that sediment settles before reaching the outlet. To optimize the size of a sediment pit, this practice should be used only after all other practices to reduce erosion and tailwater volumes have been implemented. Although this practice does not affect overall irrigation system efficiency or distribution uniformity, it provides final treatment of runoff before discharged to the receiving surface water.

Sedimentation pits may be used in conjunction with a runoff return system.

IMPORTANT!!! Pits should not be installed in highly permeable soil if possible as impounded water may leach excessively into the underlying soil.

SCS National Practice 350 addresses design and installation of sediment pits, as does American Society of Agricultural Engineers Standard S442.

IP 5.02.02 - Install Vegetative Buffering Strips

Objective

Remove sediments and other contaminants from surface runoff before it reaches other surface waters.

Description

These are strips of land covered with grass or other vegetation that will slow runoff so that any sediments or other contaminants fall out of suspension. This practice is primarily applicable to surface irrigation systems and their tailwater, however it can apply to the management of runoff from any type system. It can reduce the quantity of sediment and any attached contaminants that leaves the field with the tailwater. This practice should be used in conjunction with techniques for reducing soil erosion losses.

Note that buffering strips may also be used at the head of a field to reduce erosion from large inflows. Some farmers will use a narrow strip at the top of a furrow to reduce erosion from gated pipe streams.

SCS National Practice 393 addresses design of vegetative filter strips.

IP 5.02.03 - Gather and Reuse Surface Runoff (see IP 2.02.11)

OVERALL MANAGEMENT OBJECTIVE 6.00
PREVENT DIRECT AQUIFER CONTAMINATION VIA WELLS

Explanation and Purpose

Water wells are a direct link from the surface to ground water. Aquifer contamination can occur because of movement of nutrients or chemicals from the surface down through the well. Another type of contamination occurs when a well pierces two or more distinct aquifers. If one of the aquifers is contaminated and the well is not properly constructed, water from the contaminated aquifer could migrate to the clean aquifer.

Contamination can also occur through improperly abandoned wells. Abandoned wells must be properly filled and capped so that there is no path from the surface to the aquifer.

Much of well construction and abandonment is covered by state law. Of particular interest is Engrossed Substitute House Bill 1806 which amended many sections of the existing law and added new sections. An important element of the new law is that all constructors of wells, whether licensed or not, are to construct wells according to the Department of Ecology's well standards. Well drilling regulations are contained in RCW 18.104. Minimum standards for construction and maintenance of wells are contained in WAC 173-160.

Of particular importance to prevent ground water contamination through wells is proper abandonment procedures. Practice 6.00.04 addresses abandonment.

SCS National Practice 642 addresses design and construction of wells as does American Society of Agricultural Engineers engineering practice EP400.1.

Possible Effects on Water Diversions

Achieving this objective should have no effect on required water diversions since it does not address irrigation system performance.

Possible Effects on Crop Yields

Achieving this objective should have no effect on crop yields as it does not address irrigation, in-field fertilizer, or pesticide management. Note that the Practices do address storing and loading of fertilizers and pesticides, as well as the proper setup of injection equipment for direct injection of fertilizers and pesticides into the irrigation system.

Possible Effects on Ground Water Quality

Achieving this Objective should reduce the potential for ground water contamination via wells.

Possible Effects on Surface Water Quality

Implementing those practices related to storing and loading of nutrients and chemicals could have a beneficial impact on surface water quality since spills will be minimized. Reduced spills mean less contaminants available for transport through surface runoff.

Also note that ground water can return to surface water supplies through springs, seepage, or lateral percolation to streams, rivers, and lakes. If ground water quality is improved or protected by achieving this Objective, surface water quality will be protected as well.

IP 6.00.01 - Complete Wells Properly Where There is the Possibility of Cascading Flows Contaminating a Lower Aquifer

Objective

Eliminate a well as a pathway for poor quality water to move from a contaminated aquifer to a good quality aquifer.

Description

Many times, construction of a water supply well involves penetrating two or more distinct aquifers at different depths. One or more of these aquifers may be of worse quality than the others. Proper well construction will include sealing off poor quality aquifers. WAC 173-160 contains regulations regarding the various sealing requirements.

Reputable and licensed well drillers should be used for any well construction.

IP 6.00.02 - Do Not Store, Load, or Mix Chemicals Near a Wellhead or Other Vulnerable Place

Objective

Reduce the chances for spillage of nutrients or chemicals near a wellhead.

Description

Especially when fertigation or chemigation is being used it is tempting to store, load, and mix chemicals near the wellhead where the injection equipment is located. The wellhead is always considered a potential path for contaminants and they should be handled as little as possible at the wellhead.

Store, load, and mix chemicals away from the wellhead and deliver them in nurse tanks. Please refer to Practices 3.03.10 and 4.02.05 for discussions of proper storage, mixing, and loading of fertilizers and chemicals.

IP 6.00.03 - Prevent Back Siphonage/Flow of Chemicals or Nutrients Down a Well After Injection

Objective

Prevent back siphonage/flow of chemicals or nutrients down a well after injection.

Description

Fertigation and chemigation are generic terms that refer to the injection of nutrients or pesticides directly into the irrigation water. If this injection is directly into the piped output of a well it is imperative that proper hardware be in place to prevent back siphonage of the nutrient or chemical down the well when it is shut off.

Pacific Northwest Extension publication PNW360, *Chemigation in the Pacific Northwest*, (January 1992) contains detailed information on the correct implementation of chemigation. Please refer to the discussion of fertigation and chemigation under Practices 3.03.10 and 4.02.05.

IP 6.00.04 - Identify and Properly Seal All Abandoned and Improperly Constructed Wells

Objective

Prevent an abandoned well from becoming a pathway for contamination of aquifers.

Description

Improperly abandoned wells can be a safety hazard as well as pose a direct path for contaminants from the surface to an aquifer. There are specific regulations concerning the proper abandonment of a well contained in WAC 173-160. Specific sections include:

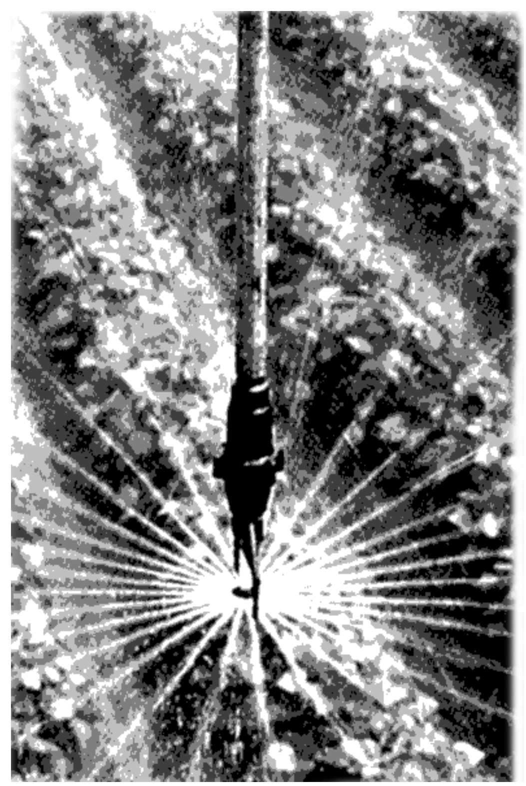
WAC 173-160-085 - capping of abandoned or out-of-use wells
WAC 173-160-415 - abandonment of wells (general)
WAC 173-160-420 - abandonment of uncased wells
WAC 173-160-425 - abandonment of drilled or jetted wells
WAC 173-160-435 - abandonment of gravel-packed wells
WAC 173-160-445 - abandonment of artesian wells
WAC 173-160-455 - abandonment of dug wells
WAC 173-160-465 - abandonment of wells - plugging of test wells
WAC 173-160-560 - abandonment of resource protection wells

Proper abandonment of a well will prevent the well from being a path for contaminants to travel from the surface to an aquifer. It will also prevent poor quality water from one aquifer from migrating into better quality water of another aquifer.

Well abandonment should only be done by qualified and licensed contractors. Note that the abandonment must be reported to the state.

A more detailed discussion of proper well abandonment can be found in WSU Cooperative Extension publication EB1714, *Abandoned Wells: Forgotten Holes to Ground Water,* (published August 1992).

CHAPTER 5.



CHAPTER 5

DEVELOPING AN ON-FARM WATER QUALITY PROGRAM

Purpose

The Overall Management Objectives presented in Chapter 4, if achieved, should minimize the potential for contaminants to move off the field or out of the root zone to surface or ground water bodies. If a water quality problem exists and it can be traced partially or in whole to agricultural practices, it may be that one or more of the Objectives are not being achieved. Again, however, it is important to realize that in some cases, achieving the Objectives may not be sufficient to reduce or control nonpoint source pollution to the degree necessary.

Knowing whether a farming operation is achieving the Objectives requires that a comprehensive analysis of on-farm activities be performed. The results of the analysis will then guide the choice of the various Implementation Practices to minimize the current and future movement of contaminants to surface and ground water bodies.

The purpose of this chapter is to provide guidance to farm operators and government personnel in developing a program to protect surface and ground water quality.

Analysis and Planning Procedure

The following steps are a recommended process of analysis and planning:

1. Determine if there are current water quality problems, or what potential problems need to be addressed.

2. Identify what contaminants are, or would be in the future, contributing to the problem.

3. Determine how the contaminants are, or would be in the future, made available.

4. Determine how the contaminants are, or would be in the future, detached. (Note that dissolving of substances or conversion of chemicals into a readily leachable form is also a form of detachment.)

5. Determine how the contaminants are, or would be in the future, transported.

6. Determine reasonable goals for the remediation or prevention program.

7. Determine what Practice or, more likely, combination of Practices can be used to achieve those goals.

These steps will now be briefly discussed.

Determination of current or future water quality problems

The question is whether current assessments of surface and ground water quality indicate that contamination has occurred. Indications from casual observations of surface waters include algal blooms, floating dead fish, heavy sedimentation, and odors. Water wells should be periodically tested for contamination, especially if it is likely that the aquifer would serve as a drinking water supply. The *Washington State Water Quality Guide* contains sections on assessing potential contamination of surface and ground water from leaching and runoff of nutrients and chemicals.

There are three main areas of interest when assessing the potential for problems:

1. Chemical/Nutrient Properties - determine the potential for adsorptivity, that is, will the chemical attach itself to soil particles readily? How fast will the chemical degrade? Is the chemical/nutrient highly soluble? Are the forms used volatile?

2. Soil Characteristics - The main factors are:
   a. texture - governs area available for adsorption as well as water holding capacity and permeability.

   b. organic matter - more organic matter means more area for adsorption.

   c. structure - governs permeability and may indicate erosiveness.

3. Site conditions - climate (particularly wind and rain patterns), depth to ground water

A combination of a coarse-textured soil, overlaying a shallow aquifer, used for intensive irrigated agriculture would likely indicate that extraordinary precautions are required. On the other hand, a flatly sloped, heavier-textured soil, with good structure, overlaying no aquifer, might not require anything more than normal management.

Identification of problem contaminants

If soils are erosive this might indicate that phosphorus moving with sediments, and the sediments themselves, could be a problem. If the soil is coarse-textured and overlays a shallow aquifer, leaching of nitrates or other chemicals may be a concern. Certain chemicals with high persistence, adsorption, or solubility are candidate contaminants. Water quality tests should indicate which chemicals or nutrients are a current problem. Note that tests do not have to indicate a chemical or nutrient to be over the limit before a water quality program is initiated. Tests that show chemical levels approaching legal limits should be taken as early warnings. Note that WAC 173-200 provides for the establishment of “early warning values” for ground water quality. If the results of a water quality test exceed the value it must be reported to the Department of Ecology.

Reducing availability

The application of potentially polluting nutrients and chemicals should be minimized. Applications should be timed and applied correctly for maximum efficiency of use. Less persistent chemicals should be used whenever possible. Integrated Pest Management principles should be incorporated as possible.

Reducing detachment

Check that tillage practices are appropriate when cropping erosive soils. Cover crops should be considered where applicable. Check that water velocities in furrows are not high enough to cause excessive erosion. Possibly there are less soluble forms of the chemicals and nutrients used. There should not be excessive surface runoff under sprinkle or trickle irrigation systems.

Reducing transport

Important transport agents are wind and surface runoff and deep percolation from excessive irrigations or unexpected rainfall. If the problem is wind or surface runoff then look to Practices that will reduce soil erosion. Minimizing deep percolation and surface runoff requires maximizing irrigation performance. Look for good distribution uniformity first. Then ensure that there is sufficient control over the system to be able to control the total application of water. Practice some form of irrigation scheduling so that there is an accurate estimate of the required irrigation application.

Determining reasonable goals

In many situations zero pollution is not an economic goal. The antidegradation policy that is the law of Washington state is not a non-degradation policy. Note that part of this process also involves setting reasonable yield goals. (Setting an unreasonable yield goal may result in excessive applications of nutrients or other chemicals, thus increasing the availability of potential contaminants.)

Determining appropriate Implementation Practices

There are certain Practices that should be a part of every water quality program. For example, deep percolation or excessive surface runoff from inefficient irrigations are prime detachment and transport mechanisms. A formal evaluation of irrigation system performance should be a priority Practice to implement. Soil and plant tissue analyses to determine fertilizer requirements is another Practice that should be implemented, especially in areas of coarse-textured soils, shallow aquifers, and growing crops requiring large amounts of fertilizer.

Key questions to ask when determining which Practices to implement include:

1. “Will this Practice reduce the specific aspect of availability, detachment, or transport that is a problem?”

2. “Will implementing this Practice cause another problem which would require another Practice to be implemented simultaneously?” A classic example would be increasing furrow flows to increase distribution uniformity. This will increase surface runoff which would imply the need for a runoff reuse system also.

3. “Is this Practice the most economical that can be used to reduce the problem?”

Preventing Contamination Problems from Occurring

If a contamination problem does not exist, the following is a list of highly recommended Practices that should be used to help prevent a problem from developing:

1. IP 1.00.05 - routinely check any lined ditches and reservoirs, or pipelines that are part of the on-farm irrigation system to prevent seepage.

2. IP 2.01.01 - measure all water applications accurately. In conjunction with IPs 2.01.05-irrigation scheduling and 2.01.06-irrigation planning, this will allow the manager to prevent overwatering while monitoring irrigation system performance for improvements.

3. IP 2.01.02 - routinely monitor the performance of pumping plants, especially if they are used to provide pressure for sprinkle or micro-irrigation systems.

4. IP 2.01.03 - routinely evaluate the distribution uniformity of the current irrigation system and management. Good distribution uniformity is required to achieve good overall application efficiency. High application efficiency will minimize surface runoff and deep percolation, the two prime transport mechanisms for contaminants. Note the different Practices that can be used to improve uniformity.

5. IP 2.03.03 and IP 2.04.06 - maintain sprinkle and micro-irrigation systems in good operating condition. Assuming that the system design was appropriate and resulted in good potential application efficiency, good maintenance will ensure continued high potential. Note, however, that hardware is only as good as the management that operates it.

6. IP 3.01.01 and IP 4.01.01 - assess the risk of contamination from applied nutrients and other chemicals based on site-specific conditions. This will indicate if special care is required.

7. IP 3.02.01, 3.02.02, and 3.02.03 - routinely analyze soil, water, and plant tissue as appropriate to guide the fertilizer program. Know how much fertilizer is required for desired yields versus how much is currently available to the plant.

8. IP 4.01.05 - read and follow all chemical label instructions.

9. IP 3.01.04 and IP 4.01.4 - maintain records of all chemical and nutrient applications as well as purchases and container disposal.

10. IP 4.01.02 - use management practices that are associated with integrated pest management so as to reduce the amount of synthetic chemicals that are required.

11. IP 6.00.01-.04 - prevent a deep well from being a direct source of aquifer contamination.

CHAPTER 5

Example of Planning Checklist

Franklin Conservation District has created a guide for helping their members develop their own Water Quality Conservation Plan, seen in Figure 5-1a-e. The guide is meant to be used in conjunction with a meeting between the farmer and a Conservation District specialist. As can be seen on Figure 5-1a at B., part of the meeting includes dissemination of information which would include the Objectives and Implementation Practices presented in the Manual. During the meeting, which ideally takes place on-site, the farm and irrigation systems are examined and many questions asked concerning the farmer's current knowledge and practices. Depending on the situation, various recommendations for improvement are made. The farmer then prioritizes the suggestions and implements them as appropriate. The Franklin CD guide was adapted for the Manual and presented in Figure 5-1a-e.

Not all of the Practices listed in the guide will be applicable, or even deemed effective, in maintaining water quality. It is important that each site be considered within its unique circumstances.

YOUR CONSERVATION DISTRICT Date: ______________

A.) Farm and Cultural Practices Inventory. ______________

1. Field ______________

2. Crop and acres for 199__ season ______________

3. Irrigation System and scheduling ______________

4. Estimated nitrogen (lbs.) to be applied (how?) ______________

____

5. Cultural practices ______________

____

____

____

____

6. Previous cropping history/rotation and N application.

19___ ______________

19___ ______________

19___ ______________

19___ ______________

B.) Information/Education provided to Cooperator.

______ Nitrogen Use Fact Sheet

______ Irrigation Water Management Information

______ Farm Bureau Self Help Checklist

______ Implementation Practices, IPs (see attached sheets)

______ Made Aware of Local Water Quality Problems

______ Other

C.) Cooperator Progress/Conservation District Suggestions.

1.) IPs Used/Suggested (see attached sheets)

2.) Other Progress/Suggestions ______________________________

FIGURE 5-1a. Water Quality Conservation Plan Development Guide by Franklin Conservation District - page 1

IRRIGATION WATER MANAGEMENT

U = USED
S = SUGGESTED
NA = NOT APPLICABLE

______ ditch and canal lining
______ divert and confine tail water
______ irrigation system evaluations
(How much and where water is applied)
  ______ know irrigation sprinkler rates
  ______ know irrigation run distances and application rates
  ______ know irrigation application uniformity
______ pump tail water pits
______ pumping plant evaluations
______ scientific irrigation scheduling
(How much and when to irrigate)
  ______ know how much water to apply each irrigation
    ______ know available water capacity of soil
    ______ know crop rooting depth
    ______ know maximum allowable water depletion for crop
  ______ know when to apply each irrigation
  (soil moisture monitoring/crop water use monitoring)
    ______ feel and appearance (are records kept?)
    ______ gravimetric (oven dry method)
    ______ pan evaporation
    ______ atmometers
    ______ tensiometers
    ______ electrical resistance (gypsum blocks)
    ______ neutron probe
    ______ computer programs/weather stations
    ______ infrared gun
    ______ other ________________________________
  ______ know critical growth stages of crop
______ sediment basins
______ straw mulching
______ upgraded well design
______ upgraded irrigation systems
  ______ buried pipe with control valve
  ______ cablegation
  ______ center pivot irrigation
  ______ cutback irrigation
  ______ drip/trickle irrigation
  ______ gated pipe
  ______ handlines
  ______ modified drip systems
  ______ solid set
  ______ surge flow irrigation
  ______ wheellines
______ use erosion and runoff controls - field borders
______ vegetative strips

FIGURE 5-1b. Water Quality Conservation Plan Development Guide by Franklin Conservation District - page 2, Irrigation Water Management

NITROGEN/NUTRIENT MANAGEMENT

U = USED
S = SUGGESTED
NA = NOT APPLICABLE

______ animal waste control facilities present
______ avoid fall application of nitrogen
______ calibrate fertilizer rigs
______ crop rotations to retrieve leftover nitrogen
______ equip fertilizer nurse rig transfer hose with valves
______ give nitrogen credits for previous crops
______ have a nutrient budget for your cropland
______ incorporate nitrogen
______ inject or band nitrogen
______ know field history - previous crops, fertilizer
______ nitrification inhibitors
______ placement of nitrogen to increase uptake by plants
______ plant tissue testing
______ proper management or other crop nutrients
______ read fertilizer labels
______ realistic yield goals
______ reduce nitrogen rate 10-20%
______ select crops with low nitrogen requirements
______ select varieties that require lower nitrogen inputs
______ sidedress nitrogen
______ slow-release forms of nitrogen
______ soil testing
______ split applications of nitrogen
______ timing of nitrogen to match high nitrogen use period
______ try for the maximum economic yield not maximum yield
______ use ammoniacal form of nitrogen

FIGURE 5-1c. Water Quality Conservation Plan Development Guide by Franklin Conservation District - page 3, Nitrogen/Nutrient Management

CULTIVATION / CROP RESIDUE MANAGEMENT

U = USED
S = SUGGESTED
NA = NOT APPLICABLE

______ conservation tillage
______ contour irrigation furrows
______ cover crops
______ crop residue management
______ cultivate furrow irrigated crops vs. chemical weed control
______ land leveling
______ paraplow
______ reduced till farming
______ reservoir tillage (dammer diker)
______ rip soils during land preparation
______ rip wheel row furrows
______ strip cropping
______ upgradient angle furrowing

SOIL / GEOLOGY

U = USED
S = SUGGESTED
NA = NOT APPLICABLE

______ identify high risk areas for ground water contamination
______ know distance to ground water
______ know permeability of geologic layers
______ know soil type - awc, texture, permeability, organic matter
______ sink holes managed adequately

FIGURE 5-1d. Water Quality Conservation Plan Development Guide by Franklin Conservation District - page 4, Cultivation/Crop Residue Management and Soil/Geology

PESTICIDE MANAGEMENT

U = USED
S = SUGGESTED
NA = NOT APPLICABLE

______ avoid overlapping of chemicals
______ back siphon devices installed if chemigating
______ calibrate pesticide rigs
______ chemigate only with irrigation systems with high efficiency
______ cultivate furrow irrigated crops vs. chemical weed control
______ dispose of wastes properly
______ do not chemigate or fertigate with high winds
______ do not chemigate when the soil is wet
______ do not drain rinse water into surface water
______ formulations of pesticides to reduce leaching
______ in-field spray rinse systems
______ know chemical solubility, soil absorption, persistence
______ know field history - previous chemicals
______ learn all you can about a product
______ low input sustainable agriculture (LISA)
______ mix and calibrate accurately
______ pest monitoring and threshold levels
______ predictive pest programs
______ prevent spills
______ proper storage of agricultural chemicals
______ read pesticide and fertilizer labels
______ triple rinse containers and return to approved locations
______ use integrated pest management
______ use the least amount of water possible to apply chemicals

FIGURE 5-1e. Water Quality Conservation Plan Development Guide by Franklin Conservation District - page 5, Pesticide Management

Local Area-wide Information

Information that is specific to an agricultural region will be helpful in developing a comprehensive water quality program for a specific site. The local Conservation District, Soil Conservation Service Office, or Cooperative Extension office will have this type of information. This might include:

1. Results of susceptibility analyses for erodability or leachability of common, specific combinations of nutrients or chemicals, soils, and terrain in the area.

2. Listings of average, annual crop evapotranspiration (ETc) and other climatic data. This would include daily ETc rates for commonly grown crops in that area, amount of wind, gross rainfall, and possibly estimates of effective rainfall for common combinations of soil and terrain. (Effective rainfall is the amount of gross rainfall that actually infiltrates and is not immediate runoff.)

   The PAWS system is a network of standardized, calibrated, computerized weather stations that are placed in major agricultural regions throughout Washington State. They track and store weather information as well as computing estimates of crop evapotranspiration.

3. Specific pest management information. What pests are important in the area and suggestions on how they are best controlled.

4. Specific weed management information. What weeds are important in the area and suggestions on how they are best controlled.

5. Results of current water quality assessments.

6. Information on local irrigation scheduling, irrigation system evaluation, pump testing, or agronomic services. Also, phone numbers, addresses, and the type of services they provide for local government agency offices.

7. Results of previous water quality control efforts and updates on current projects. What projects were implemented, why they were needed, what effect they had on water quality, what planning is being done, etc.

CHAPTER 6.

CHAPTER 6

THE ROLE OF GOVERNMENT AGENCIES IN CONTROLLING CONTAMINATION

Purpose

The purpose of this chapter is to describe the mission of the important government agencies involved in water quality control. The local Conservation District, Soil Conservation Service office, or WSU Cooperative Extension offices can provide knowledge and assistance in implementing a program for nonpoint source pollution control.

Conservation Districts

Conservation Districts were authorized with the passage of the Conservation District Law of 1939 (RCW 89-08-005). The law was subsequently revised in 1973. The Law also authorized the formation of the Washington State Conservation Commission. The Commission is an agency of the State and Conservation Districts are governmental subdivisions.

The Commission is composed of seven members, 2 that are appointed by the Governor, 3 selected by a committee of District Supervisors, and 2 that are ex-officio. Conservation Districts are governed by a Board of Supervisors consisting of 3 members that are elected locally and 2 members that are appointed by the Commission.

The major function of Conservation Districts is to develop programs and plans for, assist in carrying out, preventive and corrective measures necessary for the conservation and wise use of the natural resources of Washington. Areas that Districts work in include preservation of natural resources, flood prevention and control, protection of open space, control of pollution of surface and ground waters, and wildlife preservation.

Conservation Districts are most important due to their local orientation. The District Boards of Directors are composed of local growers elected by the voters in the District. The Districts are most familiar with the unique problems of their agricultural region and committed to dealing only with those problems. Also, due to signing the Compliance Memorandum of Agreement (discussed later), the Districts assume various levels of responsibility for education, information dissemination, handling complaints concerning water quality in their jurisdiction, and compliance assistance.
Most Districts are carrying out various programs designed to improve overall management of water resources, both in terms of quantity and quality.

Irrigation Districts

There are more than 50 Irrigation Districts or water companies in the State. They exist and operate under both Federal and State laws. Their primary purpose is to facilitate distribution of the available water supply in an efficient, equitable, and fair manner to all users in the District. Although they have authority over activities that may affect any facilities, easements, or rights-of-way of the District, they do not generally involve themselves in on-farm activities.

U.S. Bureau of Reclamation

The Bureau of Reclamation (BurRec) was authorized by the Reclamation Act of 1902. BurRec operates as an agency of the Department of the Interior. The original purpose of BurRec was reclamation of the arid West through development and delivery of irrigation water supplies. Electric power generation, flood control, and recreation would also be benefits from their projects. Some of the better known projects of the BurRec include Hoover Dam on the Colorado River, the Central Valley Project in California, and the Columbia Basin Project, with its cornerstone Grand Coulee Dam, on the Columbia River in Washington State.

In the late 1980s, it became clear that the original mission of the BurRec had been completed, the arid West had been settled. Because of increasing concerns over the long-term environmental impacts of the large projects, the BurRec began to shift emphasis from one of water resources development to water resources management. Since the remaining potential water development projects are increasingly difficult to justify both environmentally and economically, BurRec is currently seeking more efficient management of existing resources.

This new commitment has resulted in the establishment of Regional Water Conservation Centers in each of the BurRec regional offices. These Centers identify, implement, and coordinate activities to increase the efficiency of water resources use.

In the Pacific Northwest region, which includes Washington State and the Columbia Basin Project, concerns include maintenance and rebuilding of the various salmon fisheries, drainage, and irrigation district water conservation planning. Specific projects that have been completed or are on-going include:

1. Assessments of Irrigation District water management and conservation, including recommendations for improvement.

2. AgriMet - an area-wide agricultural weather network. This consists of over 40 automated stations in various agricultural regions that develop daily estimates of reference and specific crop evapotranspiration. The AgriMet system is operated in conjunction with programs at Washington State University, Oregon State University, Montana State University, and the University of Idaho.

3. A detailed Water Management and Conservation Program being implemented in the Lake Chelan Reclamation District. This Program includes implementation of centralized irrigation scheduling and remote telemetry to monitor and control pumping stations.

4. Project WET - this is an interdisciplinary, supplementary water education program for teachers. The goal of Project WET is to facilitate and promote the awareness, appreciation, and knowledge of water resources, especially the wise management of these resources to protect the future social and economic livelihood.

Soil Conservation Service

The Soil Conservation Service (SCS) is an agency of the U.S. Department of Agriculture. The goal of SCS is preservation of both quality and quantity of the soil and water resources of the United States. To that end they have initiated many programs and projects for reducing soil erosion and water pollution from both natural and man-made causes. They provide technical assistance in the planning of farm, livestock, and dairy activities as well as aid in developing on-farm water conservation plans. A recent added responsibility is monitoring to ensure farmer compliance with the regulations of the Food Security Act. Recently, they have been named lead federal Agency responsible for the designation of wetlands.

Many of the National Practices that guide SCS in on-farm engineering/planning have been referenced in the presentations of the Implementation Practices in Chapter 4.

Washington State University and Cooperative Extension

Cooperative Extension (WSU-CE) is charged with developing and disseminating knowledge that will improve the lives of all people in the state of Washington. It is jointly funded by the state and federal governments. Washington State University operates several Research and Extension Centers for plant breeding, fertilizer and pesticide use, irrigation, cultural and harvest practices, and machinery research. WSU-CE Offices are located in all counties in the State and Extension Agents are available to farmers for consultation on virtually any aspect of their operations.

Reacting to Pollution - The Compliance Memorandum of Agreement

The government agencies discussed above are by nature active. That is, their primary function is development and dissemination of knowledge, or assistance in applying that knowledge, so as to prevent and/or reduce potential pollution. However, they are also involved in reacting to existing pollution.

Some of the responsibilities of Conservation Districts, Department of Ecology (Ecology), and Washington State Conservation Commission (Commission) regarding water quality protection are described in the Compliance Memorandum of Agreement. This document has been voluntarily entered into by most Conservation Districts in Washington, Ecology, and the Commission. This Agreement basically describes the working relationships between the three entities in order to carry out a program of agricultural water quality protection and management. Specifically, the Agreement describes how water quality violations can be handled at the District level.

By entering into the Agreement the Department of Ecology agrees to, among other things:

A. Identify existing and potential water quality problems resulting from agricultural practices.

B. Receive, process, and verify complaints concerning discharges of pollutants from all farms, regardless of size.

C. Determine if an agricultural water quality problem requires immediate corrective action . . . . If so, then Ecology will maintain the lead enforcement authority. If immediate action is not required and a District has agreed to Compliance Levels 3 or 4 (explained below) then the complaint will be referred to the District. Otherwise, Ecology will continue to process the complaint.

In turn, the Conservation Districts agree to:

A. Adopt and annually update a water quality section in the Conservation District annual plan.

B. As part of the District annual report, include a water quality progress report on activities conducted that are related to this compliance agreement.

C. Encourage communication between the Conservation District personnel and local Ecology personnel.

D. Adopt and carry out a compliance option of Level 1, Level 2, Level 3, or Level 4.

The four options for compliance are:

1. Level 1 - Information/Education/Technical Assistance - the District serves as the local source of information and education concerning available statewide programs and plans for protecting water quality. The District can also provide technical assistance that is applicable to local conditions.

2. Level 2 - Information/Education, Problem Assessment, and Handling Complaints - this level includes activities described in Level 1. In addition, the District will assess current and potential water quality problems, prioritize these problems and work to apply voluntary solutions. They will also participate in the handling of water quality violation complaints by meeting with the alleged violator and, if desired by the operator, develop a plan of action which will alleviate the problem. If the operator refuses assistance the complaint will be referred back to the Department of Ecology.

3. Level 3 - Information/Education, Problem Assessment, Handling Complaints, and Assisting in Compliance - this level includes activities described in both Levels 1 and 2. In addition, the District will participate actively in the alleviation of water quality problems. This includes meeting with the owner/operator, making on-site assessments of the problem, helping in the development of plans to alleviate the problem, monitor and provide technical assistance in plan implementation, and keep Ecology informed of progress.

4. Level 4 - Compliance - this level includes all activities in Levels 1, 2, and 3 as well as “information and support” to Ecology as required for resolving water quality problems. “Information and support” includes provision for access to public information contained in the District’s files, access to District personnel for interviews, assistance and attendance at negotiating sessions, and affidavits and testimony necessary to document the case.

The Washington Conservation Commission agrees to provide assistance as appropriate to the Conservation Districts as well as coordinate District programs at the state level. The Commission also will serve as a clearinghouse of information concerning the activities and experiences of the Districts.

Table 6-1 is a list of signatory Conservation Districts in Washington and the compliance level option they have chosen.

TABLE 6-1. List of Conservation Districts Signing the Compliance Memorandum of Agreement and Their Levels of Compliance

DISTRICT	COMPLIANCE LEVEL	DISTRICT	COMPLIANCE LEVEL
Adams	4	Okanogan County	3
Asotin County	3	Othello	
Benton	3	Pacific	1
Central Klickitat	3	Palouse	3
Chelan County	3	Palouse-Rock Lake	3
Clallam	3	Pend Oreille	3
Clark County	3	Pierce County	2
Columbia	3	Pine Creek	3
Cowlitz	4	Pomeroy	3
Eastern Klickitat	3	San Juan County	3
Ferry	4	Skagit	3
Foster Creek	3	Snohomish	3
Franklin	3	South Douglas	3
Grays Harbor	3	South Yakima	3
Jefferson County	3	Spokane County	4
King County	3	Stevens County	3
Kitsap County	3	Thurston County	3
Kittitas County	3	Underwood	3
Lewis County	3	Wahkiakum	1
Lincoln County	4	Walla Walla County	3
Mason County	3	Warden	3
Moses Lake	(not signed)	Whatcom	4
North Yakima	2	Whidbey Island	3
		Whitman	3

CHAPTER 7.

CHAPTER 7

RESOURCE GUIDE

Purpose

The purpose of this chapter is to provide information concerning other resources that will enable farmers to develop effective and economical water quality conservation plans. Several of the following were developed for *Puget Sound Pest Management Guidelines, A Guide for Protecting Our Water Quality,* by Geoff Menzies and Becky Peterson (Dyvon Havens and Craig MacConnell of WSU Cooperative Extension, Project Coordinators). This publication was developed to improve understanding and acceptance of integrated pest management.

Fertilizer Management

Fertilizer Technology and Use, R.C. Dinauer (managing editor), Soil Science Society of America, Inc., Madison, WI, 2nd edition, 1971

Nitrogen Fertilizer Management in Arizona, T.A. Doerge, R.L. Roth, and B.R. Gardner, College of Agriculture, University of Arizona, publication 191025, May 1991

Nutrient and Pesticide Best Management Practices for Wisconsin Farms, University of Wisconsin - Extension and Wisconsin Department of Agriculture Trade and Consumer Protection, WDATCP Technical Bulletin ARM-1

Western Fertilizer Handbook, California Fertilizer Association, The Interstate Printers and Publishers, Danville, IL, 5th edition, 1975

Ground Water and Related Information

Agricultural Chemicals in Ground Water: Proposed Pesticide Strategy, U.S. Environmental Protection Agency, Office of Pesticides and Toxic Substances, Washington DC, December 1987

Agricultural Management Practices to Minimize Ground Water Contamination, G. Jackson, D. Keeney, D. Curwen, and B. Webendorfer, Environmental Resources Center, University of Wisconsin - Extension

Beneath the Bottom Line: Agricultural Approaches to Reduce Agrichemical Contamination of Groundwater, Publication OTA-F-418, Office of Technology Assessment, U.S. Congress, U.S. Government Printing Office, Washington DC, 1990

Best Management Practices for Agricultural, Nonpoint Source Control (IV. Pesticides), North Carolina Agricultural Extension Service, Biological and Agricultural Engineering Department, North Carolina State University

Clean Water for Washington (Ground Water Series), Washington State University Cooperative Extension, Pullman, WA

EB1622	*Washington Ground Water - A Vital Resource*
EB1631	*Protect Your Ground Water: Survey Your Homestead Environment*
EB1632	*Why the Concern About Agricultural Contamination in Ground Water*
EB1633	*Role of Soil in Ground Water Protection*
EB1634	*Washington Agriculture - Sustaining Water, Land and People*
EB1644	*Protecting Ground Water from Pesticide Contamination*

Farm Bureau's Groundwater and Environmental Pollution Self-Help Checklist for Farmsteads and Farm Fields, American Farm Bureau Federation, Natural and Environmental Resources Division, Park Ridge, IL 60068

Guidelines for Development of Ground Water Management Areas and Programs, Washington State Department of Ecology, Water Resources Program, Olympia, revised October 1986

Nonpoint Source Pollution Assessment and Management Program, Washington State Department of Ecology, Water Resources Program, Olympia, October 1989

Pesticide Movement in Soils - Ground Water Protection, EB1543, Washington State University Cooperative Extension, Pullman, WA

Pesticides in Ground Water: Background Document, U.S. Environmental Protection Agency Office of Groundwater Protection, May 1986

Protecting Ground Water: A Strategy for Managing Agricultural Pesticides and Nutrients, #91-42, Washington State Department of Ecology, Water Quality Program, Olympia, WA, April 1992

Survey of Pesticides Used in Selected Areas Having Vulnerable Groundwaters in Washington State, U.S. Environmental Protection Agency, Pesticides Section, Region 10, Seattle, WA, July 1987

Washington State Agricultural Chemicals Pilot Study, Final Report, D. Erickson and North, Washington State Department of Ecology, Olympia, WA

Washington State Water Quality Guide, Soil Conservation Service, USDA, 1989

Water Management References Notebook, Washington State University Cooperative Extension, Pullman, WA, 1988

CHAPTER 7

Integrated Pest Management (IPM)

Advances in Urban Pest Management, Bennet and Owens, Van Nostrand Reinhold, New York, NY

Biological Control, R. van den Bosch and P. S. Messenger, New York: Intext Educational Publishers, 1973

Common Sense Pest Control, W. Olkowski, S. Daar, and H. Olkowski, The Taunton Press, Newtown, CT 06740

Destructive and Useful Insects - Their Habits and Control, C. L. Metcalf and W. P. Flint, Revised by R. L. Metcalf, Fourth Edition, McGraw-Hill Book Company, New York, NY

Ecological Approach to Pest Management, David J. Horn, The Guilford Press, New York, NY, 1988

Entomology and Pest Management, L. P. Pedigo, MacMillan Publishing Co., New York, NY, 1989

Growers Weed Management Guide, H. M. Kempen, Thomson Publications, Fresno, CA

IPM Bulletins, Washington State University - Cooperative Extension

EB0491	*Crop Protection Guide for Tree Fruits*
EB0669	*Weed Control on Rights of Way*
EB0856	*European Crane Fly: A Lawn Pest*
EB0965	*Root Weevils in Berry Crops*
EB1049	*Club Root of Cabbage and Other Crucifers*
EB1398	*Small Fruit Pests Biology, Diagnosis, and Management*
EB1491	*Pest Control Guide for Commercial Small Fruits*
EB1577	*Anobid Beetles in Structures*
EM2788	*Integrated Control of Insect and Mite Pests of Apple in Central Washington*

Integrated Pest Management for Turfgrass and Ornamental, U.S. Environmental Protection Agency, Office of Pesticide Programs, Washington, D C

Introduction to Integrated Pest Management, M. L. Flint and R. van den Bosch, Plenum Press, New York, NY, 1981

Nursery and Landscape Weed Control Manual, P. Rice, Thomson Publications, Fresno, CA, 1986

Pacific NorthWest Insect Control Handbook, Cooperative Extension publication of Oregon State University, University of Idaho, and Washington State University, 1991

Pacific NorthWest Plant Disease Control Handbook, Cooperative Extension publication of Oregon State University, University of Idaho, and Washington State University, 1991

Pacific NorthWest Weed Control Handbook, Cooperative Extension publication of Oregon State University, University of Idaho, and Washington State University, 1991

Plant Pathology, G. N. Agrios, Academic Press, Inc., New York, NY, 1969

Public Health Pest Control, Publication MISC0151, Carol A. Ramsay and Gary L. Thomasson, Washington State University Cooperative Extension, Pullman, WA

The Disease Compendium Series of the American Phytopathological Society, APS Press, St. Paul, MN

Apple and Pear Diseases, 1983
Ornamental Foliage Plant Diseases, 1987
Pea Diseases, 1984
Potato Diseases, 1981
Raspberry and Blackberry Diseases, 1991
Rhododendron and Azalea Diseases, 1986
Rose Diseases, 1983
Strawberry Diseases, 1984
Turfgrass Diseases, 1983

The Least is Best Pesticide Strategy, J. Goldstein, The JG Press, Emmaus, PA, 1978

Vegetable Diseases and Their Control, F. Sherf and A. A. Macnab, 2nd Edition, 1986, John Wiley and Sons, Inc., New York, NY

Weed Science Principles, W. P. Anderson, West Publishing Company, New York, NY, 1977

Weed Science, Principles and Practices, F. M. Ashton and T. J. Monaco, 3rd Edition, John Wiley and Sons, Inc., New York, NY, 1991

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Irrigation System Management

Design and Operation of Farm Irrigation Systems, M.E. Jensen (editor), American Society of Agricultural Engineers, St Joseph, Michigan, 1981

Drainage Engineering, J.N. Luthin, Robert Krieger Publishing, Huntington, NY, 1978

Ground Water and Wells, E.E. Johnson, Johnson Division, UOP Inc., Saint Paul, MN, 1975

Management of Farm Irrigation Systems, G.J. Hoffman, T.A. Howell, and K.H. Solomon, American Society of Agricultural Engineers, St. Joseph, Michigan, December 1990

Sprinkle and Trickle Irrigation, J. Keller and R.D. Bliesner, Van Norstrand Reinhold, New York, NY, 1990

Sprinkler Irrigation, C.H. Pair, W.H. Hinz, K.R. Frost, R.E. Sneed, and T.J. Schiltz, Irrigation Association, Silver Spring, Maryland, 5th Ed., 1983

The Theory and Practice of Surface Irrigation, W.R. Walker and G.V. Skogerboe, Prentice-Hall Inc., Englewood Cliffs, NJ, 1990

Trickle Irrigation for Crop Production, F.S. Nakayama and D.A. Bucks, Elsevier, New York, 1986

Pesticide Properties

A Glossary of Pesticide Toxicology and Related Terms, Edited by Eesa and Cutkomp, Thomson Publications, Fresno, CA, 1984

Agricultural Chemicals Series, W. T. Thomson Publications, Fresno, CA

Book 1 - Insecticides, 1989
Book 2 - Herbicides, 1990
Book 3 - Miscellaneous Agricultural Chemicals, 1992
Book 4- Fungicides, 1991

Agrichemicals, Preparation and Mode of Action, R. J. Cremlyn, John Wiley and Sons, Ltd., Chichester, West Sussex, England, 1991

EXTOXNET, Extension Toxicology Network, A Pesticide Information Project of Cooperative Extension Offices of Cornell University, University of California, Michigan State University, and Oregon State University, Cornell University, Ithaca, NY

Pesticide Movement in Soils - Ground Water Protection, EB1543, Washington State University Cooperative Extension, Pullman, WA

Private Applicator Pesticide Education Manual, publication MISC0126, edited by C. A. Ramsay and G. L. Thomasson, Washington State University Cooperative Extension, Pullman, WA

The Pesticide Book, George Ware, W.H. Freeman and Co., 1978

The Pesticide Manual, A World Compendium, edited by C. R. Worthing and S. B. Walker, Eighth Edition, published by The British Crop Protection Council, 1987

Toxicity and Potential Health Effects of Pesticides, File No. IVKid R4M390, W. K. Hock and C. L. Brown, Penn State University, College of Agriculture

Washington Pesticide Laws and Safety, Publication MISC0056, edited by C. A. Ramsay and G. L. Thomasson, Washington State University Cooperative Extension, Pullman, WA

Pesticide Application and Handling

Agricultural Management Practices to Minimize Ground Water Contamination, G. Jackson, D. Keeney, D. Curwen, and B. Webendorfer, Environmental Resources Center, University of Wisconsin-Extension

Beneath the Bottom Line: Agricultural Approaches to Reduce Agrichemical Contamination of Groundwater, publication OTA-F-418, Office of Technology Assessment, U.S. Congress, 1990, U.S. Government Printing Office, Washington DC

Best Management Practices for Agricultural NonPoint Source Control, IV. Pesticides, North Carolina Agricultural Extension Service, Biological and Agricultural Engineering Department, North Carolina State University

Chemigation in the Pacific Northwest, PNW360, Washington State University Cooperative Extension, Pullman, WA

Designing Facilities for Pesticide and Fertilizer Containment, Publication WPS-37, D. W. Kammel, R. T. Noyes, G. L. Riskowski, and V. L. Hofman, MidWest Plan Service, Agricultural and Biosystems Engineering Department, Iowa State University

Liquid Calibration Handbook, C. M. Kroon, 2nd Revision, Thomson Publications, Fresno, CA, 1987

Nutrient and Pesticide Management Practices for Wisconsin Farms, Publication A- 3466, WDATCP Technical Bulletin ARM-1, University of Wisconsin-Extension and Wisconsin Department of Agriculture, Trade and Consumer Protection

Private Applicator Pesticide Education Manual, publication MISC0126, edited by C. A. Ramsay and G. L. Thomasson,Washington State University, Cooperative Extension, Pullman, WA

Protecting Ground Water from Pesticide Contamination, EB1644, Washington State University Cooperative Extension, Pullman, WA

Soil Erosion and Sediment Control Under Irrigation, EB0712, Washington State University Cooperative Extension, Pullman, WA

Washington Pesticide Laws and Safety, MISC0056, edited by C. A. Ramsay and G. L. Thomasson, Washington State University, Pullman, WA

Agencies to Contact for Nonpoint Source Pollution Information

Regulatory Agencies

Washington State Department of Agriculture
406 General Administration Building, AX-41
Olympia, WA 98504

Washington State Department of Ecology
Water Quality Program
P.O. Box 47600
Olympia, WA 98504

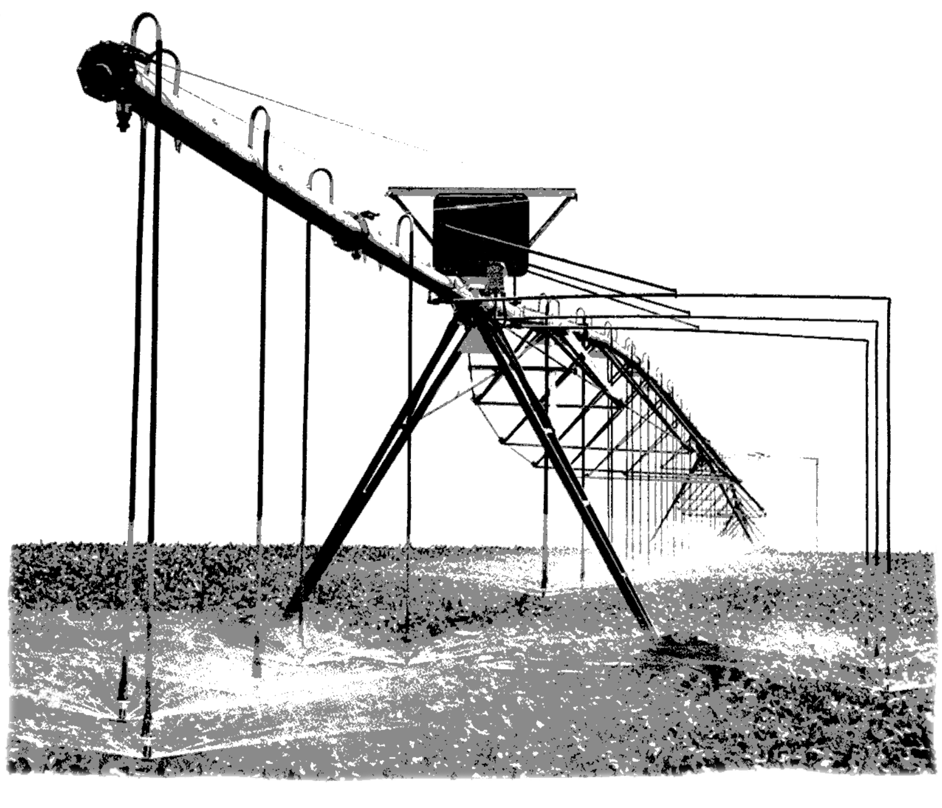
U.S. Environmental Protection Agency
Pesticides Section
Region 10
1200 Sixth Ave.
Seattle, WA 98101

Service Agencies

WSU Cooperative Extension
Cooperative Extension offices, which are located in each county, can provide information on a wide range of topics related to pest management.

Soil Conservation Service, USDA
Soil Conservation Service (SCS) offices can provide technical assistance through the development of farm management plans. SCS assistance is accessed through local Conservation Districts.

CHAPTER 8.



GLOSSARY

Absorption - The movement of a chemical into plants, animals, humans, microorganisms, or soil.

Adsorption - Gathering a gas, liquid, or dissolved substance on a surface. Clay and highly organic soils have a greater tendency to adsorb pesticides than other soils.

Adjuvant - A substance which is added to a pesticide to improve the pesticide's effectiveness or safety.

AKART - An acronym for ''All Known, Available, and Reasonable methods of Treatment.''

Algae - Simple rootless plants that grow in bodies of water in relative proportion to the amount of nutrients available. Algal blooms, or sudden spurts of growth, can adversely affect water quality. Prevention of algae growth is also a serious concern in micro-irrigation systems.

Application Efficiency - (also termed "Irrigation Efficiency") A measure of how much of the water applied to a field during an irrigation is beneficially used. Beneficial uses include crop evapotranspiration, frost control, leaching for salt control, and cooling.

Aquifer - A geological formation capable of yield usable quantities of water to wells or springs.

Best Management Practices (BMP) - A generic term referring to schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of ground or surface water.

Biological Control - Control of pests using predators, parasites, and disease-causing organisms.

Broad Spectrum Pesticide - A pesticide of broad toxicity which kills not only a range of pest species, but also many non-target species such as natural enemies.

Chemical Label - The information associated with any pesticide that describes the pesticide and the restrictions for its use. A chemical cannot be used in violation of the Label.

Chemigation - (or Fertigation) The application of formulated liquids or solutions of pesticides, herbicides, fungicides, fertilizers, or other agents through the irrigation system.

Chronic Toxicity - The capacity of a pesticide to cause long-term poisonous effects through repeated, prolonged exposure to small amounts of the pesticide.

Confined Aquifer - An aquifer in which ground water is confined under pressure significantly greater than atmospheric pressure.

Distribution Uniformity - A measure of how evenly water is applied/infiltrated in a field during an irrigation.

Ecology - The relationships between organisms and their environment.

Efficacy - Effectiveness.

Evapotranspiration - The sum total of plant transpiration and soil surface evaporation in a cropped field.

Fertilizer - As defined in Washington law (Chapter 15.54 RCW), any substance containing one or more recognized plant nutrients, is used for its plant nutrient content, and/or is used to promote plant growth. The law includes limes, gypsums, and manipulated animal or vegetable manures, but does not include unmanipulated manures. ("Manipulated" means processed or treated in any manner, including drying to a moisture content of less than 30%.)

Formulation - A mixture of active ingredient with carriers, diluents or other materials to make it safer and easier to store, transport, dilute, and/or apply.

Granular - A pesticide formulation in the form of relatively coarse particles which are applied dry with a spreader, seeder, or special applicator.

Ground water - As defined in WAC 173-200, water in a saturated zone below the surface of the land or beneath a water body.

Habitat - A physical portion of the environment within which a population is dispersed. The living plant or animal a pest depends on for survival.

Implementation Practice - As used in the Manual, an activity or practice that will aid in achieving one of the Overall Management Objectives presented in the Manual. The purpose is similar to a Best Management Practice.

Integrated Pest Management (IPM) - A combination of pesticide and non-pesticide methods to control pests. Methods include cultural practices, use of biological, physical, and genetic control agents, and the selective use of pesticides.

Irrigation Scheduling - A generic term used to describe a family of methods/techniques that aid a farmer in deciding when to irrigate and how much water to apply.

Leaching - The movement of chemicals through soil with water.

Leaching Ratio - The percentage of applied irrigation water that is intended to become deep percolation in order to flush salts down through the crop's effective root zone.

Maximum Contaminant Level (MCL) - The maximum legal content of a substance in drinking water as established by the Washington State drinking water standards.

Nonpoint Source Pollution (NPS) - Contamination contributed by diffuse sources that are not readily identifiable or which seem insignificant taken singly. Cumulative effects from nonpoint sources can result in significant environmental problems.

Nutrients - Substances necessary for plant growth. If not occurring in sufficient quantities naturally, nutrients are commonly added to soils or sprayed directly on plants as commercial fertilizers.

Overall Management Objective - As used in the Manual, a desired end result of on-farm management that, if achieved, will reduce, control, or prevent nonpoint source pollution.

Pathogen - An entity that causes disease.

Percolation - The movement of water through soil.

Permeability - The rate at which liquids pass through soil or other materials.

Persistence - The length of time a pesticide stays in the environment once it is introduced. Persistence of a substance may be days or years depending on the properties of the specific substance.

Pest - An insect, rodent, nematode, fungus, weed or other form of terrestrial or aquatic plant or animal life or virus, bacterial, or microorganism that is injurious to health or the environment.

Pesticide - As defined by Chapter 15.58 RCW (known as the Pesticide Control Act), any substance or mixture of substances intended to prevent, destroy, control, repel, or mitigate any insect, rodent, snail, slug, fungus, weed, and any other form of plant or animal life or virus except a virus in a living person or other animal. Pesticides include insecticides, herbicides, fungicides, and rodenticides as well as plant regulators, defoliants, and desiccants. Materials added to sprays to enhance their effect (known as "adjuvants") are also included.

ppb - Parts per billion, a measure of the concentration of a substance in water.

ppm - Parts per million, a measure of the concentration of a substance in water, equivalent to milligrams per liter (mg/L).

Predator - An organism that attacks and feeds on other animals (usually smaller or less powerful than itself) and consumes more than one animal in its lifetime.

Resistant - A population of organisms that are uninjured or unaffected by a certain dosage of pesticide chemical used to control other populations of the same organism successfully. Also, plants and animals that are unaffected by a pest species.

Restricted Use Pesticide - A pesticide which can be purchased only by certified applicators and used only by certified applicators or persons directly under their supervision. Not available for use by the general public because of the high toxicities and/or environmental hazards.

Root zone - As defined by WAC 173-200, the zone of soil extending from the surface to the depth of the lowest root of a specific type of crop or plant.

Saturated zone - As defined in WAC 173-200, the zone below the water table in which all soil pores are filled with water.

Sediment - Solid material that is in suspension, is being transported, or has moved from its original location by air, water, gravity, or ice.

Surface Water - All water naturally open to the atmosphere (rivers, lakes, reservoirs, reservoirs, streams, impoundments, seas, estuaries, ditches, etc.)

Surge-Flow - The irrigation technique of using intermittent pulses of water down a furrow in order to advance water to the end of the furrow using less total applied water.

Vulnerability - The relative susceptibility of ground or surface water at a specific site or geographic area to contamination, taking into consideration both characteristics of the site and the presence of contaminants.

Wettable Powder - A dry pesticide formulation in powder form which forms a suspension when added to water.