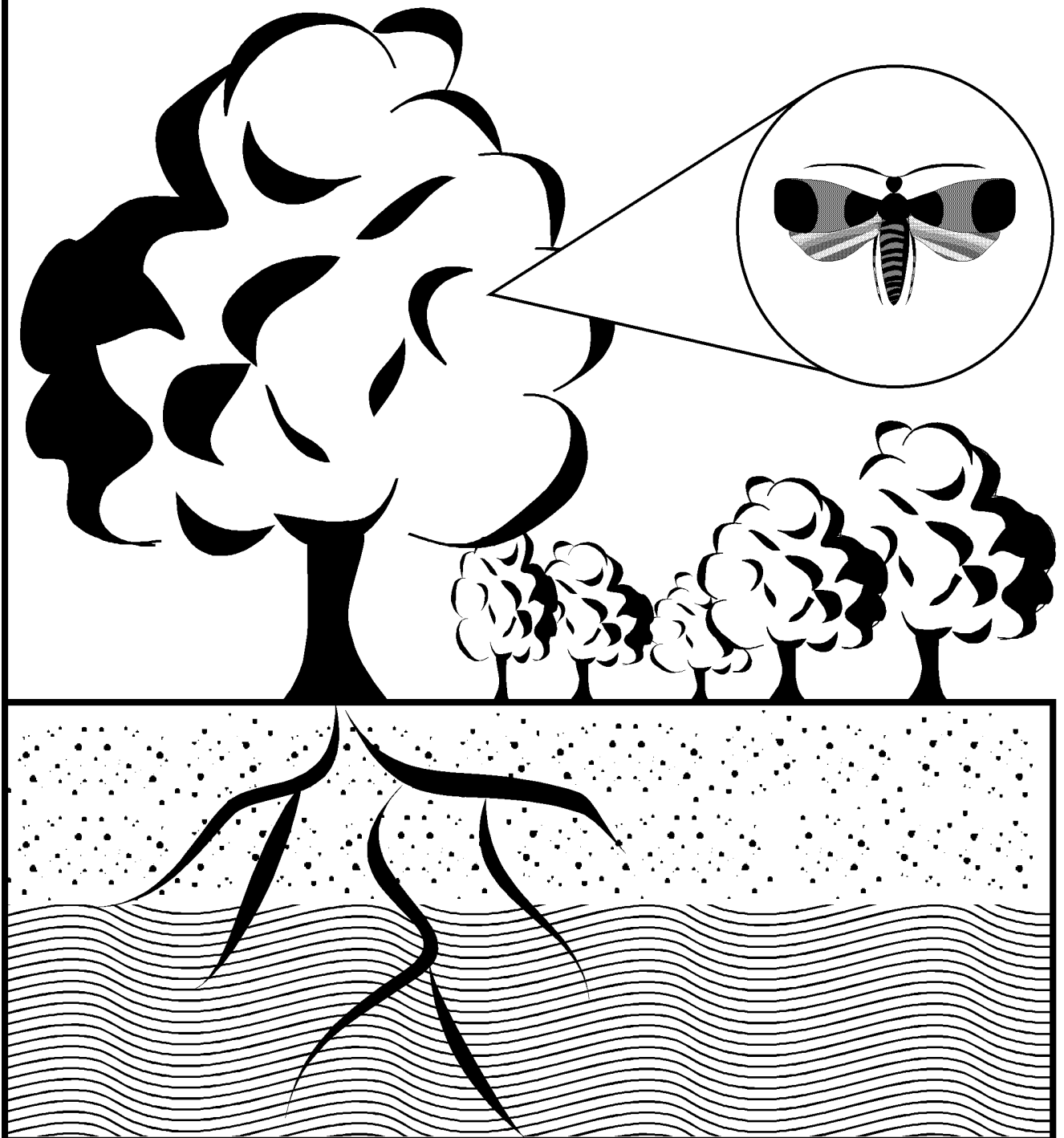


Pest Management Guidelines

*A Guide for Protecting
Our Water Quality*



PEST MANAGEMENT GUIDELINES

*A GUIDE FOR PROTECTING OUR
WATER QUALITY*

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PREFACE

The idea of this manual started back in November of 1988 when Stott Howard, WSU Weed Scientist, and I attended a meeting sponsored by the Washington State Department of Ecology on groundwater standards. We were dismayed by the lack of understanding of common agricultural practices shown by various speakers. We were concerned by the lack of participation by farmers in these discussions. In the car on the way back from the meeting, we came up with a plan to develop some “BMPs” that reflect agricultural practices. We hoped they could be of use to regulators, and others, who did not have a clear understanding of agriculture.

Shortly thereafter we added Dyvon Havens, WSU Extension Agent - Skagit County, to our team. We hoped to develop some practical recommendations on pesticide use so as to help protect water quality. These recommendations would include safe handling, storage, and application technology that farmers could adopt and which should minimize threats of pesticides to ground and surface water.

A short time later in a conversation with Chris Feise, WSU Cooperative Extension Water Quality Coordinator, Chris convinced us to convene and utilize a broad based advisory committee to assist in the development of these “BMPs”. Stott, Dyvon, and I put together a list of individuals that represented various farm and other pesticide user groups, federal and state agencies, elected officials, research scientists, agribusiness, and environmental groups. Upon invitation they all agreed to participate.

At the first meeting of the advisory group, it was suggested that rather than the original emphasis on pesticide practices, the “BMPs” primarily focus on Integrated Pest Management (IPM). The committee believed that by explaining and encouraging the adaptation of IPM practices, actual pesticide usage would be reduced, which in turn would result in reduced impact on water quality from pest management practices. This was a fundamental shift in the original concept of the “BMPs” but it was enthusiastically accepted by the committee and adopted by us as well.

Later, Stott Howard left WSU to pursue employment in the private sector. Dyvon and I felt that we were still committed to the project, but were worried about the loss of a critical member. At the next advisory committee meeting we discussed the need for assistance and an advisory committee member, Dayle Ann Stratton, with the Department of Ecology,

offered to help find outside funding to support the project. With Ms. Stratton's assistance, we obtained EPA Clean Water Fund section 319 funds through the DOE, which would support the completion of the project. We were informed by the DOE and WSU that the manual we were developing was not to be termed "Best Management Practices" as that term had regulatory connotations. Hence the use of Pest Management Guidelines evolved as the title for this manual.

In some ways this manual is quite different from what it was originally conceived to be. It is not a how-to on pesticide application and does not give specifics on pesticide application setbacks from water, operating pressures, nozzle wear, pesticide storage distances from wells, etc. It is a comprehensive review of integrated pest management that uses real examples from a diversity of commodities and other pest control uses in this region. It does not attempt to give specific IPM programs for each possible crop or pest management activity here in the Puget Sound region. Hopefully, it will establish a link between IPM and other commodity and pest specific management publications produced by Washington State University Cooperative Extension. It is these publications, - from the general Insect, Plant Disease, and Weed Control Handbooks to the commodity pest management guides, such as the Tree Fruit or Small Fruit Pest Management Guides, to the pest specific fact sheets like the one for Ophiobolous Patch on Turf - that will give control or management recommendations.

This manual is not designed just for farmers. It is directed towards all professional pest managers or pesticide applicators in the Puget Sound region. The advisory committee included farmers, ornamental nursery operators, road right of way managers, structural pest control operators, and others in the pest management field. The manual is directed towards these areas and others such as golf course and sports turf managers, utility right of way managers, public grounds managers for parks or schools, and others. The authors have attempted to illustrate IPM from a diversity of pest management uses. If a pest management area has been left out, it should not be construed that no possibilities for an integrated approach exist. These approaches may not yet be developed, but the future of pest management is clear for all areas.

The public, the customer, and the government are all encouraging and supporting the adaptation of IPM type approaches. These approaches include understanding the pest life cycle, monitoring, establishment of action levels, selection of the least environmentally disruptive yet effective techniques, and follow up of past actions. Many leading pest managers have already put these steps into practice. Some pest management businesses are already successfully marketing themselves based on this approach.

This manual does not advocate the elimination of synthetic chemical pesticides. There may well be many situations where pesticides are the most appropriate method of pest management. This manual does recommend a systematic process of evaluating the pest situation, including the analysis of various management options and their effectiveness. The term "effectiveness" should include a long term perspective of both the crop/site/ component being protected and the environment.

This manual has attempted to take a balanced approach to a subject that can be fraught with emotional reactions. Some readers may feel that not enough has been said to protect the environment while others may feel that not enough has been said to acknowledge the level of productivity that pesticides have given the world in the past. Yet, hopefully all readers can find something of value and use within this document.

I want to acknowledge the important contributions made by a number of individuals in the development of this manual. I would like to particularly thank Dayle Ann Stratton for her assistance in identifying funds to support this effort. I want to thank Kahle Jennings, our DOE project officer, for his flexible management of this project. I would like to acknowledge Chris Feise for his early direction and encouragement. I appreciate the effort made by Art Antonelli, Leonard Askam, Ralph Byther, and Kassim Al-Khatib, all of WSU Cooperative Extension, to review this document for technical accuracy and all of their contributions to the content of this document. I also want to acknowledge the contributions from the other individual resources who assisted the authors with technical information. I want to sincerely show appreciation to the members of the advisory committee who gave us guidance, reviewed the drafts, and otherwise supported our efforts. I want to thank Stott Howard for his early energy and insight for this project. I want to thank Dyvon Havens for all her support and contributions, and her willingness to manage this effort during my sabbatical. Lastly, I wish to acknowledge the efforts of the two primary authors of this document, Becky Peterson and Geoff Menzies. They have done an outstanding job of compiling all of the information on this subject into a readable and understandable document. I value their contributions and their ability to persevere through review after review.

Craig MacConnell
January 15, 1993

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CHAPTER ONE

INTRODUCTION

WATER QUALITY RISKS FROM PESTICIDES

In recent years, the concern over contamination of water resources has resulted in federal, state, and local agencies focusing their attention on pesticides and the potential risks they present to water quality. This is particularly true in the case of ground water which plays an important role in the lives of millions of people nationwide. In the United States, about half of the total population and 90 percent of the rural population depends on ground water as a drinking water source (OTA). With ground water use increasing by nearly 4 percent annually, it is estimated that a half million new water wells will be drilled each year (Agricultural Law and Policy).

As the nation's dependence on ground water continues to increase, government agencies are continuing their investigations on contamination of this important resource. This is resulting in an increase in the number and location of pesticides being detected. In 1985, the Environmental Protection Agency (EPA) estimated that 17 pesticides had been detected in the ground water of 23 states due to normal agricultural use. In 1988, the numbers increased to 46 different pesticides in the ground water of 26 states (OTA; U.S. EPA). The areas selected for most of these studies have been ones with relatively high ground water vulnerability and high pesticide use. In addition, many of the pesticides sampled are ones which are no longer in use.

The concerns being generated as a result of these studies are still valid for a number of reasons; the primary one being the inherent problems associated with cleaning-up a contaminated ground water source. Generally, recovery of a ground water source through natural processes is not relied upon because of the extremely long time it will take to regenerate that supply. Remediation efforts of contaminated ground water are often not feasible due to the cost involved, the limitations associated with some of the remediation

methods, and the fact that the problem still may not be adequately solved. Problems associated with pesticide contaminated ground water were recently seen in Whatcom County, Washington where ethylene dibromide (EDB) was detected in ground water in 1985. Since that time, bottled water has been supplied by the Washington State Department of Ecology (Ecology) to 21 homes in the immediate area. A long-term solution to the problem still has not been identified and is not expected to be for the next few years. In the mean time, the options that have been identified as a solution include connecting to an existing municipal water system, forming a public water district, installing home filtration devices, or continuing to supply bottled water. The options presented in this case do not suggest a solution that is feasible or which clearly addresses the problem. The costs that have been incurred to date by Ecology as well as affected landowners are well above the out of court settlement that was reached between the state and the pesticide manufacturer.

The Whatcom county case is not an isolated incident. Cases of pesticide contamination in both surface and ground water are found all across the country as well as here in Washington state and western Washington. As with the previously mentioned studies, a number of the pesticides detected in these additional cases are ones which are no longer in use or are restricted use pesticides. Restricted use pesticides can be applied only by certified applicators or by individuals under the direct supervision of a certified applicator.

ACROSS THE NATION

In 1990, the EPA completed its five year National Survey of Pesticides in Drinking Water Wells (NPS). During this five year period, approximately 1300 community water system (CWS) wells and rural domestic wells were sampled for the presence of 101 pesticides and 25 pesticide degradates along with nitrate. Statistically, the Survey results represent approximately 94,600 drinking water wells at 38,300 community water systems and over 10.5 million rural domestic wells throughout the U.S. Based on the NPS results, the EPA estimates that 10.4 percent CWS wells and 4.2 percent rural domestic wells in the U.S. contain at least one pesticide or pesticide degradate. The two pesticide analytes most frequently detected were DCPA metabolites (a degradate of DCPA) and atrazine, respectively. DCPA is extensively used on home lawns, golf courses, and farms for control of many annual grasses and broadleaf weeds. The second most commonly detected pesticide, atrazine, is used for general weed control on non-cropped industrial land, selective weed control in conifer restoration and Christmans tree plantations, and non-selective control of vegetation on fallow land. Other pesticides detected were alachlor, bentazon, dibromochloropropane, dinoseb, ethylene dibromide, ethylene thiourea, hexachlorobenzen, lindane, prometon, and simazine. The NPS was designed to ensure that samples were taken from wells located in areas with a wide range of levels of pesticide use and ground-water vulnerability. (U.S. EPA, 1990a)

A 1989 study undertaken by the United States Geological Survey (USGS) reported that prior to pesticide application 55 percent of streams tested in ten Midwestern agricultural states had measurable levels of triazine herbicides present. Shortly after application, the herbicides were detected in 90 percent of the streams. (Hileman). The potential impact that can result from surface water runoff containing pesticides is seen in an incident which occurred in the summer of 1991 at which time an estimated 750,000 fish in nearby waterways were killed as a result of insecticide runoff from Louisiana sugar cane fields (Webber).

In the United States, pesticide contamination of ground water was first discovered in 1979 when dibromochloropropane (DBCP) was detected in about 2500 wells in California. About 60 percent of these wells had levels above the state standard. As a result, approximately 700,000 people whose drinking water source was from the contaminated wells have been exposed to DBCP. In California's San Joaquin Valley, DBCP may be present in approximately 1/4 of the usable ground water. (U.S. EPA).

In Hawaii, thirteen public drinking water wells serving 130,000 people have been found to be contaminated by ethylene dibromide (EDB), DBCP, and/or trichloropropane (TCP). (U.S. EPA). More than 1000 wells have been condemned as a drinking water source in Florida due to contamination by EDB.

WASHINGTON STATE

In 1988, the Washington State Department of Ecology initiated the Agricultural Chemical Pilot Study in which portions of three agricultural counties (Whatcom, Franklin, and Yakima) were selected for well testing. The areas identified were ones considered to be susceptible to ground water contamination. In each area, 27 shallow wells were tested for 46 pesticides that are known or suspected to have a high propensity to leach to groundwater. Of the 81 wells tested, 23 showed indications of at least one of the pesticides sampled for; 20 of these detections were confirmed in a second sampling. Seven detections were at levels above the EPA's Proposed Maximum Contaminant Levels (PMCLs) or Lifetime Health Advisories.

A ground water study by the USGS is being conducted in portions of Franklin and Benton counties. Preliminary findings showed traces of one or two pesticides in five of the 24 wells being tested. While all are well below drinking water standards and EPA's Health Advisories, one finding of atrazine and a breakdown product of aldicarb (aldicarb sulfone) came from a well that is 340 feet deep suggesting that deeper aquifers may also be impacted by pesticides (Stratton).

WESTERN WASHINGTON

Western Washington has been the focus of a number of studies associated with both ground and surface water quality. In January 1984, EDB was detected in a private well in Skagit County. As a result of this finding, the Washington State Department of Social and Health Services conducted a study that found the compound in domestic wells in Skagit, Whatcom, and Thurston counties. Thirteen of the wells had levels of EDB above the health advisory of 0.02 ppb (parts per billion). Ten wells were public water supplies serving a total of about 550 persons. EDB has also been found in wells in Snohomish County. (PSWQA).

The Agricultural Chemical Pilot Study previously mentioned included Whatcom County as one of the study areas. In this study area, pesticides detected in ground water included carbofuran, DBCP, 1,2-dichloropropane, EDB, and prometon (Erickson). Carbofuran and prometon are restricted use pesticides under Washington state's WAC 16-228-164. The other two pesticides detected in Whatcom County groundwater study areas, DBCP and EDB, have been banned for use by the EPA and are no longer available for use.

A unique situation illustrating some of the difficulties associated with ground water contamination is again seen in Whatcom county. Preliminary results of a ground water study undertaken by Environment Canada on a large aquifer in lower British Columbia resulted in the detection of a number of pesticides. The aquifer under study extends south of the Canadian border into Whatcom county. In this situation, of the 23 pesticides sampled, 12 were detected. If EPA Health Advisory Levels (HALs) were applied to the 12 pesticides, two of them, atrazine and diazinon, would exceed the HAL for drinking water. However, the cross-border contamination of ground water presents a unique situation because the Canadian government does not necessarily use the same regulatory standards and have the same pesticide application requirements as the United States government.

Runoff studies have also been undertaken in western Washington. A two year study was completed in 1988 by Western Washington University which examined the potential effects of pesticide runoff on eelgrass communities in Padilla Bay in Skagit county. Water and sediment samples collected in the Bay and from three sloughs that run into the Bay were analyzed for fourteen pesticides (Mayer). The pesticides analyzed included active ingredients that were being used in the area at the time; 2,4-D, atrazine, chlorothalonil, diazinon, dicamba, dinoseb, methamidophos, methyl parathion, metribuzin, parathion, PCNB, simazine, terbutryn, and trifluralin. Detectable levels of pesticides were found only once in the four general sampling events conducted. Dicamba and 2,4-D were found in water samples and dicamba was found in several sediment samples. Although these levels are not expected to have a major effect on marine seaweeds and seagrasses (Mayer), it is not known what chronic effects these compounds may cause in other aquatic organisms.

From 1978 to 1981 the National Oceanic and Atmospheric Association (NOAA) conducted the Marine Ecosystems Analysis (MESA) Puget Sound Project. Sediment and biological tissue samples were analyzed for organochlorine pesticides including aldrin, chlordane, DDTs, heptachlor, and lindane. Organochlorine pesticides were found in sediments taken from Commencement and Elliott Bays. In both the sediments and fish liver samples, the highest values found were in Elliott Bay in the Duwamish Waterway. High values of organochlorine pesticides were also found in fish liver samples from sites along the Seattle waterfront. Intermediate fish liver values were found at Sinclair Inlet, Brown's Point, southwest Commencement Bay, and West Point sites. (PSWQA).

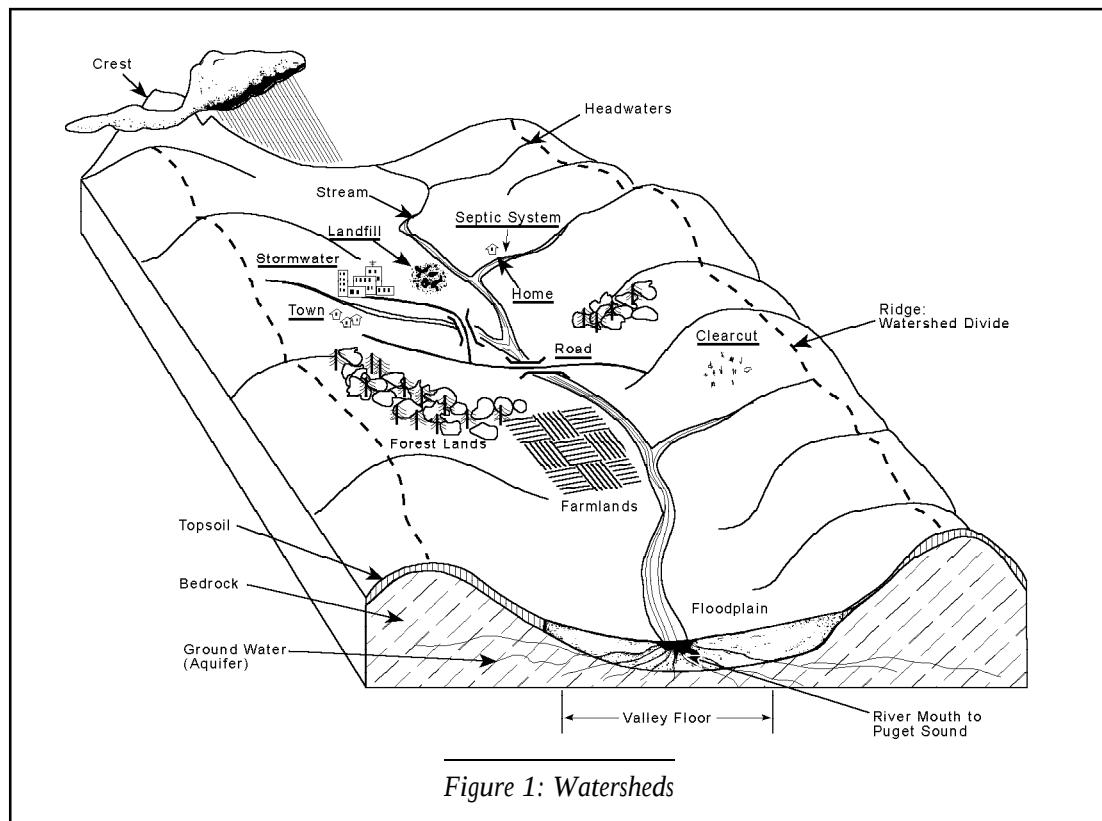
PESTICIDES AND WATER

In most cases pesticides can be used according to label instructions without harming ground and surface water. However, the unintentional transport of pesticides to surface and ground water does occur. It occurs through a combination of a number of different mechanisms including pesticide application technique, pesticide properties, and site characteristics. However, before discussing these specific mechanisms, it is helpful to review the environmental features related to water resources and how they function.

DESCRIPTION OF ENVIRONMENTAL FEATURES

WATERSHEDS

A watershed is an area of land which drains into a common body of water. A ridge or other area of elevated land, called a land divide, separates one watershed from another. Streams on one side of the land divide flow in one direction and streams on the other side flow in a different direction. As water flows overland or through soils, it recharges surface and ground water supplies.



Water continually cycles among the atmosphere, oceans, lakes, streams, plants, soils, and other materials at and below the Earth's surface. This movement and exchange of water among the various components of the environment is referred to as the "hydrologic cycle".

Therefore, every activity that occurs on the land or in the air can affect the watershed system. As water flows through the watershed, it picks up manure, sediments, pesticides, pathogens and other contaminants and transports them to other bodies of water such as streams, rivers, ponds, estuaries and, in some cases, groundwater.

WETLANDS

In Western Washington we have a number of different types of wetlands; marshes, bogs, and swamps are a few examples. All wetlands, however, serve the same basic functions. They act as “nurseries” for juvenile fish and other aquatic life, they help control flood waters by acting as a giant sponge, they recharge ground and surface water resources, and they are important habitat for wildlife. Wetlands may also protect and improve water quality by removing and storing sediments and pollutants transported in runoff.

GROUNDWATER

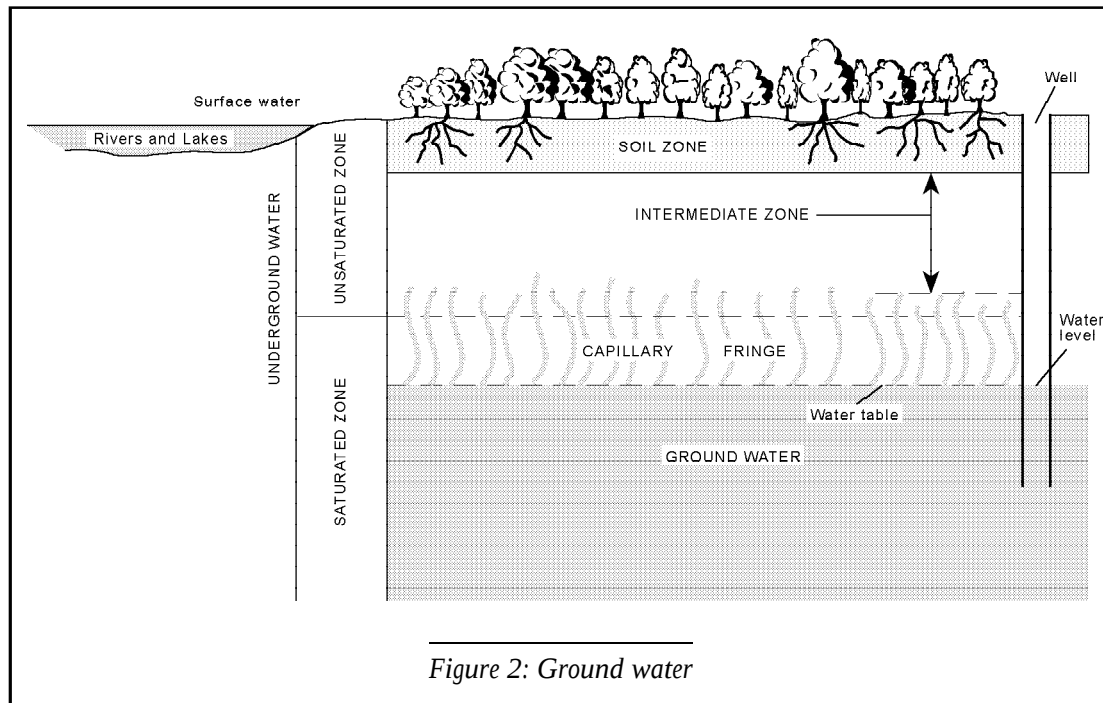
Groundwater supports a number of very important functions. In addition to supplying drinking water to half of the country’s population, groundwater provides recharge to surface streams and sustains aquatic wetlands and terrestrial ecosystems.

Often times, people think of groundwater as underground streams, rivers, or lakes. Although such bodies do occur, groundwater generally exists as subsurface water filling spaces between particles of sand, soil or rock beneath the earth’s surface.

If you were looking at a cross-section of the land surface, the first zone you would encounter would be the plant root zone. Generally this zone extends into the first few feet of the surface but in some cases can extend to over 15 feet (ie, alfalfa). In the plant root zone, a number of biological processes takes place some of which may be responsible for the degradation of pesticides (Pye and Kelly). In the “zone of aeration”, which is just past the plant root zone, there is some water present (vadose water) along with a considerable amount of air. At the bottom of the zone of aeration is the water table which is also the top of the “zone of saturation”. In the zone of saturation the soil and rock are completely filled with water.

The amount of water that a rock formation can contain is a result of its porosity (the space between the grains of soil and rock or the cracks in the rock). If the grains are of even size or randomly arranged, the spaces between them account for much of the total available space and can accommodate large volumes of water. If tightly packed, the rock will accommodate much less water.

In order for water to move through rocks, the spaces or cracks must be connected. If the connected spaces are large enough for water to move through, it is described as “permeable”. Saturated permeable rock can store and provide large quantities of water. When references are made to groundwater sources, the term aquifer is used to describe the saturated area. Aquifers are usually classified as either “confined” or “unconfined”. A confined aquifer is separated from the water table above by a layer of relatively impermeable sediment or rock and is sealed at its base by another layer of materials having low permeability.



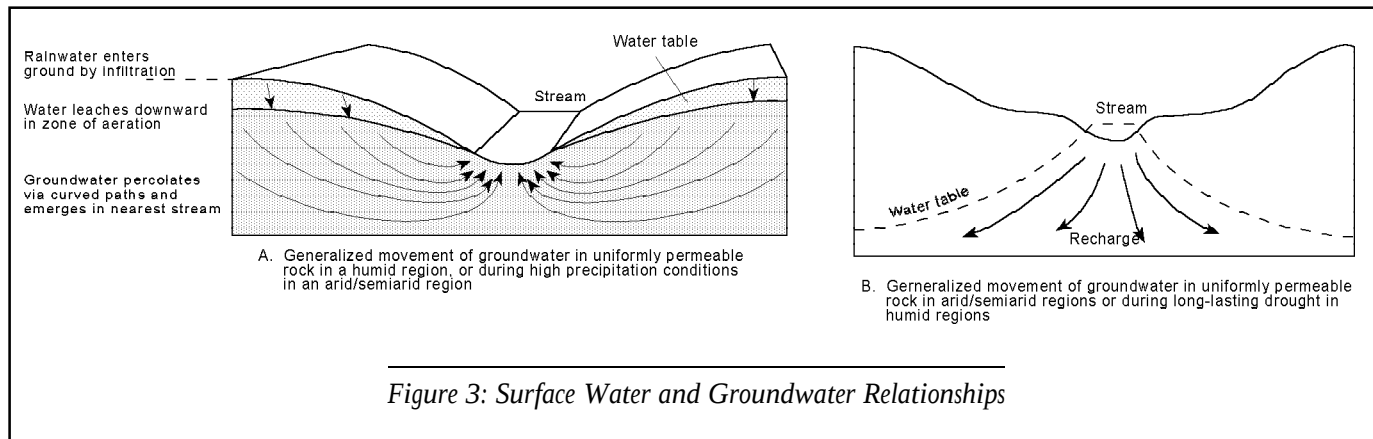
Confined aquifers are resupplied with new water (referred to as recharged) only at the point where the formation meets the surface or where it ends someplace underground. In other words, confined aquifers do not receive water from overlying land surfaces. This also makes confined aquifers less vulnerable to ground water contamination.

An unconfined aquifer is one in which the water table is usually the top of the aquifer. There are three types of unconfined aquifers: 1) those that are not connected to other aquifers or surface lakes and streams; 2) those that are interconnected hydrologically with other streams, and 3) perched aquifers. Perched aquifers occur where an impermeable layer exists in the zone of aeration, creating a groundwater formation above the water table. Perched aquifers produce wells and are likely sources of springs. (Agricultural Law and Policy). Depending on local geology and groundwater flow characteristics, water in any given well may be recharged from the land directly adjacent to the well or from areas miles away. Shallow wells typically are recharged by water originating from adjacent land. The water for recharging the aquifers comes from rainfall, snow-melt and runoff, or it has been trapped in aquifers since geologic time. Because unconfined aquifers are generally recharged from overlying land surfaces they are much more vulnerable to ground water contamination. Most private wells in western Washington are shallow wells which draw water from unconfined aquifers.

Pesticides in groundwater are an extremely serious problem due to the long turnover rate for groundwater. Although the rate may be as short as a few months, it is more commonly years or decades before the water in an aquifer is replaced. In addition, with the exception of perched aquifers, oxygen is generally not present in groundwater and the microorganisms that live in an oxygen-free environment are less effective in breaking down pesticides. (Michigan State University)

SURFACE WATER

Water that flows over land is referred to as surface water. This includes streams, lakes, ponds, rivers and even drainage ditches. Ground water and surface water are closely linked and often interconnected. The flow of one to the other depends on the relative altitudes of the surface water and the groundwater table. It has been estimated that about 30% of the flows in streams and rivers during an average year is provided by groundwater discharge. (U.S. EPA; Agricultural Law and Policy Institute).



The concerns associated with contamination of surface water by pesticides are somewhat different than those associated with ground water contamination. Unlike ground water, most surface waters have a rapid turnover rate, and contain free oxygen and microorganisms; all of which can enhance the rate at which pesticides are broken down.

Transport of pesticides to surface water is a concern with regard to the effect it may have on wildlife. Both aquatic organisms and land-based organisms depend on streams, creeks, ponds and even ditches for habitat and food. The degree of toxicity presented by a pesticide is variable depending on the organism affected. For example, a pesticide with a low mammalian toxicity may be extremely toxic to fish.

TRANSPORT OF PESTICIDES INTO WATER

Water flow is an important transport mechanism for pesticides. When water is added to the soil through precipitation or irrigation, the portion that doesn't evaporate may either infiltrates into the soil or runs off the soil surface. The fraction of water that infiltrates compared to the fraction that runs off depends largely on the intensity of precipitation and the infiltration capacity of the soil.

Water that infiltrates into the soil is either stored within the soil profile or percolates downward toward ground water, depending on the soil water conditions. When soil conditions are dry, the added water will increase soil water storage. If the moisture-holding capacity of the soil is exceeded, the excess water percolates downward through the soil to ground water. Pesticides present on vegetation or soils may be transported along with the water depending on the properties of the pesticide and the composition of the soil.

Pesticides applied to land may be transported from the application site to surface water by a number of different mechanisms including: 1) in solution with surface runoff and in association with sediment in surface runoff (adsorption); 2) volatilization into the atmosphere followed by deposition into surface water; 3) deposition into surface water through drift from aerial and ground spraying; 4) in association with inaccurate application rates; 5) movement through soil (leaching), and; 6) improper handling, storage and disposal of pesticides followed by deposition to ground or surface water. Each of the transport mechanisms discussed below will be covered in greater detail in a later chapter.

SURFACE RUNOFF AND ADSORPTION

Surface runoff occurs when water is applied to the soil at a faster rate than it can enter the soil. Runoff water can carry pesticides in the water itself or by adsorption to eroding soil particles. The extent to which runoff occurs depends on several factors including: 1) the slope or grade of an area (topography); 2) the texture and moisture content of the soil; 3) the percent organic matter in the soil; and 4) the amount and timing of rainfall. Runoff containing pesticides can cause direct injury to nontarget species, harm aquatic organisms in streams and ponds, and can lead to groundwater contamination. The presence of vegetation or crop residue tends to slow the movement of runoff water thereby reducing the amount of pesticides which may enter surface water.

VOLATILIZATION

Volatilization occurs when a solid or liquid changes into a gas. When this change of state takes place the possibility of vapor drift occurs which may result in airborne chemical vapors being transported by air currents from a treated area to other locations, where rainfall can deposit them on land surfaces, lakes, streams and vegetation. This occurrence has been confirmed in a study conducted by the USGS. Rainwater sampled from states in the upper Midwest and Northeast resulted in the detection of low-levels of triazine and acetanilide herbicides.

AERIAL DRIFT

Aerial and ground application of pesticides may also transport pesticides into water through pesticide drift which occurs when air-borne pesticides move beyond the intended target. Factors that may contribute to pesticide drift include weather conditions and equipment configuration and operation. Aerial drift is discussed in greater detail in a Chapter Five.

APPLICATION TECHNIQUES

Transport of pesticides to water may occur as a result of inaccurate application rates. In a 1979 study conducted by the University of Nebraska, applicators missed the intended application rate by over 5% with 40% of the error resulting from under application and 60% from over application. Reasons most often identified were mistakes in calibration calculations, unknown or inaccurately marked tank volumes, worn nozzles, or inaccurate pressure gauges. A study of 184 Missouri farmers found half of them using questionable calibration techniques and half of them “eyeballing” nozzle spacing and mounting height. (Jackson, et al.). In other cases, errors resulted from poorly maintained or outdated equipment, especially pumps and sprayer nozzles. Depending on the properties of the

pesticide and soil conditions, over application of pesticides may result in leaching to ground water or runoff to surface water.

LEACHING

Leaching is the movement of pesticides through the soil. Pesticide leaching partially depends on the chemical and physical properties of the pesticide. For example, adsorptivity which is the ability of a pesticide to bind with soil particles, influences the leaching potential of pesticides. A pesticide which binds tightly to soil particles is less likely to leach than one that does not. Another property of pesticides which influences leaching is the solubility of the pesticide. A pesticide that dissolves in water can move with water through the soil.

Soil properties are an equally important consideration when looking at the leaching potential of pesticides to groundwater. Soil factors that influence leaching include soil texture, amount of organic matter, and permeability. For example, a sandy soil which is much more permeable than a clay soil and which has less organic matter has a much greater leaching potential.

Leaching potential of pesticides to ground water is discussed in greater detail in Chapter Four.

IMPROPER STORAGE, HANDLING, AND DISPOSAL

In some respects, improper pesticide handling, storage, and disposal (all of which are discussed in detail in a later chapter) represent a greater threat to groundwater than field application because these activities can result in high concentrations of pesticides in small areas. Studies conducted in Iowa have shown that in commercial loading and handling areas and in areas where equipment is rinsed, pesticide concentrations in pools and soils are in the range of formulation concentrations (Jackson, et al.). The risk to ground and surface water is increased as a result and, in combination with site characteristics, may result in contamination of a water resource.

Improperly rinsed pesticide containers contain pesticide residues. Therefore, when containers are improperly disposed of they present a potential source for pesticide contamination of water resources for the same reasons as those presented when pesticides are improperly stored and handled.

CONCERNS FOR ENVIRONMENTAL AND HUMAN HEALTH

In addition to ground and surface water protection, environmental health and human health concerns need to be factored into the decision making process when considering pest management programs.

ENVIRONMENTAL CONCERNS

As previously discussed, surface water such as streams, lakes, and estuaries are also susceptible to pesticide contamination. In addition to direct application of pesticides to surface water, runoff from agricultural, forest, and urban areas, which may contain pesticides, will find its way to surface water where nontarget organisms may be affected. Environmental effects that can be caused by pesticides in surface water include short term effects such as fish kills or long term effects such as tumors in fish livers, impairment of the reproductive ability of aquatic organisms, and a decline in aquatic invertebrates which act as a food source for aquatic organisms. (PSWQA).

Plant communities may be affected by herbicide use through changes in species composition and density of plant populations. Species that are more tolerant of herbicide use may replace those that are more sensitive or susceptible to the chemicals. This is demonstrated by the fact that by 1989, about 80 out of a total of more than 500 weed species were found to be resistant to herbicides. Also, as a result of insecticides, about 440 different insect and mite species have become resistant to some pesticides. Higher doses of the same pesticides, combinations of pesticides, or substitution of different pesticides are now necessary to control the resistant species. (Hileman).

Application of pesticides with a general toxicity to broad categories of organisms may affect the “targeted” soil and plant pests as well as harmless or even desirable invertebrate species. Honeybees are one example of a valuable nontarget species that may be significantly affected by the application of some insecticides (PSWQA; Worthing). Other examples of impacts to nontarget species are discussed in Chapter Two.

Bird populations may also be susceptible to pesticide application. Bird kills can occur when they ingest food that has been treated with some pesticide products. An example of this is an incident which occurred in October 1986 when 85 American widgeons were killed after feeding from a golf course in Bellingham, Washington that had been sprayed with the organophosphate insecticide, diazinon (Kendall). This was not an isolated incident. Prior to the Washington incident, there had been a number of documented bird kills on golf courses treated with the insecticide. As a result, the EPA banned the use of diazinon on golf courses but continues to allow its use on residential lawns. (Gup).

Reductions in bird populations may also occur as a result of indirect or chronic effects resulting from pesticide use. Egg shell thinning has been shown to occur with a number of organochlorine pesticides resulting in a reduction of successfully hatched eggs. DDT is probably the most widely known example of this effect. Most of the organochlorine pesticides have since been banned from use in this country.

Field application of insecticides and rodenticides have resulted in direct mortalities to nontarget wild mammal populations such as raccoons, rabbits, ground squirrels, woodchucks, voles, shrews, and moles. Pesticides such as parathion and methomyl which significantly impair the nervous system are especially toxic to mammals (PSWQA; Worthing).

When enough pesticides reach an ecosystem, they alter both its structure and function. Because pesticides are a poison that becomes effective at a given dose, a certain number of species belonging to the ecosystem will be eliminated in the affected area, or their populations will be significantly reduced. When species richness is seriously reduced, parasites and predators high in the trophic system that depend on hosts and prey below them will be seriously affected (Pimentel, et al., 1986). Reducing species diversity and altering an ecosystem may reduce its stability.

HUMAN SAFETY

Each year accidental deaths and illnesses occur which can be attributed to pesticides (Pimentel, et.al., 1991). Farmers and farm workers have been reported to experience an elevated incidence of traumas, certain cancers, respiratory diseases, dermatitis, and acute and chronic chemical toxicity (Hileman; Council on Scientific Affairs; Pimentel, et al., 1991). Worker accidents have occurred as a result of improper pesticide handling or application methods, failure to use recommended protective equipment or other violations of established safe practices or label instructions (National Safety Council). Between 1982 and 1985 there were 238 county-reported pesticide illnesses in California involving Category I or II organophosphate and carbamate pesticides (Category I and II are EPA classifications with Category I being most toxic). Category II organophosphates and Category I and II carbamates exposures accounted for 50% of the single pesticide exposure illnesses; these exposures included chronic exposures, short-term exposures, and accidents (Brown, et al.).

An organized system for reporting of pesticide-related incidents in Washington state has recently begun. In 1989 the Washington state legislature formed the Pesticide Incident Reporting and Tracking Review Panel (PIRT). The panel, which is responsible for data management for reporting of pesticide incidents, receives information from five state agencies involved with pesticide investigations. The five state agencies include the Departments of Agriculture (WSDA), Labor and Industries (L & I), Health (DOH), Ecology (Ecology) and Natural Resources (DNR). According to PIRT's 1991 annual report there have been a number of pesticide-related incidents reported in Washington state. From October 1, 1990 to September 30, 1991 there were a total of 694 complaints filed to the five state agencies with 453 investigations completed. The location of the reported incidents was almost evenly divided between eastern and western Washington with 236 and 225 respectively. The majority of the investigated incidents (140) involved agriculture which included forestry with commercial/industrial activities close behind (107). (Washington State Department of Health)

Even when label directions are followed, pesticide applicators may be exposed to low levels of the pesticide. A study conducted on operators wearing protective clothing and performing three different operations: 1) mixing-loading, 2) boom application and 3) spray gun operations indicated exposure occurred during all operations with the highest exposure being during the mixing-loading operation (Reed, et al.).

With regard to pesticides in drinking water, actual human health impacts that may occur are unknown, especially in the case of very low pesticide concentrations which are now easily detectable with modern scientific equipment and methods. In response to concern with groundwater contamination, the Environmental Protection Agency (EPA) has issued guidelines for lifetime health advisory levels (HALs) for commonly used pesticides which includes a margin of safety to protect humans. Water containing pesticides in concentrations at or below this level is believed to be acceptable for drinking every day over the course of a lifetime.

Clearly, pesticides play an important role in controlling pests. Agriculture, forest management, nurseries, landscape management, and home gardens are just a few of the many cases where pest management is desired. However, the cases discussed in this chapter illustrate the potential risk pesticides present to ground and surface water. Adopting a pest management strategy which does not depend exclusively on pesticides will significantly reduce the risks of water resource contamination and will help ensure the continued availability of pesticides. The following chapters discuss Integrated Pest Management (IPM), an effective pest control strategy, which includes pesticides as one of a number of control mechanisms.

CHAPTER TWO

INTEGRATED PEST MANAGEMENT

Integrated pest management (IPM) represents a balanced approach to controlling pests. Although most IPM research has addressed agriculture, there are successful programs in most other environments as well. It is not a panacea or cure-all; it is a scientifically based strategy for controlling pests with minimal disruption of the earth's environment. Pesticides are an important component of most IPM programs and will likely continue to be for quite some time. IPM should not be viewed as a threat to the pesticide industry nor to the availability of pesticides. It recognizes that pesticides are a valuable resource and that through judicious use, this resource will continue to be available. IPM continues to be cited as the most sensible strategy to pursue in order to protect groundwater from pesticide contamination. Pesticide use is optimized under IPM, generally resulting in reduced frequency of pesticide application and therefore, less opportunity for ground water contamination. IPM also represents a mental shift in our approach to pest control, whereby an attempt is made to understand the dynamic nature of interactions between environment, pest and host; rather than to narrowly focus exclusively on the pest.

DEFINITION

A variety of definitions exist for the term, Integrated Pest Management. Most versions do not encompass all of the concepts that are important to a good understanding of the term and therefore some discussion is warranted.

Inherent in the term is the *integration* of biological, cultural, physical, genetic, narrow spectrum bio-rational, and/or chemical tactics where appropriate to suppress a pest population to, or maintain a population at a tolerable level. Consideration is given to each of these strategies and the most appropriate ones from an economic and environmental standpoint are used. Contrary to the perception of some, IPM is not synonymous with biological control. However, a primary goal is minimal environmental disruption and therefore, pesticides are generally relied upon as a last resort.

When most people think of a *pest*, the six-legged kind comes to mind. In addition to insects, this term refers to weeds, diseases, plant parasitic nematodes, mites, and several vertebrates including certain rodents and birds. In most cases, these organisms by their mere presence alone do not justify control actions. One of the most important concepts in IPM is the determination of pest status. This is accomplished by regular monitoring, or sampling, and comparing the results to an established treatment or threshold level usually based on economic or aesthetic considerations.

It naturally follows that *management* of the pest below an economic or aesthetically damaging level is the goal of IPM, rather than eradication. Eradication is an unattainable objective in most situations from a practical and economic perspective, if not philosophical. There are those situations where there is zero tolerance for a pest and in these cases, localized eradication may be a realistic goal. The principles of IPM would still apply.

Finally, decision making in IPM is based on a good understanding of the biology of the pest or complex of pests allowing for optimum timing and selection of appropriate control tactics when control is necessary. Prophylactic, calendar-based applications of pesticides particularly insecticides can often be avoided in most situations where IPM is implemented.

HISTORY OF IPM

“IPM”

The term “IPM” was first used by entomologists as early as 1952, but was not a common term until the late 1960s. Up until that time, the concept of IPM was referred to as “Integrated Control”. Hoyt’s work in apples in Washington in the 1960s is an excellent example of this early stage of IPM. His studies focused on careful selection of pesticides in order to minimize disruption of natural biological control of mites, a key pest in this crop. With the onset of mite populations that became resistant to miticides, damage to fruit was much less in orchards that practiced integrated control (Hoyt). His early research is the basis for Apple IPM in Washington today. (See WSU Publication EM2788 for more information.) The 1970s and the early 80s may be coined the “Golden Era” of IPM. The public outcry generated by Rachel Carson in her book Silent Spring drew attention to the adverse effects of pesticides on the environment and opened the door to IPM as the solution to environmental contamination and other risks associated with pesticide use. Entomology dominated IPM research in the 1970s when the “Huffaker Project” was underway with funding provided by the National Science Foundation, Environmental Protection Agency (EPA), and the United States Department of Agriculture (USDA). There was little attention given to weed, disease or nematode pests in this large project. During the same period, funds were given to the Cooperative Extension Service (CES) to begin the development of pilot pest management projects. From 1971 to 1975, thirty nine federally funded pilot pest management projects were initiated in twenty nine states by CES. These programs were based on field scouting to supply necessary data to determine the need for the application of insecticides. Field demonstrations were used as on-farm models for educational purposes. Recently these programs have been multi-disciplinary including management of weeds, diseases, and nematodes. (Frisbie and Adkisson).

Beginning in 1979 a 17 university project called the Consortium for Integrated Pest Management (CIPM) was developed as an inter-disciplinary project to study the effects and management of multiple pests in four major crops; alfalfa, cotton, apple, and soybeans. IPM during the 70s and early 80s received considerable funding and publicity as the reasonable approach for the management of pests in agriculture, forestry, and urban areas. According to Frisbie and Adkisson; “IPM is now established as the sensible approach to pest control”. During the mid '80s, the focus shifted from environmental concerns to economic concerns. As of 1988, fifty USDA sponsored IPM projects covering twenty three crops and two livestock pests are in effect. Over the past decade, the popularity of the IPM approach has continued to grow in urban horticulture and turf management (Foy).

IPM very obviously has its roots in agriculture. This is largely due to the nationwide land grant system of state universities which have provided research and extension services to support agriculture. For this reason, most of the early IPM projects targeted agricultural crops. In spite of this, there have been and will continue to be successful programs in forestry, ornamental, turf, urban, and public health systems.

IPM CONCEPTS GO FURTHER BACK

Despite the quite recent history of IPM, the concepts on which it is based have a much lengthier history. Prior to the development of modern pesticides in the 1940s, the use of cultural rather than chemical control methods was the norm. Crop rotation has been practiced for years in corn in the midwest partly to reduce damage from corn rootworm, a soil insect pest which can build to high populations in fields continuously planted to corn (Anon, 1984). Physical control of weeds through cultivation and hand-pulling has been and continues to be an acceptable method of weed control. The first successful example of the use of classical biological control was the introduction of the Vedalia beetle to control a citrus pest, the cottony cushion scale, in California in the late 1800s (van den Bosch and Messenger). Monitoring insect populations to estimate an economic threshold for chemical treatment has been practiced for over ninety years, beginning with Arkansas cotton in 1901. Application of pesticides has been practiced in agriculture for over a century but was initially limited in adoption by farmers due to cost, limited selection of materials, and resistance to this “new-fangled idea” of chemical agriculture (Horn). The concept of trap-cropping was used over 200 years ago in Europe to control a forest insect pest, the spruce bark beetle (Hakkanen). The importance of sanitation and plant tolerance or resistance to pests was realized in the late 1800s in both France and California when grape plants from the eastern United States carrying a root pest, phylloxera, were introduced to those areas. Grape plants native to France had never been exposed to this introduced insect pest and had no natural resistance. Thirty years after introduction, 75 percent of the vines in France had been destroyed before they began replanting vineyards with phylloxera resistant American rootstock.

CURRENT STATUS

More recently, there appears to be a renewed interest in IPM largely due to public concerns regarding exposure to pesticides. History has shown that IPM almost invariably has economic advantages compared to traditional practices by reducing rates and frequency of pesticide applications. With the recent concerns regarding pesticide contamination of groundwater, IPM is often cited as an appropriate technology for pesticide source reduction. Because IPM programs are so specific to the site and the situation, whether it be in the urban, agricultural, or forestry environment, it is difficult to make generalizations about current status or levels of adoption. Even in agriculture, few reviews have been made of IPM implementation, but as early as 1964, researchers were concerned about the slow rate of adoption of integrated control. Some recognized that due to its complexity, many potential users would hesitate to adopt it. According to a 1984 nationwide evaluation of Extension IPM programs, there is extensive use of IPM by cotton growers in Texas and California and tobacco growers in North Carolina. (Zalom, et al.). These areas have a history of exposure to IPM through the CES pilot projects mentioned above. Where there has been significant research effort, implementation and use of IPM is more likely to have gained a foothold.

One of the objectives of this manual is to highlight examples and components of IPM which are currently being practiced in western Washington but are not always identified or recognized as IPM by the user or pest manager. Most of the local references will be in the IPM strategies section.

REASONS FOR IPM

The rationale for IPM development is discussed below under three main headings. These are: the disadvantages of sole reliance on pesticides, the loss of pesticide registrations (fewer chemicals in the arsenal), and our general increased knowledge of ecological principles.

DISADVANTAGES OF SOLE RELIANCE ON PESTICIDES

RESISTANCE

Most pests are capable of developing resistance to pesticides. Generally, the more frequently a population is exposed to a specific pesticide, the more likely it is to become resistant or to tolerate its effects. This is due to a genetic process allowing for survival which is called natural selection. In a pest population, there will often be some individuals which will be genetically resistant to the pesticide. Even when a high percentage of the population is killed, these few individuals may survive and reproduce passing their genes for resistance to the next generation. Eventually the pesticide can become ineffective against the pest. For this reason, many pesticides have a limited effective life. (Zalom, et al.).

Resistance of insects to insecticides has been documented as long ago as 1914 when San Jose scale showed resistance to lime sulfur. By 1946, resistance had been documented in

11 insect species including the codling moth and the peach twig borer, key orchard pests then and now. The rate of increase in documented cases of insect resistance has been significant since WWII corresponding with an increase in the number of new insecticides and the regularity of their use in pest control. Total resistant insect species was 224 in 1970, 364 in 1975, and 447 in 1984. In addition, the time in which resistance develops has decreased with each new class of insecticide. It took six and one-third years on average for resistance to DDT to surface, four years for organophosphates, two and one-half years for carbamates, and two years for pyrethroids. There are several mechanisms for developing resistance but examination of them is beyond the scope of this study. Suffice it to say that development of resistance complicates pest management programs. (Metcalf, 1989).

One of the best examples in agriculture is the Colorado potato beetle, an insect capable of severely defoliating potato plants. It developed resistance to DDT in New York in 1949, three years after initial exposure to this insecticide. It has developed resistance to every insecticide used since that time, and currently in the Northeastern U.S. they are running out of materials for this insect (Georghiou). There is a similar history of resistance development in various species of cockroaches, the key target of many urban Pest Control Operators (PCOs). One of the impacts of this insect developing resistance to lower toxicity insecticides such as malathion is their replacement in the home and work place with more acutely toxic materials such as chlorpyrifos.

As of 1986, resistance had been reported in 447 species of insects and mites, 100 species of plant pathogens, 48 species of weeds, five species of rodents, and two species of nematodes. (Zalom, et al.).

Potato growers in western Washington are aware of this phenomenon. In 1990, a strain of late-blight, a serious fungal disease of potatoes, was found to be resistant to the commonly used fungicide, Ridomil. Weed resistance to herbicides can also be a problem. Powell amaranth, a close relative of redroot pigweed, and widespread in western Washington, was shown to be resistant to atrazine in 1968 in Stanwood, Washington (Parker). Resistance to specific triazine herbicides (simazine and atrazine) was first observed in the early 1970s for common groundsel in a nursery. Resistance developed following repeated applications of the same herbicide twice a year over a ten year period (Ryan).

Resistance has economic impacts as it depletes the arsenal of effective pesticides. Newer products are generally more expensive as a result of increased registration costs to the manufacturer. It cost \$1.2 million to get a pesticide to the market in 1956 compared to over \$50 million today. Cross resistance occurs when a pest uses the same mechanism to resist more than one chemical, and multiple resistance refers to the accumulation of separate traits, each of which permits survival against a different chemical (Dover and Croft). The phenomenon of cross and multiple resistance has resulted in a decline in the marketable life of new pesticides and reduced the discovery and development of new materials over the past 30 years (Metcalf, 1989).

SECONDARY PEST OUTBREAKS

Secondary pest outbreaks can result when natural control agents are inadvertently disrupted by chemical applications which target the primary or key pest. Organisms which previously caused no significant damage are allowed to reach pest status once their natural control agents have been destroyed. It is widely believed that spider mites have emerged

as a serious agricultural and forestry pest since 1946 because their predators have been reduced by chemical sprays for primary pests. (Zalom, et al.). The European red mite in apples is a good example of secondary pest development through disruption of predators. Prior to the introduction of DDT and the organophosphates, the European red mite was not a pest on apples since it was held in check by predators. Once spraying started, predator populations declined, which released the red mite from biological control and allowed it to reach pest status. As a result, specific miticides had to be added to the spray program at substantial additional cost to growers (Horn).

A similar situation has been documented with the twospotted spider mite, a secondary pest of red raspberries in western Washington. This mite is often kept below a problem level by a complex of beneficial insects and mites. Field studies from 1987 through 1989 showed that mites reached a problem level in those fields that received more frequent insecticide applications (Shanks, et al.). This is particularly a problem in fields which have high populations of root weevils that require a pre-harvest application of a broad spectrum insecticide that is disruptive to natural enemies of the twospotted mite (MacConnell).

PEST RESURGENCE

Pest resurgence occurs when a pesticide kills a large percentage of the pest population as well as its natural enemies. The absence of natural enemies permits the rapid return and population explosion of the pest (van den Bosch and Messenger).

OTHER NON-TARGET EFFECTS

In spite of the infinite array of application technology, the amount of insecticide applied that actually reaches the target insect is very low, ranging from one percent to five percent in most cases. The rest goes somewhere else both within the immediate area treated and outside through drift. The application of broad spectrum insecticides may kill insect pests, but also impact other non-pest organisms in the ecosystem. Potential undesirable side effects include destruction of natural enemies which can cause secondary pest outbreaks and pest resurgence as mentioned above. (Horn).

Monetary losses due to pesticide impacts on honeybees are estimated to be between twenty and fifty million dollars per year in the United States (Zalom, et al.). Herbicides can cause direct damage to crops (phytotoxicity) usually due to drift from a nearby or even quite distant application. They can also have an indirect effect on beneficial insect populations by destroying plants which provide alternate food sources for those beneficial insects. Many classes of pesticides have detrimental effects on soil microbes which play an important role in decomposition of organic matter and mineral recycling.

The turf-grass ecosystem supports a diversity of organisms including pest, non-pest, and beneficial insects, nematodes, mites, earthworms, spiders, springtails and other invertebrates which form a complex community that interacts with grass, thatch, and soil contributing to the stability of the turfgrass habitat. A single application of a commonly used organophosphate insecticide can reduce the total population of insects, mites, and spiders by 60 percent, depressing predator populations for up to six weeks. There is evidence that thatch can build to become a problem in turf maintained with multiple applications of pesticides and fertilizers. This is partly due to disruption of the decomposition process resulting from soil pH changes and reduced populations of invertebrates associated with use of these materials. (Potter, et al.).

Many of the insecticides currently in use are quite toxic to mammals even in small amounts. Field applications of these insecticides can deliver a toxic dose to wildlife present at the time of application. Humans are not immune, but exposure can be minimized by wearing proper clothing during mixing and application as specified on the pesticide label. Field workers can also prevent unnecessary exposure by adhering to reentry intervals as specified on the pesticide label. Consumers are protected from unacceptable pesticide residue on food by pre-harvest intervals which refers to the number of days between harvest and application of a pesticide. (Zalom, et al.). Poorly understood at this time is the long term effect on humans of low level exposure to pesticides.

REDUCED EFFICACY

In addition to reduced efficacy through pest resistance, pesticides can also lose effectiveness through other means. Carbofuran (Furadan) has been used for several years as a soil applied insecticide to control root weevils, a serious pest of strawberries in western Washington. Recently, it has become less effective due to the ability of soil microbes to break it down rapidly before the weevils are controlled. The more it is used, the less effective it is in controlling this pest, because it's continued use selects for microbes which are able to break it down.

ENVIRONMENTAL CONTAMINATION

Rachel Carson's book, Silent Spring, told the story of the environmental problems associated primarily with DDT use. This pesticide belongs to a class called the chlorinated hydrocarbons which were widely used during the 1950s and 1960s in agriculture and public health pest control. Its advantage was low acute toxicity to humans allowing for its safe use in the short term. Its disadvantage was its persistence and accumulation in the earth's environment. It was banned in 1972 once it was discovered to cause thinning of egg shells in many wild bird populations. In this case, the non-target birds were the end target after the pesticide entered the food chain via water into streams. It was passed from microorganisms to invertebrates to fish building in concentration along the way and eventually impacting many bird species.

Although we have moved away from this class of pesticides to less persistent materials, environmental contamination is still a concern, as evidenced by recent findings of pesticide contaminated groundwater.

LOSS OF PESTICIDE REGISTRATIONS

THE PESTICIDE RE-REGISTRATION PROCESS

Twenty years ago the EPA was created and given the responsibility for pesticide regulation. Its mandate is to ensure that pesticide usage poses no unreasonable risk to human health or the earth's environment. EPA requires pesticide manufacturers (registrants) to provide large amounts of data which are used to show whether a pesticide has the potential to cause adverse effects in humans, fish, wildlife, and endangered species. Data on how a pesticide behaves in the environment (environmental fate) are also required so that threats to ground or surface water can be detected. Potential human risks that are assessed include acute reactions as well as long term risks such as cancer, birth defects, and reproductive system

disorders. Additional data is required if a food crop application is involved in order to set crop tolerance levels. It usually costs the manufacturer \$40-\$60 million and takes six to nine years to register a pesticide. Patents for protection are good for 17 years and usually issued soon after discovery at the beginning of the registration process. As of 1988, all pesticides registered prior to 1984 must be reregistered to meet current testing requirements. This can represent significant additional expense to manufacturers and threaten continued registration and use. This is a slow process and the backlog is so great that completion of the reregistration process is not anticipated until the late 1990s. Many registrations have already been dropped, and more are expected (Cast, 1990).

REAL AND PERCEIVED HEALTH RISKS

Pesticide manufacturers can and have discontinued production of materials based on either real or perceived risks to public health. In addition, public health concerns can pressure food processors to reject crops treated with certain pesticides, even though their use is legal and they continue to be available to the user. In Washington, public concern forced many apple processors to reject fruit that had been treated with Alar, in spite of the minimal scientific evidence supporting claims that this chemical posed a health threat. Although aldicarb (Temik) was still registered in Washington for potatoes through the 1989 season, many processors would not purchase potatoes from fields where this material was used. EPA temporarily banned its use on potatoes in the spring of 1990.

MINOR CROP RE-REGISTRATIONS

Pesticides in agriculture are registered on a crop-by-crop basis. It behooves the manufacturer to develop products for a large market in order to maximize sales and return on investment. Corn, wheat, turf, and soybeans represent large markets and therefore there is much incentive for manufacturers to develop products for these markets. There are additional costs associated with gaining registration on minor crops such as apples, hops, mint, ornamentals, and berry crops to mention a few of those common to the Pacific Northwest. Oftentimes, the projected sales do not justify the manufacturers expense of seeking registration for such crops resulting in a depletion of available products to these producers. The USDA IR-4 program has provided some assistance for growing of minor crops to return or gain pesticide registration.

STATE AND LOCAL RESTRICTIONS

Even though a pesticide may have federal EPA approval, state and local agencies may restrict or prohibit its use. Washington State Department of Agriculture (WSDA) is the state agency responsible for regulating pesticide use. Certain materials are restricted in their use due to their toxicity to humans and animals or for groundwater protection, and can only be applied by commercial producers, commercial applicators or governmental agencies, all specially trained in handling these products. Certain formulations, for example, highly volatile formulations of the phenoxy herbicides are prohibited statewide. Under local ordinance number 91-44 in Whatcom County, an integrated roadside vegetation management program minimizes reliance on pesticides and prohibits the use of herbicides by County government in certain areas.

INCREASED KNOWLEDGE OF ECOLOGICAL PRINCIPLES

Naturally occurring biological control was responsible for keeping many insects below pest status prior to 1945 when the “powerful, synthetic organic insecticides appeared” (van den Bosch and Messenger). Prior to 1945, a more integrated approach to pest control was practiced using chemicals, plant resistance and cultural practices which rarely upset natural control. The new insecticides made insect suppression so easy and effective that virtually every other method of control was dropped. According to van den Bosch and Messenger, the overall non-target side effects would not have been so dramatic if the development and use of organic synthetic insecticides had been a more orderly process. Growth in manufacturing and field use was very rapid due to enthusiasm of researchers and marketing capabilities of the agrichemical industry.

In spite of the previous successes with biological control through importation of natural enemies, the connection wasn’t made between this new pesticide technology and disruptive effects it might have on naturally occurring beneficial insects and mites. Problems with resistance, secondary pest outbreaks, pest resurgence and broader environmental problems associated with pesticide use discussed above surfaced fairly quickly. This ecological backlash was due to a major flaw in the modern insecticide, its broad spectrum toxicity. Our experience with pesticides confirms the complexity of interactions that occur within an ecosystem, even if it’s an artificial one such as a cornfield. A general principle of ecology is that the more diverse a community is in terms of number of interacting organisms, the more stable it is. Applications of broad spectrum pesticides reduce diversity dramatically and in the words of van den Bosch and Messenger: “a biotic vacuum is created in which violent reactions are almost inevitable”.

The trend today, particularly in IPM, is to select insecticides and other control tactics that are more target specific so that naturally occurring beneficials and other organisms are protected. The application of broad spectrum insecticides is generally not as acceptable today as it was twenty years ago. Fungicides and herbicides are still commonly selected based on broad spectrum characteristics that make them more desirable controlling a wider range of diseases or weeds.

PRINCIPLES OF IPM

WHAT IS A PEST?

Pests are species whose population densities are sufficiently high relative to the sensitivities of man to cause economic, aesthetic, social, or medical losses (Flanders). The term “pest” is subjective, a matter of opinion. What is considered a pest to one person may not be placed in the same category by another. Some homeowners will not tolerate a single dandelion in their lawn, investing significant amounts of time, energy, and materials in controlling them. The fellow down the street appreciates the additional color which they contribute. When it comes to carpenter ant or termite infestations that threaten the structures in which we live and work, we are usually in agreement regarding their pest status. The same is true

for pests that threaten human health whether in insect or rodent form. Pests come in all shapes and sizes and can inhabit many different environments. The principles of IPM are applicable for managing the diverse group of organisms that can become pests including certain; vertebrates (birds, deer, and rodents), arthropods (mites, insects, spiders), plant diseases (fungi, bacteria, viruses), plant parasitic nematodes, and weeds in many different environments or systems including agriculture, forestry, golf courses, public grounds, greenhouse and nursery, and numerous urban settings.

A COMPLEXITY OF FACTORS AFFECT A POTENTIAL PEST

Perhaps 40 percent of the most damaging agricultural pests in North America originated elsewhere. Examples of imported pests include gypsy moth, Japanese beetle, codling moth, European corn borer, imported cabbageworm, even the “American” cockroach. Introduced vertebrate pests include starlings, house or English sparrows, pigeons and the most serious rodent pests; the Norway rat, the roof rat, and the house mouse. (Horn; Marsh). Many of our most common and troublesome weeds were introduced from Europe during the colonization and early settlement of North America. Such weeds include field bindweed, Canada thistle, johnsongrass and St. Johnswort (Anderson). More recent introductions include Eurasian milfoil which can foul fresh water lakes and diffuse knapweed, a serious rangeland weed. These organisms have become pests partially because their populations increase in the absence of natural predators and parasites which they may have left behind in their homeland.

Humans are constantly altering their environment. In doing so we often unknowingly transform what was a balanced ecosystem into one that is out of balance, allowing certain species to die off or move out and others to proliferate in the absence of predators or in response to more favorable conditions, often building to unacceptable levels. Our alteration of habitat can also open the door allowing for immigration and establishment of organisms which previously could not compete. Likewise, if we understand the environmental, biological, and physical requirements and limitations of potential pests, we are in a better position to manage them. See [General IPM Strategies](#) section for specific examples.

PEST BIOLOGY AND LIFE CYCLE

In order to effectively manage a pest, one must have an understanding of its biology and seasonal development or life cycle. The first step is proper identification of the pest which seems so obvious but in practice is often overlooked. Once the pest has been identified, the next step is to investigate how it relates to its environment. What are its needs regarding food and habitat; how is its development affected by weather; what other natural factors such as disease or predators play a role in controlling the pest. In what form does it overwinter, which stage is the most damaging, which stage is the most easily controlled, which stage is the easiest to monitor, how long does it take to complete its life cycle? Some insects can complete a generation in a matter of hours and some take several years. Weeds are generally classified by the amount of time necessary to reach maturity; they are grouped as annuals, biennials, and perennials. In order to manage them effectively their seasonal development and methods of propagation and dissemination must be well understood.

Much of this information is available, particularly for major pests which have been studied for several years, but data gaps do exist. In order for monitoring to be useful, the methods must be based on a good knowledge of the pest's biology, behavior, and seasonal development.

KEY AND SECONDARY PESTS

IPM programs are constructed around the “Key” or most important pests which obviously vary with the situation. For example, the key pests that affect strawberry production in the Pacific Northwest are root weevils, strawberry aphid, twospotted spider mites, botrytis fruit rot, and red stele, a root rot disease. Monitoring in strawberries is tailored to these pests. In addition, secondary pests such as lygus bugs, cyclamen mites, and leafrollers to mention a few are occasional pests. Typically, key pests have the potential to cause the most damage and are frequently present from year to year.

REGULAR MONITORING

It is regular systematic monitoring in order to make decisions that separates IPM from traditional pest control programs that are more dependent on calendar or prophylactic insurance sprays. This includes monitoring of the pest and associated damage, natural control agents such as predatory mites or beneficial insects where appropriate, habitat or host plant, and environmental factors such as leaf wetness or heat accumulation, where appropriate.

It is important to have a basic understanding of the biology and behavior of the pest being monitored before devising a sampling procedure that is practical. Because it is not often possible to count every individual in a population, only a portion of the population is counted. In general, accuracy increases as sampling effort increases. Greater sampling accuracy is required of the research scientist than a pest manager and therefore sampling effort is usually greater and more time demanding in a research environment than in a practical field situation. In essence, the system that is employed must fit the level of accuracy that is required and be practical at the same time (Horn).

Some of the more common monitoring techniques are described below.

MONITORING TECHNIQUES

There are many different techniques for sampling insects. Direct counting from plant foliage is one of the most common techniques in agriculture. This can be done in the field usually with the aid of a hand lens, or leaves can be collected and brushed with a mite brushing machine to extract all stages of small insect and mite pests and beneficials. Mite brushing may be used in instances where greater accuracy is desired. Threshold levels are often based on the number of pests per leaf. Insects can also be monitored by dislodging them from plant foliage by shaking vigorously and capturing them below on a cloth sheet or tray of a standard size such as a pear psylla beating tray. Sweepnets are also used to dislodge and collect insects from foliage. Both pests and beneficials are recorded on a per sweep basis. Regular weekly sweepcounts can show population trends and aid in decision making.

The Berlese funnel has gained wide acceptance for extracting insects from soil, roots, litter, or vegetation. A sample taken from the field is placed onto a screen atop the funnel and an overhead source of heat (usually a 60 watt bulb) placed above the sample drives the insects from the material down into the funnel where they are collected in a jar for counting. The population can then be expressed relative to area sampled. This method has been used for several years for extracting asparagus aphids from fern and mint root borer larvae from mint rhizomes in the Yakima Valley.

Actual insect damage, for example defoliation estimates or fruit entries, monitored regularly can help relate population estimates to damage ratings. Presence of frass (fecal matter) or exuviae (shed skins) are indicators of insect activity, which in some cases like powderpost beetles is very important.

There are many types of insect traps, but the most commonly used in pest management are pheromone traps and attractant sticky traps. They have wide use in agriculture, forestry and urban settings. The aquatic larval stage of mosquitoes is monitored by taking a standard size dip sample from breeding pools and counting the number of larvae.

Due to the scale of forestry, aerial reconnaissance and photography is commonly used to identify insect pests and determine area of infestation. Sampling from the ground as well as observations from helicopters is often necessary to confirm pest identification.

Rodents are monitored by trapping, feeding activity, electronic counting, visual observations and tracking. For example, standard size patches are placed in areas of suspected rodent activity. Tracks from the rodents are left on these patches and can be counted on a routine basis to evaluate control efforts and assist in decision making. Feeding activity is also used to evaluate food consumed from non-toxic bait packages. Indexing the results of both of these methods at various stations is a good decision-making tool. Log books to record pest sightings, activity, and observations are used by PCOs and their clients (food processors, apartments, hospitals) as a more subjective monitoring system. (Story).

Plant parasitic nematodes are sampled by field collection of roots or soil, usually comparing good to poor areas within a field or different cropping histories in the case of pre-plant sampling. Extraction and identification of nematodes is performed by a specialist. Root disease organisms, if suspected to be a problem can also be evaluated usually at a laboratory.

Certain plant diseases such as powdery mildew are easily monitored and identified in the field. Environmental monitoring can be very important in disease management because treatments may be necessary prior to onset of infection. Parameters such as soil and air temperature, soil moisture, relative humidity, and leaf wetness can be continuously monitored with a weather station placed in a field. Mathematical models can be developed through research by measuring these weather parameters and correlating them to disease development. These models can then be used to make more accurate fungicide applications based on environmental conditions, rather than applying them on a calendar basis. (Vargas, et al.). Disease predictors such as this are available for managing late blight in potatoes and apple scab, both important diseases in the Pacific Northwest. These stations record on-site temperature data, which can also be used to improve spray timing for insect pests such as codling moth and leafhoppers in orchards. Disease predictors are also available for managing anthracnose and pythium, both serious diseases affecting golfcourse turf (Vargas, et al.).

Weeds in turf can be monitored by using a transect in several representative areas. The simplest is to lay a line on the ground, walk it and record the number and species of weeds every three feet or so in a standard area. This can be converted into percentage weed cover. Regular sampling and comparison from year to year will help evaluation of the weed control program.

MONITORING PROGRAM

Once suitable techniques are identified for a given system, they are then integrated into a practical regular monitoring program that will be the basis for decision making. The program will reflect the biology and seasonality of the pest or complex of pests. Some pests are continuously monitored throughout the season and others are evaluated perhaps only once or twice a year. Intensity of monitoring is driven primarily by required accuracy in order to make a sound decision and economic considerations.

DECISION MAKING

ECONOMIC CONSIDERATIONS

Once established in a favorable environment, any population increases in density to an upper limit which it does not exceed due to predation, competition or other environmental factors. This is called the carrying capacity (Horn). In 1959, V. M. Stern and colleagues developed the concept and terms economic injury level (EIL) and economic threshold (ET) for insect pest management (Pedigo). The EIL is an arbitrary density lower than the carrying capacity. It is the population density that produces incremental damage equal to the cost of preventing the damage. The goal in pest management is to maintain the population below the EIL. The ET is the density at which control actions are necessary, also referred to as the action threshold. (Zalom, et al.; Horn). These concepts emerged as an encouragement for more rational use of insecticides due to environmental problems associated with insecticide use mentioned earlier (Pedigo).

EILs are not constant; they vary with management costs, market conditions, agronomic practices, geographic location, and crop susceptibility to injury. Consumer preferences are also factors in the determination of the EIL. The concept of EIL was derived for agricultural systems and specifically for managing insect pests. (Zalom, et al.; Pedigo; Horn).

The difficulties encountered in determining EILs are further compounded for pest complexes in which more than one pest species is simultaneously active, which is usually the case. EILs do not consider the effects of social costs of pest management decisions such as acute and chronic poisoning, costs of legal regulations, or pest resistance. The practical determination of EILs is difficult. It is a major challenge to differentiate among the effects of weather, pathogens, nutrition and so on when attempting to estimate losses to insects or weeds alone. Also, year to year variability may result in increased pest damage in certain years despite identical pest densities.

The economic threshold is the most commonly used term in applied pest management and is generally synonymous with the term “action threshold”. ET levels are determined for several insect, mite, and nematode pests of western Washington crops, including twospotted

mites on strawberries and raspberries (WSU EB1491), flea beetles on potatoes, and corn earworm on corn grown for processing. Based on corn planting date, pheromone trap catch, and other factors, a computer program called “CEWSIM” developed specifically for western Washington calculates potential earworm damage and economic benefits of insecticide application. (PNW Insect Control Handbook). Thresholds based on sweep net sampling are also developed for managing aphids and pea weevils which are pests of peas in the Pacific Northwest (Robinson). Unfortunately, ETs are not established for most pests because of the cost of research needed in order to determine them accurately.

The diverse nature of forest ecosystems plus their multiple uses makes decision making difficult for the pest manager. For example, there is no single ET for managing European gypsy moth. A homeowner adjacent to or within a commercial forest has a much lower tolerance for and understanding of this pest and its impact than the commercial forester. Where the forest manager will tolerate significant defoliation without treating, the homeowner is likely to treat for aesthetic purposes much sooner. Insect outbreaks are a natural occurrence in forest ecosystems and can be tolerated more so than if the same trees were in an urban environment. Homeowner and small woodlot owner tolerance for this pest has been increased in some areas as a result of educational programs. This has resulted in much more rational management (Boerner).

There is significant variability among farmers and consumers regarding the amount of visual damage they will tolerate. The challenge for the IPM consultant is to provide his or her client with professional advice but due to the subjective nature of our perception regarding what constitutes a pest, the advisor must also be sensitive to the farmer’s or client’s threshold level. Implementation of threshold levels is not an absolute science.

AESTHETIC CONSIDERATIONS

The economic concepts of ET and EIL are not always appropriate. In many urban situations, subjective, aesthetic tolerance levels guide decision making. For example, due to nuisance and health threats, there is virtually a zero tolerance for cockroaches in restaurants or rats in most situations. Similarly, there is no acceptable level for serious structural pests and therefore detection alone can warrant control efforts.

Even though the leaf notching on rhododendrons caused by adult root weevils has little if any effect on the health of the plant unless severe, a nursery manager may have difficulty selling plants with light notching to a potential buyer who has a very low threshold for insects or their damage. The same goes for the American consumer’s demand for insect-free and blemish-free fruits and vegetables. Considerable (and some would suggest misguided) control effort is directed against insects and plant pathogens to keep them at artificially low levels in order to satisfy consumers (Horn).

SOCIAL CONSIDERATIONS

Pests of medical importance affect humans by causing discomfort and/or disease. For example, some mosquito species are potential vectors of encephalitis and malaria in the Northwest, and all can cause discomfort due to their bite. Understandably, we have a low tolerance for public health pests like mosquitoes. Mosquito abatement programs are designed to reduce the numbers of mosquitoes to an acceptable level. Decision making is usually based on monitoring of both adult and larval stages and the decision to treat, or threshold, varies with the species and the situation.

LEGAL CONSIDERATIONS

Pesticide use is regulated on the federal level by the EPA under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Pesticides are registered by the EPA for use on specific crops or in specific situations as directed on the container label. Washington State is empowered through many pieces of legislation administered by WSDA to place further restrictions on pesticide use within the state. These laws address handling and storage, posting requirements, applicator and consultant licensing, pesticide record keeping, general use, and disposal. For example, some pesticides are restricted for the protection of groundwater or due to their toxicity to people or animals to distribution and application only by those properly licensed with WSDA. They are not available to the general public. Restrictions may be statewide or regional. See WSDA, Pesticide Management Division [Pesticide Laws and Rules](#) for more information regarding regulation of pesticides in Washington.

EXPERIENCE

Although the principles of IPM are universal in a geographic sense, pest dynamics are very site specific and decisions are often made based on the experience of pest managers and their clients who are both familiar with local conditions. A historical perspective is very important in evaluating action thresholds as well as potential disruptive effects of pesticide applications.

EXPERT SYSTEMS

This is a term which describes the computerized extension of the IPM consultant and the research scientist and is designed as a decision making tool. Potato growers in British Columbia are benefitting from a program that is currently built around disease forecasting to manage late blight. The program is managed by Agriculture Canada personnel and a private IPM consultant. Weather stations throughout the potato growing areas of the lower mainland of B.C. measure and record data which is entered into a computer program. These data and field specific data (field location, scout observations, and variety) are used to predict development of the disease and to generate recommendations for fungicide timing and selection. Field specific pesticide use is also entered into the system. This network provides a link between growers, consultants and researchers and allows for regular monitoring and upgrading of the system. The intention is to expand this program as a tool to also guide insect and weed management. (Vernon).

EVALUATION AND SELECTION OF CONTROL STRATEGIES

Inherent in IPM is that different strategies and tactics that are likely to be appropriate for the particular situation be considered. Within this thought process, consideration is given to economic practicality, effectiveness, liability to applicator, public perception, non-target impacts, and broader environmental impacts of various strategies such as impact on water quality.

For example, rearing and introduction of exotic insects to control weeds may be appropriate in large scale highway or rangeland systems but for many reasons is not realistic for controlling the same weeds in other environments. Exclusion is a suitable strategy for

managing certain pests such as fencing to protect an orchard from deer, or window screening for mosquitoes, but hardly an option in most large scale farming for insect pest management. However, floating row covers are being used in some commercial crops in western Washington to exclude specific insects (covered in greater detail in section on Species Selection).

Non-target and environmental impacts are of primary concern particularly when evaluating different pesticides, since a major focus of IPM is to minimize disruption of the environment. Where possible, the material with the lowest acute toxicity and greatest selectivity for the pest should be chosen. In addition, consideration should be given to pesticide properties and methods and rates of application in order to prevent pesticide contamination of groundwater.

Naturally, the next step in the process is to select the control strategy or strategies most suitable for the specific pest situation. It may be determined that no action is necessary at a particular time and additional monitoring is needed in order to make a decision. Some strategies such as habitat modification and various cultural practices may be ongoing preventative methods as part of a larger program to suppress pests below treatment level. Once direct control is deemed necessary based on monitoring results and accepted threshold levels, the most appropriate tactic or tactics are selected and implemented.

POST-TREATMENT FOLLOW UP

Monitoring continues in order to determine the effectiveness of the treatment and possible non-target effects. It is important to allow adequate time after treatment before evaluating control. For example, certain miticides are very fast acting and control can be measured within three to five days. Other materials may take a week or two before there effects can be accurately evaluated. Post treatment monitoring may indicate: the need for a second follow-up application, inadequate control due to several possible factors, or effective control with minimal immediate non-target effects. Recordkeeping is the final step in the process and the basis for future pest management decisions.

U.S.D.A. Forest Service and IPM

The use of IPM is Forest Service policy and this is particularly evident in their approach to vegetation management. As part of the NEPA (National Environmental Policy Act) process, the Forest Service has developed a five step analysis and deci-

sion-making process very similar to the IPM principles discussed above for managing unwanted vegetation. These steps are: site analysis, selection of strategy, project design, action, and monitoring. (Smith, G.).

GENERAL IPM STRATEGIES

The following section outlines the general *strategies* for managing pests and the more specific *tactics* within those strategies. Specific examples from western Washington will be used as illustrations where appropriate. Examples will be used from other geographic areas as well. These will be drawn from several different systems including agriculture, forestry, greenhouse and nursery, roadside and utility rights of way, ornamental and turf, and various urban settings including structural and medical pests. The purpose is to illustrate components of IPM that are being practiced in these various settings and to encourage further consideration and use of ecologically sound tactics for pest management.

PREVENTION

The old adage, “An ounce of prevention is worth a pound of cure” rings true as the first line of defense in IPM. In order to prevent an organism from reaching pest status, we must have an understanding of those conditions that favor and limit its development. There are a myriad of preventative tactics. Although “prevention” is presented here as one of seven general strategies, it could be considered a larger heading under which each of the other strategies can be a subset.

QUARANTINE

In the U.S., certification of plants and quarantine of plant pests are under the authority of the USDA-APHIS-PPQ. Establishments of quarantines are sometimes termed legislative control, giving this government agency the authority to manage threatening pests, be they insect, nematode, disease or plant. USDA-APHIS personnel examine incoming goods at ports of entry into the U.S. to prevent introduction of potential pests. (Horn). In addition to preventing importation of exotic pests, quarantines can be placed on regions to prevent spread of pests from those areas to uninfested nearby or distant areas. State departments of agriculture often work in conjunction with USDA to impose quarantines.

WSDA issued a quarantine in western Washington in 1983 to control the spread of the apple maggot, a serious pest of apples, following an outbreak of this pest in the southwestern part of the state. This quarantine restricted the transfer of homegrown apples in western Washington through or out of the region. It was implemented to prevent introduction of the pest to apple producing areas in eastern Washington which continue to be free of this insect. In order to comply with California State Dept. of Agriculture permits, WSDA has overseen a detection trapping program in counties throughout the state where apples are grown commercially. Whatcom, Skagit, Snohomish, and San Juan counties are considered maggot-free and therefore the quarantine was lifted in those counties as of February, 1991. One of the main incentives for excluding this pest from commercial orchards is that additional sprays would most likely be necessary if it was established. Not only would this result in a greater outlay of effort and money; it may disrupt existing natural control of secondary pests such as mites. (Klaus).

SANITATION

From a pest management standpoint, sanitation is a reflection of the food, water, and harborage in an environment. Modifying these components can affect pest population density and is a very important prevention strategy in many urban settings. The best examples of this are high populations of cockroaches, rats and mice associated with poor sanitation. A well implemented sanitation program for rat control in Baltimore in 1953 resulted in a sustained population decrease over time, while baiting alone resulted in only a short term population reduction (Marsh and Bertholf). Improper handling of garbage, animal feces and infrequently turned compost piles provide breeding site for many filth flies. Sanitation alone will not always cause a reduction in pest density but can often enhance other strategies such as chemical control, as has been shown with cockroaches. Insecticides are often more effective when used in a clean environment. The principles of sanitation apply to the most common urban pests: rodents, birds, bats, cockroaches, filth flies, mosquitoes, termites, powderpost beetles and stored product pests. Public education is critical to implementation of this strategy. Agencies involved include public health and regulatory officials, state extension personnel, and pest control operators (PCOs).

A cooperative sustained effort is often necessary in many urban situations in order to impact pest populations. This can be costly over the short term and unfortunately is often perceived by the public as more complicated than chemical control.

Sanitation is very important in managing many serious plant diseases which can survive on plant debris and be a source of infection to current or subsequent plantings. Late blight is a serious disease affecting both market and seed potatoes in western Washington. This fungus can survive on piles of culled potatoes and on volunteer plants (plants that emerge from tubers left in the field from a previous season). Elimination of cull piles and removal of volunteer plants will help reduce the source of inoculum for new infection. (PNW Plant Disease Control Handbook; Flint). The same principle applies for managing several cane diseases affecting raspberries. Infected grass clippings are an important source of inoculum for leaf spot and brown patch and should be collected and removed where these diseases are prevalent in turf. Sterilization of greenhouse soil mixes is an important sanitary step in eliminating soilborne diseases and minimizing subsequent plant infection.

Removal and destruction of plant debris that harbors or encourages development of insect populations can reduce rates of reproduction and survival. In forestry, salvage logging and prompt slash burning of infested timber are recommended practices in managing bark beetles. These tactics can help prevent further spread of these insects to nearby healthy stands. It is important as part of an integrated approach. Pruning and destruction of insect infested twigs and branches have been used as management tactics for European pine shoot moth. Removal of spillage and regular maintenance cleaning of grain elevators reduces infestations of stored grain pests (Pedigo).

PEST-FREE PLANTING STOCK

The WSDA Plant Services Division oversees certification programs on nursery plants grown for agricultural and ornamental use. These programs are the buyer's insurance that he is receiving material that has met tolerances for certain important pests. For example, strawberry growers can purchase stock certified to have minimal levels of black root, red stele, verticillium, dagger and root knot nematodes, and several virus diseases. In instances

where growers compromise by not using certified plant material, usually due to initial expense compared to alternatives, chronic disease and nematode problems that are difficult or impossible to control can reduce yields and stand longevity and result in expensive applications of pesticides that are an economic and environmental burden.

Seed potato growers in western Washington supply stock for commercial production in eastern Washington and other areas. These growers must follow certain production rules and meet WSDA standards in order to market certified tubers. Certification is based on field history, field observations during the growing season, winter testing for viruses, and post harvest examination of tubers. There is a zero tolerance for some pests and others may be tolerated at very low levels. Tolerances are set for certain fungal, bacterial and virus diseases, one insect (tuber moth), plant parasitic nematodes, and variety mixture.

SITE SELECTION AND PREPARATION

This is a critical consideration when growing perennial crops such as strawberries or raspberries to prevent damage from plant parasitic nematodes and soilborne disease organisms. Nematodes can be monitored prior to planting as has been mentioned above. Sampling intensity is very important in order to make reasonably accurate decisions based on laboratory results. Infested fields can be treated prior to planting or avoided entirely if that is an option. A review of cropping history is important in evaluating the potential threat from diseases such as phytophthora and verticillium. The verticillium which damages strawberries can persist in the soil for several years even in the absence of susceptible host plants. In the case of the root disease, phytophthora, soils which drain poorly should generally be avoided for planting to susceptible crops.

Placement and alignment of a right of way can impact subsequent vegetation management. It is important to minimize disruption of natural vegetation, conform to contour and drainage patterns, and avoid areas of difficult vegetation management when planning a right of way. (Swan, et al.).

Many lawns get a poor start, particularly in new home construction, where soil is often quite compacted by months of heavy machinery travel. Pre-plant preparation is often less than adequate; topsoil may have been removed prior to construction, and grass seed is thrown in quickly as an afterthought to help the property sell. (Olkowski, et al.). Poor conditions at time of establishment create stresses that reduce a lawn's tolerance to most pest problems, particularly weeds.

EXCLUSION

This is one of the most commonly used and long term tactics for vertebrate pest management. Examples are screening between rafters, a common practice in building design to exclude birds from nesting within homes, fencing to protect resources from deer or predators, tree guards to protect tree trunks from being girdled by rabbits, and netting most commonly used to exclude birds from berries and even statues and buildings (Marsh). Netting is commonly used to protect blueberries grown in western Washington from birds. Excluding rodents from buildings can be accomplished, but understanding their capabilities is critical to success. For example, rats are great climbers and they can gain entrance through holes as small as 1/2" square. They can also gnaw through several materials including lead, aluminum, wood, rubber, vinyl and concrete blocks. In spite of this, heavy

mesh hardware cloth, metal flashing and generally good construction are effective mechanical barriers (Ramsay and Thomasson, 1991).

Window and door screening is a very effective way to exclude insect pests such as mosquitoes, wasps, and flies from several indoor environments and is such standard practice that we hardly think of it in the context of pest management. Plumbing and electrical ducts are used as runways by cockroaches. Sealing these ducts between structures can impede movement and disrupt aggregation which favors their rate of development and reproduction. (Schal and Hamilton).

Floating row covers to protect cole crops from root maggots has been experimented with on a commercial scale in the Skagit Valley. This tactic has been very successful for excluding the crop from this insect, but it impedes and complicates some cultural practices such as weed control. For this reason and the high cost, it has been most appropriate in small non-commercial plantings. (Havens).

Agriculture Canada researchers in British Columbia are currently experimenting with barrier fencing using nylon screening to exclude several species of root maggots from vegetable crops. The three to four foot tall fence is designed with an overhang away from the area to be protected. Adult flies migrating towards a field are stopped by the barrier and eventually trapped in the overhang where they die. This tactic exploits the natural behavior of this insect. Fencing has excluded up to 80 percent of the migrating adults and provided effective control. Efficiency of control is expected to increase with field size. This tactic is being evaluated as an alternative method which may eventually replace prophylactic granular soil applied insecticides, which pose a particular threat to groundwater. (Vernon).

SPECIES SELECTION

Often times there is no viable option regarding site selection. In these situations, selecting plant species that are suitable to a particular site is an important strategy to prevent pest problems in forestry, turf and ornamental plantings and particularly on rights of way along roads and under utility power lines.

With turf, a grass or mix of grass seed should be selected that suits the soil and climate of the site. A mix of species is often favorable to increase the stand's tolerance to insects, disease, and variable environmental conditions typically experienced throughout a year. IPM programs developed for low maintenance lawns for the National Park Service and municipal parks throughout the U.S. rely on a mix of grasses and clover. One of the clearest benefits of this mix versus single species Kentucky bluegrass is reduced weed problems. (Olkowski, et al.).

In situations such as power lines and along roadways where vegetation can be tolerated, the goal is to foster a mix of species that are competitive with undesirable plants, blend in with the surrounding landscape, and is cost efficient to maintain. This requires an understanding of the interrelationships between climate, soil, plants and animals in a variety of settings. (Swan, et al.)

Whatcom County Dept. of Public Works received the 1991 national award for excellence in county agency vegetation management from the National Roadside Vegetation

Management Association. The department has the responsibility of managing vegetation along county roadways including adjacent drainage ditches and their banks. This includes low growing plants as well as trees and shrubs. Undesirable vegetation can obstruct visibility and threaten public safety, impact power lines and interrupt service, and impede drainage efficiency. The department has switched from a traditional herbicide intensive program to a more integrated approach which is commonly called “Integrated Vegetation Management”.

One of the important changes in the past several years is the management of vegetation in roadside drainage ditches. The policy had been broad spectrum chemical control to eliminate all vegetation in ditches which was designed to enhance water movement/drainage within the ditch. This practice was effective in controlling vegetation, but caused problems with erosion of the ditches and the need to reshape them by excavation more frequently. The current strategy is to encourage desirable vegetation in the ditches by species selection and regular mowing. This allows for adequate water flow but minimizes erosion. Another major benefit of grass lined ditches is their ability to filter potential contaminants. Herbicides are no longer used in ditches in Whatcom County. They are in the process of purchasing a hydro-seeder which will allow them to efficiently seed these areas with desirable grass species that are very competitive and tolerant of wet and dry environmental conditions. Low growing wildflower plantings are being evaluated as desirable mixes in certain situations. (Scrimsher).

Our increased understanding of plant succession has allowed power line rights of way managers to consider selective removal of young trees as a tactic to allow a dense shrub community to dominate. This lower growing shrub vegetation is preferable compared to tall trees which can impact power lines. Once established at the right density, shrubs can out-compete tree seedling establishment through competition for space, light, water, and nutrients. This minimizes the reliance on herbicides for controlling undesirable vegetation. Some shrubs are also allelopathic; that is exudates from their roots suppress growth of other plants. Shrub vegetation particularly along the edges of a forest is favorable for deer and birds due to nutritional value as well as providing protection. (Daar, 1990).

CULTURAL PRACTICES

Cultural control in agriculture and horticulture refers to the adjustment of procedures so as to reduce pest abundance or minimize or prevent pest damage. The environment is altered in such a way that it becomes less favorable for the pest. Strategies include sanitation, crop rotation, trap cropping, mixed cropping, and timing of planting or harvest (van den Bosch and Messenger). The same basic strategy of environmental manipulation is appropriate in many urban settings. Cultural tactics can be preventative as well as curative.

CROP ROTATION

Crop rotation is practical mainly with field crops to suppress soilborne pests of limited mobility and host range such as certain soilborne diseases and nematodes. It is often necessary to rotate to a non-host crop for several years in order to suppress certain diseases in particular. Due to the recent limited availability of soil applied pesticides, this tactic which was commonly practiced in the pre-pesticide era is coming into wider use now.

Rotating to non-host crops for control of insects is usually done over a shorter time frame.

Long term crop rotation is a key in managing the fungus disease, club root, a serious pest of crucifers (plants in the mustard family including cabbage, cauliflower, and broccoli) in western Washington. Fields which have a history of disease should be rotated out of susceptible crops for a minimum of five years. Rotation combined with application of lime to make the soil more alkaline can help reduce disease severity. (Davidson and Byther). Although long term rotation to non-hosts is often advised for suppression of other soilborne diseases such as verticillium in strawberries, our knowledge is incomplete regarding the precise amount of time between susceptible crops necessary to realize adequate control.

Rotation from corn to soybeans or other non-hosts is a classic example of this strategy to suppress populations of the corn rootworm, a serious pest of corn in the Midwest. In western Washington, crop rotation in potatoes is encouraged to avoid the build-up of tuber flea beetles. Seed potato fields in Whatcom county are usually rotated to wheat and peas prior to replanting. Rotation to wheat allows for herbicidal control of volunteer potatoes.

Experiments in South Dakota have shown that rotating to sorghum for one year compared to corn or soybeans can significantly reduce weed populations the following season. This is due to a phenomenon called allelopathy; exudates from the sorghum roots can restrict weed growth. This tactic is in the experimental stage. At this time, control is not as certain as with herbicides and not as aesthetically appealing to farmers who desire 100 percent weed control (Kozlov).

One of the major limitations of crop rotation in many situations is that it may not be economically feasible or attractive for the farmer (Horn).

TRAP CROPPING

Trap crops are plant stands that are grown to attract insects or other organisms to protect target crops from pest attack. This tactic is based on the fact that all pests have a distinct preference for certain plant species, cultivar or crop stage. A major benefit is that the main crop may not require treatment with a pesticide and thus natural control of pests occurs in most of a field. In addition, pesticide use is lower than in conventional farming. Trap cropping is also used to attract natural enemies of pest insects to enhance naturally occurring biocontrol. Practical applications of trap cropping in modern agriculture have been very few. Only 11 pest species have been successfully controlled in four crop ecosystems using this tactic. The widest use is in cotton and soybeans. In forestry, this technique combined with pheromones is now used for managing bark beetles. Trap trees were used over 200 years ago in Europe to control the spruce bark beetle. Although trap cropping is not widely used now, at least 35-40 important agricultural pest species are likely candidates for this technique. (Hakkanen).

The cotton boll weevil is claimed to be the most costly insect in the history of American agriculture and it is estimated that it is the target for one third of all agricultural insecticides applied. Trap cropping is now an integral part of boll weevil management in the southeastern U.S. An early fruiting trap crop of cotton treated with an attractant pheromone concentrates migrating weevils in the trap crop area where they are sprayed with an insecticide and controlled. Lack of knowledge of the ecology and behavior of many

target pests is often a limiting factor for this strategy. Managing the trap crop can present practical problems to the farmer that outweigh perceived or actual benefits derived. Trap crops have no advantage if pests are scarce and therefore pest predictability is a key factor (Hakkanen).

MIXED PLANTING

Mixed planting increases plant diversity and can aid in keeping pest populations at low to moderate levels (van den Bosch and Messenger; Horn). Unfortunately, this tactic is not well suited to mechanized agriculture and there are few examples of its commercial use. A reduction of pest problems on urban shade trees is enhanced by planting a variety of species. The rapid spread of Dutch Elm disease was due largely to monocultures of these trees (Horn).

TIMING OF PLANTING OR HARVEST

In situations where there is some flexibility regarding timing of either planting or harvest, adjustments can greatly reduce damage from insects, disease or nematodes. Losses from bark beetles (*Ips* species) in pine are minimized if logging operations are completed during the fall or winter months when beetle activity is usually low (Pedigo).

Damage from the fungus *Rhizoctonia* on potatoes can be reduced if planting is delayed until soil temperatures reach 45 degrees (Flint). In practice, this can present logistical problems to the grower who has a limited amount of time in which to plant a crop and a short growing season. If the crop isn't planted by a certain date, it may not reach full maturity. For this reason, growers will often start planting as soon as physically possible with little regard for disease implications. This strategy may be very workable in some cases and impractical in others, but regardless, it behooves the manager to consider this option. For example, *Fusarium* basal rot of flower bulbs is reduced by harvesting in spring before soil temperature reaches 55 degrees Fahrenheit (Byther).

MAINTAIN A HEALTHY HOST

Plants that are under stress are generally more susceptible to pest damage. There are several examples of this in lawn and turf management. Mowing height and frequency, fertilization amount and timing, irrigation scheduling, and thatch management can all impact turf pest problems.

Mowing height should be tailored to grass species mix, climatic conditions, and the purpose for the lawn. Mowing too closely and too often is an invitation to weed invasion and disease. In general, lawns should be mowed so that no more than one third of the surface area is removed with one cutting (Clark).

Maintaining balanced fertility is important for good growth of turf grasses. Nitrogen requirements vary with location, and applications should be based on occasional soil testing results and visual observation of lawn condition. Clover included in the lawn mix can contribute as much as 30 percent of the yearly nitrogen requirement of a lawn (Olkowski, et al.). Insufficient nitrogen can favor weed encroachment and encourage certain diseases and excessive fertilization may enhance some weed species and favor certain diseases (Potter).

Irrigation scheduling is an important component of lawn and turf disease management. In general, excessive and frequent irrigation should be avoided. Infrequent watering to wet the entire root zone is recommended for control of general fungus diseases in western Washington. (PNW Disease Control Handbook)

Thatch buildup creates a favorable environment for fungal pathogens as well as insect pests. Thatch buildup in turf within four to five years can result from pesticide and fertilizer use which directly or indirectly reduce populations of microorganisms or earthworms (Potter). Rather than removing grass clippings, retaining them will add several pounds of nutrients to a lawn in a season. They also add organic matter to the soil (Clark).

HABITAT MANIPULATION

Like all living organisms, pests have certain habitat requirements that must be met in order for them to thrive. By altering habitat, we can create conditions that are less favorable for the pest. This can be an effective method to prevent, suppress, and/or control pest populations.

Wood infesting Anobiid beetles (powderpost beetles) can cause extensive damage to wooden buildings in coastal areas of western Washington. Damage can be overlooked since beetles live in portions of the structure where people seldom see them such as crawl spaces. Infestations build to damaging levels over several years. They are most common in older homes with crawl spaces or damp basements. In Washington, these beetles attack hardwoods, softwoods, and plywood, causing an estimated seven to ten million dollars in damage per year in wood replacement and chemical treatment costs. Favorable conditions for development are high moisture, no ventilation and poor drainage. The beetles thrive when wood moisture content is between 14 and 20 percent. Steps to reduce wood moisture include improved ventilation under the structure, use of vapor barriers in crawl spaces to contain soil moisture, and repair of gutters. Removal of wood scraps left on the ground during construction is also important because they may host beetle larvae which could subsequently infest the structure (Suomi).

The technique of maintaining a vegetation-free strip in orchard tree rows has proven to be very effective for managing voles, which are dependent on vegetation for cover and protection. This cultural practice has largely replaced organochlorine pesticides formerly used for this purpose. This practice requires either the use of residual herbicides or mechanical tillage to control vegetation within the tree row.

Plant diseases can be reduced by manipulating the micro environment within the plant canopy. Botrytis fruit rot of wine grapes is favored by a heavy canopy that reduces air movement and contributes to a moist environment. Timely removal of leaves and laterals adjacent to fruit clusters at late bloom reduces disease incidence and frequency of fungicide applications. This tactic has been widely adopted by vineyard managers and is practiced by some growers in the Yakima Valley. The same principle of canopy management applies to managing this disease in raspberries in some situations in western Washington, where extremely vigorous canopies favor infection of fruiting laterals and subsequent fruit infection. Canopy density can be controlled by maintaining proper fertilization and cane density.

In the management of mosquitoes, the first step is identification of the species in a

geographic management area, and locating and mapping larval breeding sites. The larval stage of this insect is aquatic; this stage must be completed in order for it to develop to the adult pest form. Sites which support larvae are either removed or modified thus creating an inhospitable environment (Sinsko).

RESISTANT HOSTS

The use of resistant plants or cultivars (varieties) is common for managing many of the more important plant diseases. For example, The PNW Plant Disease Handbook lists approximately forty agricultural, nursery and ornamental plants that are resistant to verticillium wilt and about the same number that are susceptible. This information is valuable when considering selection of ornamental plantings for specific sites. The same basic information is available for phytophthora, another serious disease with a wide host range in this area. Use of resistant plants can be very important with these diseases because they are often difficult to control by other means.

The Hood cultivar in strawberries is more susceptible to aphid transmitted viruses than either Totem or Sumas varieties. Where this variety is used, aphid treatments will more likely be necessary to protect the field from virus infection. When choosing varieties, the farmer must weigh several factors including marketability, growth characteristics, cold hardiness, and resistance to pests. In ornamental settings, Rhododendron materials can be selected based on their resistance to feeding by adult root weevils. Refer to WSU Extension Bulletin 0970 for a list of species and Hybrid Rhododendrons which are highly to moderately resistant to this pest.

Fusarium wilt of peas became a serious problem in western Washington in the late 1960s. This soilborne fungus can survive in the soil in the absence of a host for ten years or more, making crop rotation impractical. WSU research personnel oversaw a plant breeding program to develop fusarium resistant varieties. Currently this disease is managed primarily by soil sampling to determine the specific race of the fungus present in a specific field, and selection of a variety which is resistant to that race. (Haglund).

Where available, there are several advantages of the use of resistant hosts in pest management. Plant resistance is usually limited to a key pest species and like other narrow spectrum methods, there is minimal environmental disruption. It usually offers longer term control than many methods, and finally, it is compatible with normal production practices (Horn). This method can be impractical in those situations where disadvantages in marketing or production or other factors outweigh the pest resistance benefits. For example, although apple scab resistant varieties are available to apple growers in western Washington, due to storage problems and consumer acceptance problems associated with them, they are not widely planted.

BIOLOGICAL CONTROL

Biological control is that method of pest control that relies on natural enemies-parasites, predators, and pathogens to reduce pest populations or damage to tolerable levels. It is further defined as a natural phenomenon, that component in the control of numbers of any organism, pest or otherwise, which is produced by its natural enemies. When successful, biological control can provide a relatively permanent, harmonious, and economical

solution (van den Bosch and Messenger). In the context of pest management, biological control comprises three areas of activity; importation of exotic natural enemies into a target area (classical biocontrol), increasing the number of natural enemies present in a target area (augmentation), and prevention of any reduction in numbers of natural enemies within the target area (conservation) (Mills).

CLASSICAL

Many of our most serious pests have been introduced into this country in the absence of their natural enemies. Without natural controls, they are able to reach pest status. This is the logic behind classical biological control. Virtually all successful classical biocontrol programs to date have resulted from the reassociation of invading pests of foreign origin with their adapted natural enemies (van den Bosch and Messenger). Importation of natural enemies is handled by state and federal agencies, primarily USDA, in the United States. Natural control agents are collected from the homelands of exotic, introduced pests. This collection can be difficult to achieve for many reasons, among them political. Many of our crop pests originated in Eastern Block and Mideast countries where exploration by foreigners is not usually encouraged. Potential agents are held in quarantine and studied extensively before being released.

The first successful example of the use of classical biological control was in the control of the cottony cushion scale in California in the late 1800s. This pest, native to Australia became a widespread pest of citrus in California by 1880, 12 years after it was first observed in the state. In 1888, a USDA entomologist travelled to Australia to collect two of the scale's natural enemies which were subsequently reared and released on citrus in California. Within months, both agents were successfully established and had reduced scale infestations to harmless levels. The key introduced enemy was a coccinellid "lady beetle" called the Vedalia and the other was a parasitic fly which has received much less notoriety. Biological control efforts were increased following this major success, peaking in the decade 1930-1940. There were 32 successes during that ten year period. Biocontrol efforts dropped dramatically during WWII and the development of synthetic organic insecticides after the war slowed efforts in biological control.

At the same time, there was a reduction in the USDA biological control program because there was a feeling that the returns from the program did not justify the effort (van den Bosch and Messenger). A recent success was the use of a parasitic wasp to control the alfalfa blotch leaf miner, a pest of alfalfa in the northeastern U.S. The USDA figures that the public recoups the entire annual biocontrol budget of six million dollars every year from the savings on the alfalfa crop alone (Budianski). Increasing cost of insecticides, resistance problems, and real and perceived threats of pesticides to the environment are all factors which must be considered when evaluating returns from biological control today.

In addition to controlling insect pests, biological control has been very successful for controlling certain weeds. One of the best examples of this was the control of Klamath weed which is also known as St. Johnswort. This is a perennial plant native to Europe and Asia which was introduced to North America in northern California near the Klamath River in the early 1900s. It spread from this original infestation to cover more than two million acres by the mid 1940s, infesting and downgrading valuable rangeland. Based on successes with controlling this weed in Australia, three species of beetles were collected from Australia and released in California in 1945 and '46. Within three years, two of the beetles were

flourishing and providing good weed control. By 1950, the entire infested area in California was colonized and the weed stands were well under control by 1956, ten years after introduction of the beetles. Attempts were made with the same insects to control Klamath weed in British Columbia in 1951 and '52 with disappointing results. This tactic has still not been successful for Klamath weed control in British Columbia, for whatever reason. One of the fears raised by some agricultural scientists and public authorities of introducing plant feeding insects for weed control, is that the insect may shift its attention to other desirable plants. This did not occur in the Klamath weed control program and is the reason that any introduced plant feeding insect must pass stringent feeding tests to determine host range prior to release (van den Bosch and Messenger).

Biological control of St. Johnswort in Washington state began in 1948 with the introduction of two European beetles which both became established and in some locations reduced weed populations by 99 percent. Tansy Ragwort is a noxious weed of poor quality pastureland and disturbed soils in western Washington. Biological control of this weed was initiated in Washington in 1960 with the introduction of the cinnabar moth. The caterpillar stage of this insect can severely defoliate ragwort plants, but the plant is often capable of surviving and producing seed. For this reason, two additional biocontrol agents were added to the arsenal (Piper). A combination of the cinnabar moth and the ragwort flea beetle may take four to five years to control this weed. For this reason, the use of biological control is most appropriate in lower value settings such as along stream courses, fencerows, and ditchbanks, rather than in high value pasture where rapid control is necessary (PNW 210). Release and establishment of these two agents have significantly reduced tansy ragwort populations in many areas of western Washington. Since the St. Johnswort program was initiated in Washington in 1948, 38 different natural enemies have been used to suppress 18 exotic weed species. Of these, 71 percent have become established and contributed to suppression of weeds in noncropland settings. In addition to being long term, safe, and ecologically desirable, biological weed control can return 30 dollars for every dollar invested in research, development, and application (Piper).

More than one thousand natural enemies have been imported and established against a range of 300 insect pests around the world. Of these, about 40 percent have provided significant success. There have been successes with this tactic for controlling both exotic and indigenous pests. The biggest challenge is deciding which natural enemies to release against a target pest. In practice, the number of natural enemies released to control a pest have ranged from one to 53 agents. The most successful programs have targeted exotic pests that have not been of pest status in their native land. There are general criteria now that can be used to select most suitable natural enemies. Unfortunately, many of the programs implemented have not been adequately evaluated and therefore there is no firm basis from which to improve biological control successes in the future (Mills).

Limitations to widespread use of this strategy are numerous. It is generally not suitable in pesticide intensive systems because the introduced biological agent itself may be threatened. The organizational and up-front economic requirements are high. Classical biological control requires very specialized knowledge and skills. There has recently been relatively little funding available for researchers to explore this strategy. It can often take several years to achieve control. In some situations, such as rangeland or roadside weed control, this time lag is acceptable. In regular crop production systems, control must be achieved quickly in order to prevent economic loss. Finally, this method is highly selective usually for a single pest species, whether insect or weed, etc., which can limit its practicality.

AUGMENTATION

Augmentation refers to increasing the number of natural enemies at critical times, usually through mass release. This method is used in localized areas such as a single field or greenhouse rather than large geographical areas typical in classical programs. Releases often have to be repeated, rather than providing sustained control as with successful classical biocontrol. This tactic is used to provide a rapid increase in the natural enemy population to control a target pest. One of the biggest questions is the effectiveness of mass-reared laboratory agents when released into the field, and the difficulties in evaluating the role of the released natural enemy population versus the naturally occurring beneficial population (Mills).

Although there are some successful augmentation programs ongoing in agriculture in other areas of the country (Horn), this strategy has not received much attention in agriculture in the Pacific Northwest. Due largely to scale in agriculture and the costs to rear beneficials, mass release is not practical from an economic standpoint. Release of mites, lady beetles, and parasitoids is common in greenhouses in Europe (Horn) and an augmentation program has been ongoing in vegetable producing greenhouses in the Fraser Valley of British Columbia since 1979.

Biological Control of Whitefly and Twospotted Spider Mites

In the 1970s, two greenhouse pests, whitefly and twospotted spider mites became resistant to pesticides and caused serious losses to greenhouse tomatoes and cucumbers grown in the Fraser Valley. In addition there were phytotoxicity induced yield reductions, increasing costs, and legislative restrictions associated with insecticides (Costello). Agriculture Canada research indicated there was great promise in using natural biological control agents to control these pests as part of an integrated control program. B.C. Ministry of Agriculture was interested and set up a demonstration biological control program in 1979 for commercial greenhouse growers. In this program, a spider

mite predator and a whitefly parasite were reared in the laboratory and released in greenhouses at no charge to the growers. In the first year of the program, growers got excellent control, often for the entire growing season. Based on this success, the program was available on a commercial basis in 1980. Over seventy percent of the cucumber and tomato greenhouses now use biological control. Many growers have greatly reduced or eliminated the use of pesticides. The laboratory now ships throughout North America and Europe. Research is underway for regular commercial application of biological controls for orchard and field crops. (Elliott).

The winter moth is a pest that has recently been introduced to western Washington and Oregon with few natural enemies. The populations are especially high in Whatcom county and in 1990 caused damage to commercial blueberries and filberts and to deciduous landscape trees. Caterpillars have been collected to determine presence of a tachinid parasite (fly family) which kills the cocoon stage of the winter moth. WSU and WSDA personnel are overseeing a local predator enhancement program which has worked elsewhere including Vancouver Island, British Columbia where the infestation may have begun. If successful, this locally supported biocontrol program could bypass costly federal control programs and eliminate a need for chemical pesticides.

CONSERVATION

Conservation of natural enemies is a key objective of applied IPM and is often realized when calendar-based prophylactic pesticide applications are replaced by threshold-based applications. Other pesticide management tactics which can be used to conserve natural enemies are improved timing of application, reduced rates, and selection of more narrow spectrum pesticides (Mills). Regular monitoring of both the pest and beneficial populations is critical in determining ratios of predator to prey or in some cases simple trends in populations over time. Naturally occurring biological control can be very subtle, often escaping even the keenest observer. For instance in raspberries in Whatcom county, twospotted spider mites are often suppressed by a small beneficial “Coccinellid” beetle commonly called the mite destroyer. Even when this predator is suppressing a mite population, it can be difficult to detect with regular field monitoring, particularly when mite populations themselves are quite low (Congdon). Conservation of natural enemies is a very important focus of traditional IPM programs in mint, alfalfa seed, and tree fruits in eastern Washington.

The narrow spectrum microbial insecticide, *Bacillus thuringiensis* (Bt.), is now commonly used to control leafrollers in raspberries in western Washington. This material is very selective and is not disruptive to natural enemies that can suppress twospotted spider mites.

BIOLOGICAL CONTROL SUMMARY

Biological control is most appropriate when the target pest has a high economic or aesthetic injury level and in single pest situations. It is not appropriate in those case where there is a zero or near zero tolerance for the pest, because a moderate pest population is necessary in order for the natural enemy population to grow and become effective.

For this reason, its use in many urban situations will be limited (Schal and Hamilton). The potential for use of natural enemies to control urban pests is better targeting plant pests compared to sanitary pests, exterior pests compared to interior pests, and exterior plant pests in parks and road sides compared to residential gardens. Successful importation and establishment of natural enemies requires intense effort and coordination. Such efforts in urban situations have been minimal. This is probably due to lack of funding for research, the fact that this method is usually not commercially exploitable, and the types of groups that normally develop such programs are difficult to find and organize for urban situations (Flanders). Improving cultural practices to minimize plant stress and modifying insecticide usage in urban as in agricultural settings may be a very effective way to enhance and conserve natural enemies (Flanders).

At this point in time, the most widespread form of biological control is conservation of existing natural enemies resulting from IPM programs which minimize the use and frequency of disruptive pesticide applications.

PHYSICAL

Physical methods have been used for centuries to control pests. Various methods for exclusion have already been mentioned, particularly in reference to urban pests. In addition, physical tactics can be used for direct control as well as removal of pests.

Mechanical methods for controlling weeds include such practices as hand pulling, hoeing, mowing, flooding, smothering with non-living material, burning and machine tillage (Anderson). The most commonly used methods are hoeing, mowing, and machine tillage. As mentioned earlier, mowing has replaced herbicide use for managing vegetation in roadside ditches as part of Whatcom County's integrated vegetation management program (Scrimsher). Hand hoeing, though labor intensive is still a regular practice in high value crops such as strawberries for removal of weeds that escape control by herbicides.

Tillage in the fall is a common practice for controlling European corn borer in the Midwest. This tactic alone provides up to ninety percent control of this insect. Tillage with specialized equipment combined with a soil insecticide for control of mint root borer in the Yakima Valley enhances control of this insect and is now standard practice. In western Washington, tillage is advised as a method to control root weevils in older, heavily infested strawberry fields adjacent to younger fields. Immediately following harvest, the field scheduled for removal is disc'd in order to control weevils and minimize spread to neighboring healthy fields (Shanks, 1983). Machine tillage or cultivation continues to be one of the principal methods of weed control in western Washington.

Burning has been practiced for several years for general weed control in non-cropped areas such as railroad rights of way and irrigation canals. Selective flaming has been used to control weeds in cotton once the crop reaches a certain stage. Flames are directed at the base of the cotton plant to control small weeds and selectivity is achieved by adjusting intensity and direction of the flame and speed of travel (Anderson). This technique is being used in strawberry fields in the Skagit Valley as a post-harvest, late season tactic for suppression of weeds and insects, particularly aphids which are capable of vectoring virus. Additional benefits may be adult weevil control and reduction of twospotted mites. (Allen).

Use of mulch or black plastic to exclude light is a very effective means of controlling weeds in smaller scale situations and in some cases in commercial agriculture (Anderson).

Trapping can be an effective way to remove or directly control insect, bird, and vertebrate pests. In agricultural areas such the Skagit Valley, local populations of starlings have been managed by trapping with the modified Australian Crow Trap usually baited with a food source such as cull apples. Trapping rodents may be effective for managing small populations but requires more skill and labor than most other methods. It is appropriate in home situations and others where poisons are not as advisable. Bait traps are quite common and enough traps should be used to make the campaign short and decisive (Ramsay and Thomasson, 1991).

A very interesting physical barrier tactic to protect structures from subterranean termites is being studied now in California under a grant provided by the University of California Davis IPM program. Research conducted in the late 1950s showed that western subterranean termites could not penetrate sand barriers with particles in a specific size range (Su, et al.). Current studies are evaluating the use of sand barriers inside foundations to prevent termites from gaining access to structural wood. Termites usually gain access to wood that is not contacting the ground by constructing tunnels from the soil surface over the foundation itself or over cement post supports. Surrounding post supports and the inside of foundation walls with a 2" deep and 20" wide sand barrier if effective, may replace insecticide treatments in these areas. Since August of 1989, a commercial PCO in that area has completed twenty sand barrier treatments with only three partial failures. One was due

to poor installation and in the other cases, termites bypassed the barriers by travelling along cracks in the foundation. (Carver). This technique is twenty five percent more expensive than the standard use of soil applied insecticides, but offers longer protection than the one year guarantee that accompanies chemical treatment. Sand barriers are not practical on the outside of foundations because of possible disruption from gardening activities, erosion, and animals (Daar, 1990).

Two materials, silica aerogel and diatomaceous earth, are dessicants. They can kill insects by absorbing the waxy coating on the insect's cuticle which causes the insect to dehydrate and die. Uses are primarily around the home for household and stored grain pests as well as in the yard (Olkowski, et al.).

NARROW SPECTRUM BIORATIONAL

Narrow spectrum insecticides are those that are generally non-toxic to vertebrates and nontarget insects. Included in this category are the microbial insecticides (bacteria, fungi, and viruses), insect growth regulators, semiochemicals (pheromones), entomopathogenic nematodes and avermectins. Most can be applied using the same equipment as used for applying broad spectrum pesticides. They have been developed for only a limited range of pests and are generally more expensive than broad spectrum pesticides. These methods generally apply to insect pest management.

MICROBIALS

Microbials are very target specific compared to most conventional pesticides. This characteristic is advantageous in IPM. Greatest successes to date have been with bacteria and viruses for insect control. Fungi and protozoa also cause disease in insects and there have been successes with these as well.

BACTERIA

Two spore forming bacteria have gained widespread use. These can be stored long term with the bacteria in a latent form. *Bacillus popilliae* was the first microbial registered in the U.S. and is used for larvae of Japanese beetle, a pest of turf. Following ingestion, spores germinate and destroy the internal organs of the larva which become milky and hence the name "milky disease". Upon destruction of the insect, the spores are released into the soil and can survive for several years (Horn). Manufacturing costs are expensive relative to chemical insecticides such as diazinon which is commonly used for this pest. It is one of several recommended treatments for controlling white grubs in lawn and turf in Washington (PNW Insect Control Handbook).

Bacillus thuringiensis (Bt.) spores are activated in the insect's midgut, then enter the hemocoel (blood) where they replicate and release crystalline proteins which are lethal. Bt. production costs are less than *B. popilliae* but still more expensive than conventional insecticides. There are several strains, each affecting different insects. Some strains are very effective for control of aquatic stages of mosquitoes, which have developed resistance to conventional pesticides, and black flies, where it is widely used in the northeast U.S. and Canada. Some strains are also effective for foliar feeding lepidopteran pests. It is very important to match the specific strain with the pest. As mentioned earlier, Bt. is commonly used for leafroller control in raspberries in Washington and Oregon. Due to its specificity

for this pest, its use does not disrupt natural biological control of mites. It is particularly appropriate in situations where some foliar feeding damage can be tolerated and rapid control is not necessary such as in raspberries. Bt. has become the material of choice for managing most defoliating insects in commercial forestry due to its selectivity and minimal impact on the environment. Washington, under the guidance of WSDA, was the first state to make an aerial application of Bt. for controlling gypsy moth. This program started in 1983 was very successful and has been a model for similar programs in other states (LaGasa). Pest identification is critical when using Bt. It is only effective when the proper strain is matched with the pest.

VIRUSES

Viruses that are important in management of insects fall into two classes: nuclear polyhedrosis virus (NPV) and granulosis viruses (GV). NPVs affect primarily Lepidoptera and GVs affect only Lepidoptera. They have been responsible for natural control of outbreaks of forest insects and they have potential in forest pest management to help prevent outbreaks (Horn). The study of viruses as potential control agents for forest pests began with the gypsy moth in the 1960s. This original work started by researchers at the Forest Service's lab in Connecticut eventually resulted in registration of Gypchek, a virus for controlling gypsy moth. The Forest Service also began work on viruses for controlling the tussock moth, a pest of douglas fir trees at about the same time in Corvallis, Oregon. This agency now maintains a production facility for the virus with enough material to treat 400,000 acres (Torgersen; Olieu). The viruses can remain infective for up to five years in soil. They have great potential for controlling *Heliothis* spp. in cotton, a pest that has shown resistance to conventional pesticides for years. Manufacturing insect viruses is expensive since they can only reproduce in living systems. This represents a major limitation to large scale use at this time (Horn). Although virus application is rare in agriculture, looper (*Geometridae*) populations often succumb to naturally present levels which can cause populations of this pest to crash rapidly and chemical treatments can be avoided.

FUNGI AND PROTOZOA

Of the various naturally occurring fungi that infect insects, *Beauveria bassiana* shows the most promise for commercialization. Attempts to produce industrial quantities have been underway in Poland since 1986 but production there has been limited to small amounts for experimental use. The Colorado potato beetle, which has widespread resistance to most insecticides, has been the main target pest for this organism. Results for controlling this insect have been variable when the fungus is used alone (Lipa). A major deterrent to widespread use is the production of an effective material of a constant and accurately determinable effectiveness relative to insecticides (Samsinakova, et al.).

Wheat bran treated with the protozoa, *Nosema locustae*, is registered as a bait for the control of rangeland grasshoppers. This tactic normally takes two to three weeks before significant mortality occurs. It is a suitable tactic for control of grasshoppers in rangeland situations where the goal is population reduction to minimize destruction of range plants which are a source of food for livestock. In these situations, 40 to 50% reduction in population may be adequate. In most other settings, this level of control is not acceptable. (Lockwood et al.; Horn)

MICROBIAL SUMMARY

With the exception of fungi, microbials are stomach poisons which take some time for control. This is in contrast to most quick acting insecticides. Timing of application is critical as most larger/older larvae require a higher dosage. Due to inactivation by exposure to ultraviolet light, they have short residual activity on agricultural crops. Microbials are exempt from EPA tolerance levels and therefore can be applied until and including the day of harvest. Due to their specificity, they can fit into pest management programs where a broad spectrum chemical might upset preexisting biocontrol of another pest. The most appropriate use may be in soil ecosystems where microbials are protected from dessication and ultraviolet effects (Horn).

INSECT GROWTH REGULATORS

Insect growth regulators (IGR) are chemicals that alter normal growth and development of insects. They are suitable for IPM because they are selective for insects and generally harmless to vertebrates, mollusks and plants. They may not result in death of insects but suppress populations through reducing reproduction. There are two main types of IGRs.

Chitin synthesis inhibitors interfere with the normal production of insect cuticle and the insect fails to moult properly. One product of this type (diflubenzuron) is registered in the U.S. and is used primarily for controlling gypsy moth and boll weevil. Because it is broad spectrum against insects, care must be taken with its use to avoid disruption of natural enemies.

Juvenile hormone analogs (JHA) interfere with normal metamorphosis and perpetuate the immature stages of insects, not allowing them to reach adult stage. These are only appropriate in situations where the adult stage is a pest problem and the immature stages can be tolerated. JHAs have been very useful in managing mosquitoes and fleas but they may not be appropriate in situations where biological agents are relied upon for pest suppression. Methoprene is very effective for controlling aquatic stages of mosquitoes. Due to its virtual non-toxicity to birds, fish, and mammals it is very appropriate in aquatic settings. JHAs have also been effective for controlling German cockroaches. Research conducted by the Agricultural Research Service (ARS) has shown that hydroprene can provide 95 percent control within about seven months of treatment (Ralof). Materials like this may be most useful when initial treatments are combined with insecticides. The insecticides control the adult stage and the JHA causes the immatures stages to become sterile adults. JHA use is sensible as a component of an integrated approach including insecticides, boric acid, sanitation and physical exclusion tactics (Olkowski, et al.; Koehler and Patterson). Other types of IGRs are under study.

SEMIOCHEMICALS

Semiochemicals are organic molecules produced by animals or plants which illicit behavioral responses in the receiver whether it be of the same species or a different one. The most common semiochemicals used in pest management are the sex pheromones. In nature they are chemicals released by the female to attract her mate. They are a complex of compounds which are either extracted from living insects or synthesized for commercial use. Over three hundred pheromones have been isolated and synthesized to date. Their uses in pest management include population monitoring to aid in decision making, trapping out for direct control, and confusion or mating disruption to suppress populations.

MONITORING

Pheromones are used primarily for monitoring insect populations to aid in decision-making in pest management. Pheromone traps are effective tools in codling moth management when used at the proper density enabling the manager to determine whether the population is large enough to justify treatment. When trap catch is combined with weather data (degree days) insecticide applications can be timed very accurately providing optimum control and reductions in use of up to 50 percent (Kirsch). WSU researchers have developed a model based on trap catch and heat accumulation which is the basis for this program in the large commercial growing areas of central and eastern Washington. (Brunner, et al.)

In the case of the gypsy moth, traps are used primarily in detection programs to determine spread of this insect and to define boundaries of localized infestations. WSDA Plant Services Division places several thousand traps throughout western Washington every year to monitor the distribution of this pest (LaGasa). Leafrollers, the key defoliating pests of raspberries in western Washington, are also monitored using pheromone traps. Guidelines for decision making are based on research conducted in Oregon (Knight, et al.).

TRAPPING OUT

Pheromone traps laced with insecticide have had some success but this strategy is not cost effective on a large scale. This technique called “removal trapping” has been effective for controlling low density gypsy moth populations on the periphery of the insect’s range (Horn).

There has been significant effort to manage bark beetles in commercial forestry by mass trapping. This tactic is appropriate only when combined with sanitation measures in selected areas within a forest that are sensitive to infestations (Vite and Baader). Mountain pine beetle is a serious pest of commercial pine grown in the Pacific Northwest and British Columbia. There is no pesticide program for controlling this insect. It is usually managed by silvicultural practices that reduce its impact such as timely harvest and proper stand density so that tree stress is minimized. Attractant pheromones placed on infested trees within stands that are scheduled for harvest is used in British Columbia to concentrate beetle populations and help reduce spread to nearby stands. Population reduction is achieved by removal of infested trees after harvest. This sanitation aspect is critical and if not carried out, undermines the effectiveness of this tactic (Lindgren).

MATING DISRUPTION

There is quite a bit of interest in the confusion or mating disruption technique. Larger than natural amounts of synthetic pheromones are released into the environment to disrupt the orientation of male insects to their mates. If successful, there is a reduction in the number of matings and the population is lowered. In the past several years, commercially acceptable levels of control have been achieved with this technique on several pests in the United States and elsewhere. In spite of this, commercial expansion has been limited due to many factors including new concept, limited market due to species specificity, high technical service requirements, and regulatory requirements that have delayed field experimentation efforts (Booth; Howell, et al.). Technical challenges include determining the most suitable method of dispensing the pheromone, chemical formulation of the pheromone itself to maximize attraction, and improved understanding of pest behavior, as well as pheromone behavior in different crop environments.

This tactic has been very successful in many agricultural crops over the past few years and is being commercialized at an impressive rate. Cherry tomato plots in the San Joaquin Valley of CA treated with a pheromone to disrupt mating of the tomato pinworm moth experienced three percent infestation versus 33 percent infestation in plots sprayed with insecticides (Booth). In work at Cornell's Geneva research station pheromone mating disruption has been very successful in controlling the grape berry moth, a serious pest in New York vineyards. In research trials, damage has been kept below one percent with mating disruption alone compared to two and one-half percent to 18 percent damage with insecticides. Even in fields with tremendous infestations, the pheromone works as well as four applications of insecticides (Booth, 1988).

Oriental Fruit Moth

Mating disruption has recently been very successful in managing the oriental fruit moth (OFM), a widespread pest of peaches. This pest has been controlled for years with conventional insecticides that created problems with the secondary pests; twospotted spider mite and green peach aphid due to elimination of their natural predators. In 1975, experimental results showed control with mating disruption was comparable to that achieved by conventional insecticides. Initially, the cost of the pheromone was too high for this strategy to be economically competitive but with improved pheromone delivery, technology costs have been reduced. By 1985, twenty five percent of the peach production in Australia was relying on this technique.

Work in California starting in 1985 has shown similar success. Registration was granted in 1986 and by its second year of use in 1988, 3500

acres were treated commercially, twice the acreage treated two years before. In most cases, no insecticides are necessary combined with pheromones. However, in some situations, one application is necessary to control mated females migrating into the orchard or secondary lepidopteran pests normally controlled by broad spectrum insecticides.

Benefits include low toxicity, ease of application, no re-entry or pre-harvest restrictions, compatibility with cultural practices, compatibility with natural control agents, resistance is unlikely, and long term population reduction has been observed in areas treated for more than three years. Limitations include lack of effect on immigrating mated females, and secondary pests may reach damaging levels due to reduced insecticide treatments which previously may have kept them below threshold (Horn).

Codling Moth

In 1991, mating disruption was used commercially for the first time in the apple growing areas of eastern Washington to control codling moth (CM). Two thousand acres were treated and very few growers applied the conventional cover sprays that would have normally been used. There were some late season applications of insecticides to reduce fruit damage from CM. There was no observable difference in the spray programs for other pests such as leafminers and aphids. Sprays to control these insects are typically supplementary to the conventional CM spray program. There was more of a problem in some cases with leafrollers, a secondary pest which is usually controlled by CM sprays. In some orchards, fruit damage from this secondary pest was significant. Use of Bt., if timed properly may be

an effective strategy to manage these secondary pests in the future. Expectations are that mating disruption will be used on four to five thousand acres during the 1992 season. Improvements are needed in the technology for dispensing the pheromone to provide season-long release. The economics of this tactic compared to the conventional cover spray program has not been studied in detail to date (Knight). Results from recent USDA field research in the Yakima Valley indicate that this tactic has much potential for codling moth control, but caution that unacceptable levels of CM fruit injury (greater than one percent) may result when population densities of moths are high and mating disruption is used alone (Howell, et al.).

ENTOMOPATHOGENIC NEMATODES

These organisms show great potential for controlling a broad spectrum of soil insect pests. These nematodes and their associated bacteria are exempt from EPA registration and regulation requirements. The infective juvenile stage of these nematodes applied to the soil surface under proper environmental conditions can move through soil via water films to locate and enter a host (pest). Once inside the pest insect's body, they liberate a bacteria which kills the insect within 24-48 hours. They feed on the bacteria and dead insect tissue, and after passing through several stages emerge from the cadaver in search of another host. It normally takes from ten to twenty days for the nematode to complete its life cycle. Their effectiveness can be limited by lack of soil moisture, extreme temperatures, soil texture, and natural enemies. These limitations are significant to impeding their commercialization in many agricultural crops.

For example, experimental trials in strawberry fields in western Washington have not been very promising. The reasons for this aren't well understood but it is most likely that cool soil temperature and/or inadequate soil moisture have limited nematode survival and mobility.

There are several different species and it is important to match the species with the pest and the pest's environment. Various species of this nematode are commercially available for controlling soil inhabiting insect pests in lawn and garden, turf, citrus, artichokes, cranberries, and ornamental nursery and greenhouse markets. (Georgis and Poinar). Field research is underway in the Pacific Northwest for root weevil control in strawberries, control of mint root borer in mint, and European crane fly control in turf (Smith, K.). This biological control agent is a possible alternative to chemical insecticides for the control of a wide host range of soil-inhabiting insect pests. In addition, insecticides applied to the soil and incorporated with irrigation or natural rainfall are of particular concern as a potential threat to groundwater. An example, although not widespread by any means, is the detection of carbofuran (Furadan) in well water in western Washington (Cogger and MacConnell).

Cranberries

Entomopathogenic nematodes have been used commercially in cranberries for black vine weevil control in southwestern Washington since 1989. Although carbofuran is still registered for this use, it has been largely replaced by this product. Carbofuran is not as effective now as it had been for weevil control and due to its high mammalian toxicity, applicator safety is a concern for many growers. Nematodes are usually applied in both the fall and spring in infested fields. An IPM program administered by Ocean Spray is available to cranberry growers. This program was the result of a Washington State University research/extension IPM project designed, implemented, and administered by Shanks and Antonelli for two years, before being taken over by Ocean Spray. This program keys on black vine weevil management and thresholds have been developed based primarily on results of evening sweep counts to monitor adults. In infested fields, the soil

inhabiting and damaging larval stage is monitored in the late summer to optimize timing of treatments. Soil temperature and stage of larval development must be within a certain range in order for the nematodes to provide control. When conditions are suitable, the nematodes are applied through the overhead irrigation system. The nematodes can provide up to ninety five percent control of the larval stage of this insect which is adequate to suppress them below the economic injury level in most cases. Control can be much less effective if timed poorly or environmental conditions do not favor the nematode. Insecticides which target the adult stage are also used during the summer for weevil management in cranberries (Broadus). The effectiveness of this tactic in cranberries is largely due to the ongoing professional support provided by Ocean Spray pest management specialists.

THE AVERMECTINS

Avermectins are a group of compounds that are secreted by *Streptomyces avermitilis*, a bacteria originally isolated from a Japanese soil sample. They are generally broad in spectrum with activity against insects, mites and nematodes. One of the avermectins with the common name “abamectin” is being developed for the control of household and agricultural insect and mite pests. Abamectin is environmentally acceptable because it is used at low rates, is rapidly lost from the environment, binds strongly to soil, and does not bioaccumulate (Lasota and Dybas).

Abamectin is more effective than conventional insecticides when used in baits for controlling German cockroaches (Schal and Hamilton). Its most widespread use is as an acaricide to control mites in ornamentals, food crops and cotton. It is effective at much lower rates than conventional miticides. It penetrates the leaf surface and penetrability varies with the plant depending on leaf cuticle properties. Its major benefit is its long residual activity within the plant. On strawberry, two applications timed seven days apart has given up to seventy nine percent control for 35 days after application. It is appropriate for control of leafminers, an aesthetic pest on many ornamentals including chrysanthemums, due to its penetrability within the leaf where larvae feed as well as minimal impact on leafminer parasitoids. This makes it suitable for chrysanthemum IPM programs. Its suitability in other IPM systems will vary depending on its impact on beneficials specific to those systems. Based on research so far, there appears to be low potential for mites to

develop resistance to abamectin. In addition, mites that are currently resistant to some of the commonly used miticides are not resistant to abamectin. A new derivative of abamectin, EMA, shows great promise for controlling a wide range of important lepidopteran pests even when used at low rates (Lasota and Dybas).

GENETIC

The most widespread genetic method is traditional breeding of plants for resistance to insect, disease, and nematodes. As has been mentioned under the prevention section, many commercially available varieties or cultivars of plants have been selected based on their pest tolerance. More recently, genetic engineering, the insertion of genetic material into plant tissue to resist pests, is being researched. There are no commercial products from this technology available for use (Zalom, et al.). The most successful techniques to date have been use of insecticide resistant biocontrol agents and the release of sterile males to reduce the fecundity (reproductive potential) of insect pest populations (Horn).

STERILE MALE RELEASE

Males are bred and sterilized with radiation prior to being released. Females which mate with these sterile males produce sterile eggs. The classical and most widespread success with the sterile male technique was for controlling the screwworm, a pest of range cattle in the southwestern United States. This program initiated in 1962 eliminated the screwworm in the U.S. by 1983 and until the present. It was estimated that \$140 million was saved for the first \$10 million spent. This technique was also used in 1982 for controlling the Mediterranean fruit fly in California, but its effectiveness was difficult to evaluate because insecticides were used as well (Horn). Sterility programs require very specialized knowledge and in most cases are implemented over a large area. This method is not technology which is readily available. It is similar to classical biological control in terms of the expertise required, the scale of effort, and the organizational challenges. Its advantage is that if successful, long term control can be achieved with minimal if any environmental impact.

Sterile Male Release for Control of Codling Moth

In the mid 1970s, a three year large scale trial was run in the Similkameen Valley of British Columbia. Sterile males were released throughout this 1700 acre valley to control codling moth in apple and pear orchards. All of the growers in the area agreed to forego their regular chemical spray program during this period. It was very successful and reduced fruit damage to an acceptable level. This program was originally subsidized by Agriculture Canada with the intention that growers would eventually assume the costs.

The growers chose not to support the program, partly because they already had investment in application equipment and were spraying for other pests. A full economic analysis including all environmental effects was never completed, but might have been very instructive. (Hall, 1981). Agriculture Canada is presently considering an even larger sterile male release program for controlling codling moth throughout the entire fruit growing region of south central British Columbia (Lindgren).

F1 Sterility Program for Gypsy Moth

WSDA in cooperation with USDA implemented a two year sterility program to eradicate a localized gypsy moth infestation in Bellingham, Wa. In 1986 and 1987, sterilized gypsy moth egg masses were released throughout the infested area. Larva emerging from these eggs develop normally with the exception that as adults, they

are sterile. Sterile males breed with female moths, but no offspring is produced. This project was the first of its kind in the world and was very successful. Pheromone trapping results upon completion of the project confirmed that the population had been eradicated. (LaGasa).

INSECTICIDE RESISTANT BIOCONTROL AGENTS

Insecticide use can release secondary pests such as plant feeding mites from naturally occurring biological control. This happens when the insecticide kills mite predators allowing the mites to cause economic damage. One logical approach to this problem is to select mite predators which are resistant to commonly used insecticides, rear them in the laboratory, and release them in the field. There are predatory mites that are commercially available for release in certain orchard crops. Almond growers in California who have used this method have been able to save \$24 to \$44 per acre. (Horn).

PESTICIDES

HISTORY

Prior to world War II, farmers relied largely on non-chemical methods of pest control such as crop rotation, use of resistant or tolerant varieties, tillage, bait trapping and hand removal of pests. Weeds in particular were removed by hand-hoeing and tillage. Available inorganic pesticides contained metals such as copper, lead, sulfur and arsenic. Lead arsenate was widely used in orchards. It was very persistent in the soil and due to phytotoxicity is still a limitation to tree growth in blocks that are being replanted many years after its use. There was also some use of botanical (plant derived) compounds such as nicotine and pyrethrum. Extracts from tobacco were used in 1690, 200 years before nicotine was identified as the active ingredient. Both synthetic and natural pyrethrum (from chrysanthemum) are still used in household pest control due to low mammalian toxicity and quick knockdown, which homeowners like to see. Recently developed botanicals include an extract from citrus peels for flea and lice control and an extract from the Indian neem tree. These early pesticides were toxic, expensive to produce in quantity, and their availability was limited. In addition, inorganic insecticides were effective primarily as stomach poisons rather than providing control on contact. Equipment for their application was unsophisticated or lacking. (Zalom, et al.; Horn).

With the exception of a few botanicals and inorganic pesticides such as sulfur, most of the pesticides used today are synthetic petroleum-based materials which were developed following World War II. The pesticide industry was a spin-off of the development of nerve gas poisons during the war. One of the first synthetic pesticides to come into use was an organochlorine, DDT. The public health uses of this insecticide from 1942 to 1952 was estimated to have saved five million lives and to have prevented 100 million illnesses. Crop

yields almost across the board increased dramatically as a result of insect control provided by DDT and closely related compounds. (Metcalf and Flint). DDT had the advantage of low acute mammalian toxicity enabling its short term safe use for the handler. It was applied directly to humans for control of lice. Its downfall was due to its persistence and accumulation in the environment. Another closely related organochlorine, Chlordane, was used widely for years as a soil drench barrier treatment for termite control. Its soil persistence allowed for long term control but due to environmental threats, it is no longer available. Due to environmental contamination from the organochlorines, there was eventually a shift to the organophosphate class of insecticides. These are generally short-lived in the environment but are high in acute toxicity.

The new pesticide technology was rapidly accepted by the agricultural community revolutionizing pest control. In the twenty five year period from 1951 through 1976, pesticide expenditures increased from \$194 million to almost \$2 billion, a ten fold increase (Eichers). Over the same period, herbicide use in agriculture increased dramatically. Between 1952 and 1976, the proportion of U.S. corn acreage treated with herbicides increased from 11 to 90 percent with a one third reduction in labor and a doubling of yield (Eichers). Herbicide use has doubled since 1970 and now accounts for 65 percent of all pesticides used in the U.S. There is widespread use of fungicides to protect agricultural and ornamental plants from diseases. Due to the difficulties in monitoring diseases, many fungicides are applied on a preventative basis, but certain diseases lend themselves to computer forecasting to predict infection periods so that unnecessary applications can be avoided. (Zalom, et al.; Schmidt and Sturgul). Overall, pesticide use in agriculture has decreased by about 14 percent since the early 1980s. The decline in insecticide use has been attributed to replacement of conventional insecticides by those having higher unit activity and increased use of IPM (Calderoni). Agriculture currently accounts for about 72 percent of total pesticide sales in the U. S. (Pedigo).

The intensity of pesticide use (amount applied per unit of land area) is greater in urban areas than in most agricultural situations (Bennett and Owens). Lawns/turfgrass are probably the most intensively managed systems in the urban environment. The lawn care industry averaged 22 percent annual increase in sales from 1977 through 1984, most of which is due to material and application costs of pesticides and fertilizers. (Potter, et al.)

In agriculture, it has been estimated that 33 percent of all crops is lost annually to pests (13 percent to insects, 12 percent to pathogens, and 8 percent to weeds) in spite of pesticide and cultural control practices. In the forty year period from 1940 to 1980 there was a ten fold increase in insecticide use. In spite of this, crop losses due to insect pests doubled over the same time period increasing from seven percent to 13 percent. This was due to many factors including; abandonment of cultural practices that were relied on before insecticides were available, destruction of natural enemies, insect resistance to insecticides, use of varieties that were more susceptible to pests, and increased cosmetic standards particularly for fruits and vegetables. It is surprising that if insecticides, fungicides, and herbicides were withdrawn from agricultural use, crop losses would likely increase by only nine percent. The largest impact would be on fruits and vegetables in terms of quality and availability. (Pimentel, et al., 1981). It is important to recognize that this is an estimate for both food and non-food agricultural crops over a broad geographical area and is an average based on crop acreage and use patterns. There is significant variability in pesticide benefits between crops and regions. For example, Pimentel estimates that removal of just insecticides in apples would increase crop loss by 60 percent, but only a two percent crop loss would be

expected in wheat if insecticides were unavailable. (Pimentel, 1981). The benefits of pesticides and availability of practical alternatives must be evaluated for each situation.

Synthetic pesticides are still the mainstay in pest control for many of the reasons below. If used properly based on actual need rather than on a prophylactic basis, they should continue to be a useful tool for many years, and an important component of IPM programs.

ADVANTAGES OF PESTICIDES

ECONOMICS

On average, pesticides are very cost effective. It has been estimated that in U.S. crop production, they return \$4 for every \$1 invested (Pimentel, et al., 1981). This is based on a relationship between their cost and anticipated losses that would result in their absence. Some would argue that this impressive cost to benefit ratio is inflated and should consider the negative environmental effects such as ground water contamination which are real, but very difficult to quantify. It has been estimated that if these external costs of pesticide use are considered, the cost to benefit ratio drops to \$3 for every \$1 invested. (Pimentel, et al., 1981). One of the most significant benefits from pesticide use has been protection from malaria. Over 600 million people now live in areas that were once malarious, but are now free of this disease, due mostly to organochlorine insecticides (Young).

EFFECTIVE

When used properly, pesticides are also generally effective in controlling target pests and accomplish this control in short order. The effect of most insecticides can be determined within a few days; contact herbicides usually show visual signs of control quite soon after application. The control achieved with fungicides can be more difficult to measure and varies with host plant and disease. Pesticide application technology has been available for years and enables treatment of large areas with minimal labor and expertise.

BROAD SPECTRUM

Due to the broad spectrum activity of many pesticides, they often provide control of several potential pest species with a single application. Historically, control was achieved with little regard for proper identification or determination of pest status. With resistance problems and recognition of the role of beneficials and other factors, we have realized that this property is not always advantageous. According to Horn, broad spectrum pesticides will continue to be the dominant tactic in pest management and the critical need is to manage these chemicals more effectively.

CONSIDERATIONS WHEN USING PESTICIDES

Pesticides continue to be an important tactic in IPM. As mentioned earlier, IPM stresses the consideration of less disruptive methods as outlined above, but where pesticides are appropriate, they should be used on an as-needed rather than on a calendar basis. Even though many fungicide applications are used as a preventative spray, these applications are based on need in many situations. When using pesticides, consideration is given to selection of the most appropriate material, timing of application, and rate and method of application.

SELECTION

TOXICITY

Pesticides are classified based on their acute mammalian toxicity or LD50 values into four categories. The classifications are most dangerous, dangerous, less dangerous, and least dangerous, also referred to as category 1 (most dangerous) through category 4 (least dangerous). These values provide a useful index of the relative acute toxicity of different pesticides. In general, it is preferable to select pesticides that are less toxic in order to minimize threats to the applicator as well as to other non-target organisms.

DISRUPTION OF NATURAL ENEMIES

In those situations where preservation of natural enemies is a factor, materials are chosen based on acute toxicity as well as impact on specific natural enemies, when known. Charts have been developed which rate insecticides based on their effectiveness (efficacy) in controlling pests and their toxicity to specific natural enemies. These are very useful in crops which support a variety of pests and beneficials. A chart is available for apples in central Washington (WSU EB 0419). In the absence of such information, experience can be quite valuable in determining impacts of specific pesticides on beneficials.

EFFICACY

One of the most obvious considerations is efficacy. Herbicide efficacy tables on specific weeds are readily available as a tool to help select an appropriate herbicide. In order to use them effectively, the manager must have accurately identified the target weeds. Proper pest identification is critical when selecting a pesticide. This is not always as simple as it seems on the surface, particularly with plant pathogens and soilborne pests. Efficacy can vary from one location to another and even from one year to the next in the same location. Local experience and good recordkeeping are essential in selecting pesticides based on their efficacy.

RESISTANCE MANAGEMENT

The widespread phenomenon of pest resistance to pesticides has forced us to consider this factor in the selection process. "Resistance management" is a fairly recent term which refers to monitoring the development of resistance, assessing the risk of resistance, and managing pesticides to minimize development of resistance (Horn). In practice, resistance is managed by alternating pesticides, avoiding sub-lethal doses of insecticides, reduced frequency and extent of treatments, and reduced use of materials that have prolonged environmental persistence. Proper timing, method, and rate of pesticide applications can also prevent development of resistance. Again, one of the most important strategies is to monitor regularly and use pesticides only as needed. In essence, the combination of these principles is a blue-print for IPM (Metcalf, 1989). The following example in western Washington illustrates the multi-faceted approach to managing pesticide resistance. The principles are applicable to other situations.

Late blight of potatoes was a serious problem in western Washington during the 1990 season. Environmental conditions were favorable for disease and suspected resistance to the systemic fungicide, Ridomil, was confirmed. The extent of resistance is not known at this time but recommendations by WSU researchers highlight several strategies to manage the problem. Cultural management and sanitation practices are stressed to minimize carryover inoculum from one year to the next. Regular field scouting and environmental monitoring are advised in order to properly time the first fungicide applications. In the absence of early season foliar infection, a protectant fungicide application is recommended for late July. Fortunately there are several effective fungicides available for this purpose.

Growers who have used Ridomil with poor results are advised to use other fungicides. Based on the manufacturer's experience with Ridomil resistance in other areas, only certain formulations of Ridomil are advised for use and Ridomil sprays should be limited to two applications early in the season. These recommendations point out the importance of preventative cultural practices, field scouting, environmental monitoring, proper application timing, use of alternate materials, and use of certain formulations to minimize resistance.

PESTICIDE PROPERTIES

When selecting a pesticide, in order to reduce the threat of pesticide contamination of ground water, consideration should be given to several pesticide properties including persistence and degradation rate, adsorptivity, solubility, and volatilization. These properties are discussed in detail in Chapter Four.

TIMING OF APPLICATION

One of the clearest benefits of IPM regarding effective use of pesticides is that by regularly monitoring pest and beneficial populations where appropriate, optimum timing of application can be achieved. This translates directly to effectiveness of control and therefore reduced frequency of pesticide application. In turn, fewer applications means less opportunity for contamination of water. Timing can be based on crop or host plant development, susceptible stage of pest, predator to prey ratios, environmental conditions, and determination that treatment is necessary based on established threshold levels. Timing is normally based on a combination of these factors which vary from one situation to the next.

Many people wait until weeds are too large before using herbicides. Rates can be reduced with many post-emergent broadleaf herbicides to one quarter to one half rate if weeds are sprayed at a very young stage (less than one inch tall). The same goes for some post emergence grass killers (Putnam). Timing is very important when using the translocating herbicide, glyphosate (Roundup) designed to control weeds by moving from foliage to roots. This herbicide should be applied during the period when photosynthates are being translocated from foliage to roots, towards the end of the weed's seasonal life cycle.

Insect pests must also be in a susceptible stage in order to achieve adequate control. This is particularly true for soil inhabiting insects such as black vine weevil on strawberries or mint root borer. In both of these cases, the soil inhabiting larval stage is most susceptible to control and there is a short period of time in the fall which varies from season to season when effectiveness of soil applied insecticides should be optimal. This timing is also critical because this is the most damaging stage and considerable damage can occur with both of these pests at this time of the year. The PNW Insect Control Handbook recommends controlling another common soil inhabiting insect pest, the European crane fly, between April 1 and April 15 because this is an opportune time for monitoring population levels, the insect is in a susceptible stage, and it is usually prior to the onset of significant damage. However, reliance on this calendared approach may be disastrous in years where mild winters precede the spring wherein feeding will commence far earlier (WSU EB 0856).

Timing of fungicide applications is critical for disease control. In the case of *Botrytis cinerea*, which causes fruit rot in strawberries, raspberries, and wine grapes, early season sprays to prevent initial infection during bloom must be properly timed. Exact timing

depends on the specific fungicide used and the development of the host plant. For diseases such as late blight of potatoes and apple scab, timing can be based on environmental monitoring to determine when an infection period is likely. Disease forecasting models are available to optimize timing of fungicides in some situations. See example below:

Computer forecasting Model Use by Wisconsin Potato Growers

Wisconsin potato growers have had access to a Potato Disease Management (PDM) program which combines a late blight computer forecasting program called BLITECAST (developed by Pennsylvania State University) with an early blight program based on research in Australia and Wisconsin. Late blight and early blight are two major foliar fungus diseases of potatoes. Infection and spread of these diseases is based on certain environmental conditions. Field data requirements include maximum and minimum daily temperatures, duration of relative humidity equal to or greater than 90 percent, and daily

irrigation/rainfall. Based on this site specific information and potato cultivar, recommendations are made regarding timing, rate, and interval between fungicide applications. The programs are helping growers reduce fungicide sprays in seasons when environmental conditions do not favor disease development. This program became available to growers in 1985. During the 1987 season, the system was used in the Midwest on over 27,000 acres with estimated savings exceeding \$350,000. The acreage using this system is projected to double by 1992 (Schmidt and Sturgul).

Predator to prey ratios are considered by IPM consultants when timing lygus sprays in alfalfa seed, and mite sprays in apples and mint in Central Washington. This is based on sweep counts in alfalfa seed and mite brushing in apple and mint pest management. Mite control on small fruit crops in western Washington is based on pest density, relative levels of mite predators and crop development and time of the season.

RATE AND METHOD OF APPLICATION

Some pesticide labels provide a range of rates as well as methods of application that will provide control under a variety of circumstances. Rates are based on averages determined by manufacturer and university testing to be effective most of the time. Nothing is gained in terms of improved control by exceeding recommended rates and in many cases adequate control can be achieved with reduced rates and tailored methods of application. Motivated by liability concerns and desire to maximize product sales, manufacturers are hesitant to suggest reduced rates. A goal of IPM is to reduce rates without compromising control. There are economic and environmental incentives for doing so. However, using reduced rates must be based on either university studies, supportive experience, or manufacturer's suggestions. Extension agents can provide an important service to pesticide users by keeping them updated through newsletters and other forms of communication of this type of research.

Labelled rates for soil applied residual pre-emergence herbicides are based on soil type, percent organic matter, method of irrigation, and the anticipated weed type. Thorough knowledge of these factors on a field by field basis is essential for determining the proper rate of application. One of the most practical methods for reducing pre-emergence herbicides is by limiting the treatment area. Treating only a band over the crop row

combined with tillage between the rows rather than a broadcast application is a good example (Schmidt and Sturgul; Putnam). This is the common practice in raspberries in western Washington. There is more opportunity for reducing rates with post-emergence herbicides because there is a relationship between weed size and recommended rates. If treatment is applied when weeds are small as mentioned above, significantly lower rates will provide control. Mixing herbicides can also allow for comparable or improved control of certain weed species. There are also selected combinations of herbicides that have a synergistic effect; that is the results are greater than expected from their additive effects.

Rates and methods of insecticide and nematicide application can be adjusted based on plant density and size, pest population estimates, presence of natural enemies, and site specific history. For example, the rate of application of nemacur in raspberries is dependent on nematode population estimates. Higher rates should be used to treat excessive populations, and lower rates are advised where populations are only slightly above threshold levels. In addition, the material is usually applied as a band treatment in the rows to provide protection within the rooting zone. Low rates of azinphosmethyl (Guthion) for codling moth control are appropriate in orchards with a history of low populations of this insect as determined by trap catch data and experience. As a general rule in insect pest management, least is best. There are exceptions. In the case of newly introduced exotic pests where the goal is localized eradication, maximum rates may be necessary. Certain mites and insects may be reproductively stimulated by sub-lethal doses and in these situations low doses should be avoided (Pedigo).

Regardless of the pest, a method of application should be chosen based on distribution of the pest relative to its environment so that adequate coverage is achieved. For example, mites are found on the underside of strawberry leaves, and populations are usually highest on lower leaves just a few inches above the ground. In order to place miticides in this area of the canopy, spray nozzles must be arranged so that spray is directed upwards from below the canopy. In an orchard environment, air blast sprayers are necessary to achieve adequate coverage of foliage and effective insect, mite, and disease control. Sprays are often directed to certain areas within the canopy in order to maximize control. It is standard practice for wine grape growers in the Yakima Valley to adjust nozzles on sprayers so that fungicides for *Botrytis* fruit rot control are directed at the clusters to prevent initial infection as well as subsequent spread. The same principles apply regardless of the system under consideration. In cockroach control, placement of insecticide in areas where these insects hide during the day or travel at night will be more effective than treating areas which are seldom frequented by cockroaches (Ramsay and Thomasson, 1991).

Proper application will maximize effectiveness and minimize need for additional sprays. Rate and method of application can greatly influence the potential for a pesticide to reach either surface or groundwater. See Chapters Four and Five for more information regarding application as it relates to protection of water quality.

CHAPTER THREE

IPM IN PRACTICE

PRACTICE VS. THEORY

The previous text discussed the principles of IPM and outlined the strategies and tactics used in pest management. Although they have been presented somewhat independently, the challenge of IPM is to blend appropriate tactics into a program in order to manage pests efficiently with regard to economics, aesthetics, and the environment within an ecosystem that is dynamic or ever-changing. In practice, pest management is usually the blending of a few management tactics rather than several. This is usually due to practical constraints and/or limited basic information to support the use of several tactics for a specific pest.

IPM development is most advanced in agriculture, largely because of the research infrastructure that has been in place within this discipline for years. For this reason, the following examples of traditional IPM delivery based on review of the literature are from agriculture. Forestry has also practiced IPM principles for years, however there is less documentation of the delivery and implementation process. IPM development in turf, ornamentals, and vegetation management largely in urban settings has been more recent. These developments are based more on environmental concerns associated with pesticide use than on economic concerns, which was initially the driving force in agriculture.

Following is a discussion of some of the important concepts of IPM in practice.

KEY PESTS

Regardless of the level of sophistication, all IPM programs are based on management of the key pest or pests in the system. Apple IPM in the Northeast U.S. has some similarities in strategies to that in the Northwest, yet because of a different key pest complex, the specifics of the programs are different. The pest manager must be very familiar with the

biology and behavior of key pests in each of the systems under consideration. This often poses a significant challenge even within a single crop, but can become very complex when one considers the large number of potential pests and the ecosystem variability in urban environments. This is particularly true in diverse urban landscapes where many host plants may be represented.

INTEGRATION OF STRATEGIES/TACTICS

A combination of tactics is usually more successful in managing pests than reliance on a single tactic. This is not simply a matter of adding a number of tactics to form a program. Integration considers the effect of each tactic with regard to the pest, natural enemies when present, and other tactics. As more tactics are considered, integration becomes more complex and the opportunity for negative interactions increases (Pedigo). Usually, the integration of a few tactics is adequate and reasonable in applied IPM.

For example, in many agricultural crops, natural enemies can be enhanced through pesticide selection, timing, or general moderation. This can be difficult because important natural enemies are often closely related to the pests themselves, and both can succumb to destructive tactics. In most cases, natural enemies are slower to recover than pests. Many plant diseases are managed through the integration of cultivar selection, sanitation and other cultural practices, and preventative sprays when necessary. In almost every situation, some preventative tactic plays a role. Managing vegetation along rights of ways in particular allows for integration of several strategies.

However, the number of appropriate tactics varies with the particular situation. There are situations which do not lend themselves to an integrated approach. For example, due to its ability to transmit viruses to seed potatoes and a zero tolerance for this pest in this crop, the green peach aphid is managed by a single tactic: regular prophylactic insecticide applications. Even in systems where prevention is so important such as in the management of structural pests, the opportunity may be lost because the specialist, in this case the PCO, is usually not involved until a structure is infested. The PCO's role in many situations is control using pesticides rather than addressing the original conditions that led to the problem. Sanitation can be advised by PCOs for cockroach and rodent management, but carrying it out is usually and justifiably left up to the client.

DATA GAPS

In the words of Horn, "Despite a scientific, objective approach, one cannot know everything, and management decisions may contain an element of educated guess work. Decision-making in IPM involves a large dose of scientific objectivity and a bit of speculation". Regarding the current "state of the art" in pest management, this is an important concept. Data gaps do exist but there is still a strong scientific base which supports IPM in many systems. The base of knowledge in agriculture and forestry is broader than in most urban systems. This is a reflection of the infrastructure that has supported these industries as mentioned above. Despite the fact that most crops do not have the research database found in cotton or alfalfa, workable IPM programs have been put together in some crops using common sense, field experience, and a minimum of research. One example of this is the pear pest management program in California, which was developed based mostly on observations of a county extension agent combined with

research at the University of California. This agent, a generalist with much field experience, was instrumental in putting the program together. Field men, primarily private consultants, adapt, modify, and often improve original sampling methods and management techniques. Complete IPM programs are lacking in most crops, but many well-trained professionals have been successful in conducting IPM programs based on extensive monitoring, experience, and a feel for what is happening in the field. Some of these programs may lack sophistication, but by simply monitoring a field on a regular basis, one can generally improve a grower's pest control program. (Barnett).

Many of the principles of IPM are incorporated into a new program which an Ohio company has made available to urban clients. Their "plant health care" program focuses on prevention through proper species selection, planting methods and basics of tree care. They spray selectively, based on regular monitoring, with conventional and alternative pesticides. They have reduced traditional pesticide use by 75-80 percent with no reduction in quality of service to their customers (Funk).

IPM is a continuous learning and development process. There will always be missing pieces of information regarding a particular tactic's overall effect on the system or even some basics regarding pest biology. The challenge is to apply the principles of IPM with the knowledge that does exist.

TRADITIONAL IPM DELIVERY

Historically, many of the IPM programs currently in place in agriculture developed from CES demonstration projects in the late 1970s and early 1980s. Examples in Washington are the hops and alfalfa seed programs. These programs developed monitoring guidelines and decision-making criteria for the farmer or pest manager. They were designed to expose farmers to the principles of IPM and demonstrate the benefits of properly timed pesticide applications compared to spraying on a prophylactic basis. Most universities were not interested in continuing to manage these programs once the demonstration period is completed, but many continued and some still continue to train field scouts with industry support. More commonly, the technology is transferred to the private sector and delivered to users by consultants or grower/producer cooperatives. In some cases, larger individual growers employ a full time pest management specialist.

INDEPENDENT CONSULTANTS

Extension services and farm supply dealers have historically advised farmers in pest control. That advice was typically based on calendar spraying or stage of plant growth rather than intensive field monitoring which is required in IPM. Extension is not designed to supply individual field advice, and farm supply dealers have generally concentrated on providing materials rather than specialized advice based on intensive monitoring.

Applying IPM techniques requires more labor to monitor and more specialized knowledge regarding pest biology. Increased IPM research in the 1970s accelerated the development of the private pest management consultant industry. Private IPM consultants generally provide services only and do not benefit from the sale of pesticides. The CES IPM projects of the 70s were a training ground for many private consultants. Many of the field scouts trained in these programs transferred the technology from the public (university) sector to

the private (consultant) sector. Consultants have now become a major force in delivery of information to growers in the Midwest, Texas, and California (Zalom, 1990; Post, 1988; Wearing; Frisbie and Adkisson) as well as many other areas.

Due to Extension IPM budget constraints, private consultants will become increasingly important in the transfer of pest management information to producers. A USDA survey of the private consulting industry found that 90 percent of the companies started after 1970, and 54 percent started since 1980. Private consultant businesses are now in practice in 45 states and Puerto Rico. Most of these companies (85 percent) offer other services in addition to pest management. Consultants rely heavily on Cooperative Extension publications, Extension specialists, and their own research and observations. (Lambur).

Although there was much discussion twenty years ago regarding potential conflict between consultants and Extension agents, there is currently a good working relationship between the two groups (Post; Lambur). The private consulting industry in the Yakima Valley of eastern Washington is most evident in the tree fruit industry which is now serviced by at least six consultants. Field crops including primarily hops, mint, potatoes, and asparagus and wine grapes are also serviced by private pest management consultants (Jameson). There are at least two private consultants in western Washington servicing agriculture and the forestry nursery industry (personal experience).

PRODUCERS

Grower owned cooperatives, like consultants have historically played an important role in IPM implementation. Many of these cooperatives supplied services to growers at cost. An example was the Safford Valley Cotton Growers Co-op in Arizona, which supplied field monitoring and pest control recommendations to interested growers. Cost of the service was deducted from grower's proceeds at the close of the season. (Goldstein).

Ocean Spray Cranberry, Inc. is an excellent local example of a grower owned cooperative that has embraced IPM and played a critical role in its implementation. Their first IPM program was developed in Wisconsin based on university research made available to growers in that state in 1984. IPM programs are also available now in Massachusetts and most recently in New Jersey and Washington. The Washington program was based on a WSU pilot project undertaken in 1988 and 1989 which was partially supported by the growers. The chief field scout in that university program was hired by Ocean Spray, thus transferring the program to the private sector. It has been available to growers in southwestern Washington since the 1990 season on a voluntary basis. (Broaddus).

IMPLEMENTATION IN OTHER SYSTEMS

As has been mentioned, IPM research and delivery in urban systems, with the exception of pests of medical importance, is behind that found in agriculture and forestry. This is partly due to the complexity within urban systems compared to agriculture and the difficulties of decision-making in urban environments where decisions are based largely on subjective sociological factors (Sawyer and Casagrande). Advancement of urban IPM is threatened by the public's general low tolerance for insects (and other pests) which is deeply entrenched, lack of a research system similar to that serving agriculture, low cost of pesticides, and a poorly educated public regarding knowledge of pest life cycle or habitat

(Bennet and Owens; Byrne and Carpenter). In spite of some of these inherent obstacles to implementation, advances are being made in turf and ornamental pest management (Foy).

In response to homeowner concerns about lawn pesticides and their effects on pets, University of Massachusetts funded a turf IPM program that stresses cultural practices (Clark). Maryland homeowners exposed to a fourteen week IPM program (similar to agricultural demonstration projects) overseen by extension personnel were highly satisfied with the program, but resubscription rates were well below those common in preventative spray services offered by lawn care companies. (Potter). The reason for this was that many homeowners believed that once they had the information needed to manage their landscape more effectively, there was no reason to continue the IPM service. An IPM landscape demonstration project undertaken by University of Maryland extension specialists was eventually commercialized under the direction of a private consultant (Raupp). (See more under benefits section below). Just as consultants have played a major role in IPM implementation in agriculture, some PCOs routinely call on consultants for assistance in designing IPM strategies (Story). In some cases, PCOs can play a major role in development and implementation of IPM. A good example in structural pest management is the research being carried out to evaluate the use of sand barriers as a physical tactic for termite control mentioned previously. This research is being done by a pest control company and funded under a university IPM grant (Carver).

Implementation of IPM in vegetation management is generally undertaken by the responsible agency or company. The Philadelphia Electric Company was one of the first utilities in the U.S. to implement selective vegetation management as a strategy.

LIMITATIONS/CONSTRAINTS

Proponents of IPM in agriculture have been complaining about the slow rate of adoption by farmers since as early as 1965 (Wearing; Zalom, et al.). It has been estimated that it takes from five to twenty five years to modify practices and educate growers to recognize the benefits of IPM (Schal and Hamilton). A review of the implementation process in agriculture by Wearing (1988) identifies many of the real and perceived factors that can impede IPM. Though this review focused on insect and mite pest management, the principles are applicable to IPM in general in many settings. Based on this survey of research and extension specialists and consultants in several countries, technical, financial, educational, organizational, and social constraints were identified. Over 50 percent of the U.S. respondents ranked social obstacles as the most common barrier.

SOCIAL

Probably the largest social constraint to IPM adoption is the infrastructure for pesticide supply and use. There is a high ratio of chemical sales and support personnel to private pest management consultants and extension IPM staff. Marketing skills of agricultural chemical corporations are far superior to that of private consultants and extension staff in general. (Zalom, et al.). IPM also requires the substitution of skilled labor for capital investments, which is against the prevailing trends (Wearing). Arthropods are generally not tolerated well by 20th century Americans and probably most urban and suburban persons are unwilling to accept the low densities of insects that may result from ecological approaches to pest management such as IPM. This condition (fear of insects) referred to

as “entomophobia” contributes to overuse and misuse of insecticides in the domestic urban and suburban settings when compared to agriculture, forestry, or public health operations (Horn). This mentality is also seen in the public’s demand for pest-free plants (Potter). Part of our reliance on pesticides stems from incentives offered to pesticide supply fieldmen and PCOs which are based on amount of pesticide used or dollars generated per month (Burke). Competition in the structural pest control industry has often suppressed prices to the point that long term, non-chemical procedures have been omitted from management practices (Moore).

EDUCATIONAL

IPM is education intensive; implementation is dependent on education of growers, consultants, and extension staff. In most cases where IPM has been implemented in agriculture, extension agents and extension material are the initial source of information on IPM techniques. Wearing points out that a lack of education of IPM developers about the perceptions of farmers is probably a much greater obstacle to implementation than the reverse. For IPM to succeed, appropriate technologies are a must. Most farmers initially equate IPM with increased risk. This is because pesticides have been historically valued for reducing risk. In practicality, IPM techniques such as regular monitoring are tools for managing risk.

The education process in the urban sector is behind that found in agriculture. The urban public has been at a disadvantage because most land grant institutions are located in rural areas to provide support to the agricultural community. (Schal and Hamilton). With increasing awareness of pesticides and urban growth in many areas of western Washington, extension agents in proximity to major metropolitan areas in particular are spending more time addressing urban pest problems. According to Antonelli, Extension entomologist stationed in Puyallup since 1976, his focus has shifted from what was initially 70 percent agricultural and 30 percent urban to currently 60 percent urban and 40 percent agricultural. Extension agents in more agriculturally oriented counties such as Whatcom and Skagit naturally spend more time addressing agricultural problems but are also involved in the urban sector. (Antonelli). The volunteer Master Gardener program is a good example of Extension education designed for the urban dweller.

In Monmouth county, New Jersey, education of the public has been the key to rational management of the gypsy moth in urban settings. With the knowledge that trees can tolerate significant defoliation, and use of homeowner management strategies including collection and destruction of larvae and eggs, people have learned to tolerate moderate populations of this pest (Boerner).

Despite the need for education, it can often be difficult to achieve. Consider the plight of the PCO. Many clients are not interested in being educated, they see the PCO as the person who will solve their problem and they like to divorce themselves from the equation. Most clients expect the PCO to treat the problem with pesticides. What they often fail to realize is that even the best conceived program can fail if they don’t do their part, which usually involves some preventative tactic. In addition, although PCOs must be certified in order to apply pesticides, they have in most cases received minimal training to enable them to deal with the human aspects of urban pest problems. (Frankie, et al.).

ORGANIZATIONAL

There are significant organizational challenges to implementation, particularly when the multi-disciplinary nature of IPM is considered. Some government programs such as commodity price supports reward growers for maximizing production often through increased pesticide use which would not be profitable in the absence of support. In most IPM programs, pesticide use is decreased. Farm subsidy programs encourage growers to plant the same crop each year. This discourages crop rotation, an effective IPM tactic for suppression of many pests. Lack of interdisciplinary research efforts is a major constraint and interdisciplinary degree programs in pest management are not well supported in our universities. Cosmetic quality standards set by government agencies, industry, and commodity associations can present obstacles to IPM. These standards have been imposed based on consumer concerns but have also been used as market regulating tools. (Zalom, et al.). In the words of Schal and Hamilton: "Implementation of urban IPM programs is complicated by the diffuse allocation and control of resources among residents, landlords, businesses, local and federal agencies, extension personnel, consultants, and PCOs."

COMPLEXITY

The complexity of IPM is widely acknowledged as a major obstacle to its implementation. However, growers who have adopted IPM perceive it as much easier to use than those who have not adopted it (Wearing). Without direct experience, complexity is perceived to be high and can impede adoption.

FINANCIAL

Financial obstacles are seen as a serious constraint to implementation of biological control components in IPM programs (Wearing). This mostly applies to the use of augmentation or periodic releases of natural enemies in agriculture as a widespread practice. However, there are examples where augmentation is economical such as greenhouse biological control and in high value agricultural crops in some areas where insecticide use has been very intensive.

Farmers are not accustomed to paying for advice. In the initial stages of IPM adoption they often see consultant fees as an extra expense and it is usually not until they have experienced IPM in practice that they appreciate its economic benefits. Many of the financial constraints are perceived rather than real but consideration must always be given to economics when developing practical IPM programs to insure economic feasibility. For example, in Washington agriculture, IPM is currently practiced primarily in high value crops which have significant pressure from a complex of pests.

In spite of a growing interest in IPM in turf, current satisfaction with the way lawn care companies are managing pests is generally high. Costs to monitor regularly and hire or train highly qualified consultants is prohibitive relative to routine preventative spraying costs. (Potter).

TECHNICAL

The most common technical constraints in agriculture identified in Wearing's survey were lack of simple monitoring methods, action thresholds and general decision-making guidelines. This is even more of a shortcoming in urban settings. Lack of efficient trapping

methods is probably the single most important factor contributing to heavy reliance on scheduled applications of insecticides for cockroach management. To date, there has been no correlation between trap catch and population density, complicating decision-making. Both consumers and PCOs favor scheduled applications of long residual activity insecticides versus a more integrated approach. Only when effective monitoring tools become available will scheduled treatments be replaced by judicious timely applications of insecticides. The monthly “crack and crevice” approach for insecticide application is the standard and rational approach at this time. (Schal and Hamilton). In order to circumvent these technical constraints, research funding and efforts must be broadened so that more energy is directed towards development of monitoring and decision making tools that will improve pest management in practice.

BENEFITS

The literature on IPM in agriculture contains numerous references which emphasize its advantage over conventional control in terms of increased production, greater net return, improved risk management, and lessened environmental impact both in general terms and on specific crops (Zalom, et al.; Grieshop, et al.).

ECONOMIC

Economic advantages of IPM have only recently become widely studied yet there are many programs in place which have never been studied in this regard. In nearly every economic evaluation of IPM programs, increased profits have been shown at the farm and commodity level. Greater net returns are usually the result of lower pesticide costs, resulting from reduced frequency of application. Implementation of the Texas High Plains boll weevil control program benefitted the region’s cotton growers by \$27 million. Risk was also shown to be lower compared to conventional cotton production practices. Insecticide use on the over one million acres of cotton in the San Joaquin Valley is among the lowest in the world due to implementation of an extension IPM project which started in 1971. The University of California Statewide IPM Project targeted almonds as a perennial crop where growers are now widely using a complex of IPM techniques. IPM reduced pesticide use by 31.2 percent for an annual saving of \$3.56 million. (Zalom, et al.). Significant savings from reduced reliance on pesticides have been documented in several University of Maryland urban IPM projects targeting homeowner landscapes, grounds maintenance supervisors, and urban arborists (Raupp, et al.). Similar savings have been realized with golfcourse IPM in the Southeastern US primarily due to improved timing of insecticide applications resulting in better control and reduced pesticide usage (Foy). Pesticides in greenhouse vegetable production in the Fraser Valley of British Columbia have been virtually replaced by biological control as mentioned earlier (Elliott).

In most cases, the savings that result from IPM use are due to reduction of calendar-based pesticide applications. Regular monitoring allows the manager to base decisions on actual site-specific need rather than a predetermined schedule. Improved timing of application also results in better control and therefore lengthens the interval between applications. Spot treatment rather than total area treatment also translates into reduced pesticide use and cost.

RISK REDUCTION

Contrary to the perceptions of many, IPM is a risk reduction system (Leslie; Zalom, et al.; Grieshop, et al.). Results of monitoring often indicate need for treatment which may not have been realized by managers who rely on scheduled treatments. In contrast to conventional pesticide intensive programs, IPM is knowledge and labor intensive. As long as decision-making guidelines are established, implementation of that knowledge will reduce risk.

MARKETING ADVANTAGES

IPM has also been used in order to gain marketing advantages. In response to the public's concern for food safety, IPM has been used as a marketing tool by some grocers. Cornell University is in the process of developing a grower certification program. (Zalom, et al.). IPM probably has its greatest marketing advantage with fresh market fruits and vegetables (Goldstein). Although marketing benefits are not widely documented, considering the public's concern regarding pesticide residues on food, there is likely to be an increase in advertising IPM grown products. Ocean Spray Cranberry, Inc. mentions its use of IPM in promotional material (Broaddus).

Marketing advantages can go beyond the farm. A golf course developer in Vermont proposed using IPM to satisfy environmental requirements which as part of a state growth act were threatening the development of this course. With assistance from the EPA, the developer agreed in principle to implement a comprehensive IPM plan, which satisfied the concerns of local environmental organizations previously opposed to the project. In essence, the program would be based on selection of well adapted varieties of grass, proper irrigation, fertilization, aerification, mowing and other cultural practices. Monitoring, record keeping, and setting thresholds is the basis for pesticide applications, and biological and alternative tactics will be recommended where appropriate. In this case, IPM implementation sold the community on the merits of golf course development compared to other development uses of the property. (Grant).

IPM IN RASPBERRIES IN WESTERN WASHINGTON - A CASE STUDY

Raspberries serve as a good model for illustrating IPM in practice in western Washington. Although several WSU publications address pest management in this crop, there is no "IPM manual" for raspberries. In essence, many of the pieces of the puzzle are out there; they just haven't been formally put together. As in many systems, IPM in raspberries is developing primarily through the effort of private pest management consultants in coordination with producers and university research and extension personnel. In Whatcom County, raspberry IPM services have been provided by a private consultant since the 1990 season (Menzies).

With regular systematic field monitoring, improvements in pesticide spray timing, selection, and impact on natural enemies are being realized. However, significant data gaps exist, particularly regarding the impacts of specific pesticides on both pest and beneficial species.

KEY PEST COMPLEX

Raspberry pests can be broadly divided into those which contaminate the fruit as a result of mechanical harvesting, those which threaten the general health of a raspberry planting, and those which directly damage the fruit itself. Some pests can fall into more than one category. For example, adult weevils when numerous can contaminate fruit. The larval stage of the same insect threatens plant vigor through feeding damage to the roots.

Harvest Contaminants: A wide array of insects and spiders can be dislodged from foliage during the harvesting process. Many of these pose little if any threat to the planting but cannot be tolerated as fruit contaminants. Historically, growers have applied “clean-up” sprays prior to the onset of harvest to prevent contamination of fruit. The most common contaminants include a variety of caterpillars (among them are leafrollers, loopers, cutworms and armyworms), aphids, adult weevils, lady beetles, spiders, and various true bugs (stink bugs, minute pirate bugs, and lygus bugs) which can also be beneficial as predators of insect and mite pests (Antonelli et al.)

Pests that weaken plantings: There are numerous pests which can threaten the general health of a raspberry planting. At least two species of nematodes feed on root tissue. The most common is the root lesion nematode which when numerous in the soil can destroy root tissue and allow for disease infection resulting in chronic decline of a field. Less common is the dagger nematode which is capable of transmitting viruses that also cause decline. Several species of root weevils can damage raspberry fields. The most common is the black vine weevil. It is the larval stage of this insect which feeds on roots and weakens plantings. The presence of adult weevils and their feeding on foliage before and during harvest is a good indicator of the status of this pest within a field. Because soil insecticides are no longer available for controlling the larval stage (no longer registered due to potential for groundwater contamination), control efforts are directed at the adult stage prior to mating and egg laying. Plant pathogenic fungi which reside in the soil are capable of damaging roots under certain environmental conditions. Water saturated, anaerobic (oxygen deprived) soils inhibit normal root growth and create conditions favorable for infection by certain diseases. Weeds compete with raspberry plants for water and nutrients. The general strategy for vegetation management is a weed-free zone within plant rows accomplished by herbicides and/or cane suppression chemicals applied in that zone, and either periodic cultivation or planting a sod cover to manage weeds between the rows.

Above ground pests which can weaken plants include the twospotted spider mites and a variety of fungal diseases which can infect foliage and canes. Spur blight is the most common such disease.

Direct damage to fruit: The most important pest that causes direct damage to fruit is the fungus, commonly referred to as botrytis or gray mold, which infects the fruit tissue and appears as a gray mold on the fruit surface. Infection and spread of this disease is favored by wet conditions and poor air movement.

MONITORING PROGRAM AND DECISION-MAKING

With a perennial crop like raspberries, field site selection is very important. Once a good site is chosen, seasonal monitoring is carried out beginning in the early spring (late March/early April through early September).

Site selection: The most important factors to consider are soil type, field history, and nematode complex and population size. Heavy clay soils which are slow to drain should be avoided in areas that experience high rainfall such as western Washington. Saturated soil creates an environment unfavorable for root growth and quite favorable for root rotting fungi. It is better to avoid such soils than to become locked into a soil fungicide program that is expensive, hard to evaluate, and may at best allow for below average production. Field history should be considered as well. Important things to consider in fields previously planted to raspberries are yield records, specific soilborne disease and nematode problems if known, and life of the field. History will provide only a rough indicator of current suitability. Soil should be analyzed for nematodes to determine the species that are present and population size. Sampling methodology is very important to accurate decision-making. Several samples, each representing not more than a five acre area should be submitted to a laboratory. Sampling should be stratified to represent topographical variation, soil type variation, and historically good or poor performing areas within the field. Results can be used to determine whether fumigation is necessary and if alternative sites should be considered. Consideration should also be given to weed complex prior to planting. This is the best time to control weeds (WSU EB 1491).

Seasonal monitoring: Monitoring in established fields begins in the early spring and continues on a regular basis (at least every two weeks) through late August. Frequency of sampling varies between fields and years depending on pest pressure, but a minimum of eight to ten visits is usually necessary (Menzies). The monitoring season is logically broken into three periods for discussion purposes; pre-harvest, harvest period, and post-harvest.

Pre-Harvest (thru June): Leafroller pheromone traps are placed throughout the field in early April at a density of one trap per five acres. These traps are checked regularly throughout the season for two species of adult leafrollers. The orange tortrix is the most important leafroller because the larval stage is present during the harvest period and can contaminate fruit. The more common species, the oblique banded leafroller is less of a contaminant problem because the damaging larval stage is found towards the end of the harvest period. Interpreting trap catch results and other considerations are outlined in OSU Extension Circular 1263 (Knight et al.). Overwintering leafroller populations (larval stage) can be monitored during March and April. The number of larvae found during a timed search can provide a rough estimate of field populations and help determine whether pre-bloom treatments are necessary. In fields with a history of leafroller problems or where sampling indicates, the bacterial insecticide, Bt. has become standard due its specificity and minimal disruption of predators. The early season is also a good time to evaluate overwintering mite populations and mite predators by examining the underside of leaves at several sites within the field. The mite predator, Stethorus punctum, discussed earlier under the biological control section, can often be found on foliage in late March and early April. Knowledge of its presence can influence spray decisions later in the season. Both mites and their predators are monitored by collecting a minimum of ten leaves per site at several sites throughout a field during the entire season. Results provide information on population trends and predator/prey ratios. When populations reach 25 mites per leaflet prior to September, a mite spray is usually necessary (WSU EB 1491). In addition to pheromone traps and foliar insect and mite counting, other insects within the developing canopy should be monitored. This can be done by using a white sheet placed on the ground or held below the foliage (pear psylla tray) and then shaking the canopy vigorously to dislodge insects. The insects can then be identified and counted. This is a good technique for monitoring adult weevils which begin to inhabit the canopy in late May. The presence

of a few weevils may justify treatment prior to the onset of harvest. Trends in weevil numbers will also help determine when peak emergence from the soil has occurred so that spray timing can be optimal. The spectrum of insects detected from this sampling procedure is critical for selection of appropriate insecticides for the “clean-up” or pre-harvest spray.

The most important disease during this period is botrytis. Because initial infection occurs during the bloom stage and the disease is microscopic, preventative fungicide applications are recommended at the onset of bloom and then on 14 day intervals. Usually three applications are sufficient. Alternating fungicides is advised to avoid development of resistance (WSU EB 1491). Frequency of sprays can be reduced under dry conditions or in fields with little history of botrytis infection. Disease incidence should be monitored to help evaluate effectiveness of spray programs. Preventative cultural practices include proper pruning to maintain desirable cane density, and weed control and primocane suppression to enhance air movement (Brun). Avoid over fertilization which results in excessively vigorous foliar growth (WSU EB 1491). Removal and destruction of botrytis infected plant debris following pruning (sanitation) may be practical in reducing carryover inoculum from year to year in particularly susceptible varieties. Commonly grown raspberry cultivars have been ranked for susceptibility to botrytis (Brun). Occasional diseases such as cane blight and anthracnose should be detected if present with regular field visits. Early season plant collapse may indicate root rot or nematode problems and justify field analysis and possibly laboratory diagnosis.

Research has confirmed that growers making one or no insecticide applications are less likely to have mite problems that warrant miticide applications (Shanks et al.). Pre-harvest monitoring is essential to determine necessity, proper timing, and selection of insecticides. In fields not infested with weevils, it is possible in some years to avoid insecticide applications even up to the onset of harvest. Unfortunately, weevil infested fields must be treated usually before harvest begins and as frequency of sprays increases, so does the likelihood for disruption of mite predators.

Harvest Period (early July thru mid-August): Most commercial raspberry fields are machine harvested. Examination of fruit as it comes across the belt for presence of insects and disease is a good way to evaluate fruit quality and presence of harvest contaminants. Results from the first pick will also determine effectiveness of pre-harvest treatments and necessity for additional sprays. Some insecticides have short pre-harvest intervals and therefore can be used during the harvest period if needed. Leaf sampling for mites and predators continues during harvest as does examination of leafroller traps. Mite populations should be watched closely in the middle to latter part of harvest, particularly in fields that have had more than one insecticide application. Populations can increase rapidly under hot conditions in August in the absence of predators. Monitoring for spur blight intensifies during harvest as damage from harvesters can create entrances for infection of primocanes. (Byter)

Post-Harvest (mid August thru early September): This is still a critical period for managing twospotted mites. If the population remains below 25 mites per leaflet thru August, sprays are probably unnecessary, particularly if mite predators are present. Avoiding a spray late in the season should enhance carryover of mite predators into the next season. Adult weevil monitoring should continue through August with particular attention to field borders. A fungicide spray is usually necessary after harvest to minimize primocane infection by spur blight, which if untreated can destroy buds and increase susceptibility to winter injury.

If significantly weak areas exist within a field, this is a good time to determine nutritional status by comparative leaf analysis between good and poor areas. Critical nutrient ranges have been determined for raspberries (WREP 43). Leaf analysis results may suggest soil fertility sampling be done in either the fall or following spring. Fertilizer practices should be based on soil and foliar analysis. Leaf sampling results might also reflect soil pH problems. For example, high foliar manganese levels indicates possible low soil pH, which can be corrected with lime applications (Scheer). This is also a good time to sample both soil and root tissue for nematodes. This diagnostic sampling will help determine causes for poor growth and identify appropriate management strategies.

RASPBERRY IPM SUMMARY

IPM is currently being practiced on a small percentage of raspberry farms in western Washington. Economic benefits of IPM use in Whatcom county have not been studied, but it has resulted in reduced spray frequency in many fields compared to previous practices. Grower satisfaction is indicated through repeat support of the services over the three year period, 1990-1992 (Menzies). An economic analysis of IPM in raspberries is needed. Further development will likely result from the continued efforts of the private sector in coordination with research and extension personnel. We are currently lacking basic information on specific pesticides registered for use in raspberries regarding their toxicity to predators. Conservation of natural enemies is difficult to realize in weevil infested fields because insecticides that control weevils are hard on mite predators as well. Research on alternative weevil control methods should be encouraged.

Although more research is necessary, application of IPM principles is underway in this crop. Continued research, development and implementation of IPM should result in fewer pesticide applications, greater reliance on alternative methods of control, and less opportunities for pesticide contamination of groundwater.

CHAPTER FOUR

PRINCIPLES OF PESTICIDES

Pesticides have been and will continue to be a valuable strategy in most IPM programs. Considering the increasing research and development costs, resistance problems, and the re-registration process, the effective market lifespan and availability of pesticides is threatened. The adoption of IPM will extend the effective use period of pesticides as a pest management tool.

The basis for IPM adoption is usually short term benefits such as financial gain and risk reduction. Some users also identify reduced health threat to workers and the public as major benefits (van Lenteren). A longer term benefit is less environmental impact from pesticides. Reducing the overall use of pesticides and supplementing them with narrow spectrum, less toxic alternatives will reduce the likelihood for environmental problems, including surface and groundwater contamination.

With the recognition that pesticides are a valuable resource even within IPM programs, the following sections address pesticide management as it pertains to protection of groundwater. At the present time in most systems, pesticides are selected based primarily on efficacy, economics, toxicity, and on-site environmental factors. Pesticide properties as they relate to potential for groundwater contamination are often not considered in the selection process now, though they will be more and more in the very near future.

PESTICIDE DEFINITION

Pesticides are a group of substances that have been specifically designed to repel, kill, prevent or regulate the growth of unwanted biological organisms such as insects, weeds, and rodents. Pesticides are characterized by their toxicity which is the inherent ability of a chemical to cause injury. Toxicity is further characterized as either acute or chronic and is almost always determined through laboratory procedures. Acute effects are immediate and become apparent within minutes or hours of exposure, and are usually associated with concentrated exposures. Chronic health effects occur after extended exposure usually at relatively low levels of concentration.

The *acute* toxicity of a pesticide is usually expressed as LD₅₀ (lethal dose 50) or LC₅₀ (lethal concentration 50). It is the amount or concentration of a chemical required to kill 50 percent of a test population of animals under a standard set of conditions. The LD₅₀ and LC₅₀ values are useful in comparing the toxicity of different active ingredients as well as different formulations of the same active ingredient. The lower the LD₅₀ value of a pesticide, the less it takes to kill 50 percent of the test population, and therefore the greater its toxicity. LD₅₀ values of pesticides are recorded in milligrams of pesticide per kilogram of body weight of the test animal (mg/kg), or in parts per million (ppm). LC₅₀ values of pesticides are recorded in milligrams of pesticide per volume of air or water (ppm).

The *chronic toxicity* of a pesticide is determined by exposing test animals to a pesticide over a long period of time. The harmful effects that occur from small doses over a long period of time are called chronic effects. Some of the chronic effects found in test animals include birth defects, production of tumors, genetic changes, blood disorders, nerve disorders, and reproductive effects. The chronic toxicity of a pesticide is much more difficult to determine than the acute toxicity.

PESTICIDE INGREDIENTS

Pesticide products registered for use in the U.S. are made up of complex formulas consisting of “active” and “inert” ingredients.

Active ingredients are identified by the EPA as the agents that “prevent, destroy, repel, or mitigate any pest” (PSWQA). *Inert ingredients* are used in pesticide formulations and are defined by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) as any ingredient that is not active. This means that these ingredients are not the primary agents in the pesticide formulation acting on the designated pest.

Inert ingredients are primarily used in formulations as diluents, dyes, solvents, carriers, adsorbents/binding agents, or preservatives. The proportion of active and inert ingredients varies by product with some formulations containing up to 99 percent inert ingredients. The fact that they are labeled “inert” does not necessarily mean that these ingredients are chemically or biologically inactive. (C&EN).

There are approximately 1,200 to 1,300 inerts currently being used in pesticide formulations. Since only the toxicity of the active ingredient is tested, the contribution of the inert ingredient to the toxicity of a pesticide formulation is largely unknown. Although the EPA considers about 300 of these inerts to be innocuous or of minimal concern there are more than 120 compounds considered to be of toxicological concern or potentially toxic and high priority for testing. The toxicity of the vast majority of the remaining inerts is still unknown. (PSWQA and C&EN).

PESTICIDE CLASSES AND USES

Pesticides are more specifically categorized according to their use or intended target. The following discussion will focus on the most common categories of pesticides.

INSECTICIDES

Insecticides may be used in a number of different ways. They may be sprayed on the soil during the growth stage of a plant, sprayed directly on fruit and vegetables to protect it from pests until it is harvested and sprayed on stored crops prior to sale. In addition to agriculture, insecticides are also used in nurseries, landscaping, yard maintenance, homes and other structures for a wide variety of uses and on animals for uses such as flea and tick control. There are three important groups of insecticides; organochlorines, organophosphates, and carbamates.

Organochlorines, also called chlorinated hydrocarbons, were among the early synthetic organic insecticides. Examples of organochlorines include DDT, endrin, chlordane, aldrin, dieldrin, methoxychlor, and mirex. The solubility of organochlorines in water is low and they have a strong tendency to adsorb to soil. Because of these characteristics, some organochlorines have persisted in the environment and have resulted in harm to certain wildlife species, particularly raptors. The registration of most organochlorine compounds have been suspended, canceled, or restricted by the EPA.

Organophosphates (OPs) are generally less persistent than organochlorines but are often considered more toxic because of their direct and immediate effect on the central nervous system (CNS). Many OPs are restricted in use due to their high mammalian toxicity. Disulfoton (Di-syston) is an example of an OP that is restricted in Washington state. It is a granular soil insecticide registered for use in potatoes, crucifers (broccoli, cabbage, and cauliflower), ornamentals, and some nursery stock for systemic control of aphids in western Washington. Chlorpyrifos (Lorsban) is used prior to planting several vegetable crops to control various species of root maggots. It is also used as a post-plant soil drench treatment for maggot control in vegetables. Dursban, another product with the same active ingredient, is widely used to control soil insect pests of turf and ornamentals as well as important structural pests. It is also used as a larvacide for mosquito control. Other examples of OPs include mevinphos, malathion, methyl parathion, diazinon, disulfoton and phorate.

Carbamates are similar to OPs in that most of them are not highly persistent and most are soluble in water. They act on the enzymes of the CNS by inhibiting a specific enzyme activity (known as cholinesterase inhibition). Three important members of the carbamate group are carbaryl, carbofuran and aldicarb. Two of these, carbofuran (Furadan) and aldicarb (Temik), are Washington state restricted use pesticides under WAC 16-228-164 for protection of groundwater. Furadan which had been detected in early testing of groundwater in western Washington, has been the standard for control of root weevil larvae in strawberries for several years. Unfortunately, there are no alternative chemicals for this specific purpose. Furadan was also registered for weevil control in raspberries but this use was discontinued by the manufacturer due to concerns regarding contamination of groundwater. Aldicarb which was the standard systemic insecticide in commercial and seed

potatoes from 1974 through spring of 1990, was temporarily withdrawn by the EPA for this use. It is still registered for non-food uses such as field grown ornamental and nursery stock, bulbs, and holly in western Washington.

Pyrethroids include both natural products and the newer family of synthetic derivatives (e.g., permethrin, cypermethrin, and fenvalerate). They are usually degraded quickly in soil and have presented no leaching threat (CAST, 1985).

Botanical Compounds are naturally derived organic insecticides in contrast to the synthetic organic compounds discussed above. They are derived from plant material and are relatively unstable and short-lived. With the exception of nicotine, these insecticides have low mammalian toxicity. Examples of botanical compounds include rotenone, nicotine, and pyrethrin. (Pimentel, et al, 1981)

FUNGICIDES

Fungicides are widely used to protect agricultural crops, ornamental plantings and turf management from fungal pathogens. They are also used to treat the seeds of nearly all commercial crops, although the total amount used in this latter category is small. Carboxin (Vitavax) is an example of a fungicide used for seed treatment.

Three classes of fungicides have been established based on their structure: dithiocarbamates, nitrogen containing compounds, and hexachlorobenzene (Landis).

The dithiocarbamates are usually separated into two groups, the dialkyldithiocarbamates and the monoalkyldithiocarbamates. Of the two groups, the monoalkyldithiocarbamates are of the greater economic importance. Fungicides in this group include, metham, nabam, zineb, maneb and mancozeb. (Pimentel, 1981).

Captan and related fungicides are examples of nitrogen containing compounds. Captan, folpet, and captafol are broad spectrum fungicides used as surface protectants on many crops. Analizine is another example of a nitrogen containing compound. It too is a broad spectrum surface protectant and is used mainly for control of turf and vegetable disease. (Pimentel, 1981).

HERBICIDES

Herbicides are widely used in agriculture, turf management, forest management, landscape management and utility, rail and road right-of-ways to kill or inhibit the growth of weeds or unwanted vegetation. The characteristics of water solubility and persistence which make certain herbicides effective soil treatments also contribute to their potential for leaching to ground water. Herbicides are also used extensively in aquatic weed control programs which require a permit from the Washington State Department of Ecology under WAC 173-200. In addition to requirements placed on the permit from the Department of Ecology, pesticides used to control pests in or on water are restricted use pesticides under WAC 16-228-166.

Phenoxy acids are one class of herbicide. They were introduced in about 1944 and still represent an important group of foliar-applied herbicides. They are especially used for

broadleaf weed control. An example of this class of herbicides is 2,4-D which is commonly used in turf and forest management. Washington state applicators should review WAC 16-228-162 for restrictions placed on application of phenoxy herbicides.

Another class of herbicides, *benzoic acids*, usually have a somewhat greater tendency to leach in soils. Although excessive migration of dicamba has led to injury to deep-rooted plants, it has not yet been linked to groundwater pollution (CAST).

The herbicide glyphosate (Roundup) is an *aliphatic acid* and is widely used as a broad spectrum post-emergence herbicide for control of most perennial weeds in noncrop areas. It has a low toxicity to fish and wildlife.

The *phenols*, such as dinoseb, are weak acids. As with phenoxy and benzoic acids, they can be formulated as salts (with increased water solubility) or esters (with diminished solubility).

Atrazine, which has been detected in shallow groundwater wells, is representative of the *triazine* herbicides. These herbicides are of low to moderate water solubility and, in most cases, very low toxicity. Regardless of their adsorptivity to soil particles and tendency to resist leaching, several triazine herbicides are restricted under WAC 16-228-164 for ground water protection. Among them are simazine, atrazine, metribuzin, prometon (Pramitol), and cyanazine. The triazines are primarily used for selective pre-emergence and early post-emergence control of seedling grasses and broadleaved weeds in many situations in western Washington. Special uses for simazine include control of algae and submerged weeds in lakes and ponds that meet certain criteria. Prometon, which can persist in soil for several years (Linscott), is used exclusively for non-selective vegetation control in noncroplands and is an herbicide commonly used by homeowners. It has been detected at very low levels in groundwater in western Washington. It is important to consider soil type before selecting from triazine herbicides in order to avoid crop damage and/or increased leaching potential.

Amides are selective herbicides, typically with moderate solubility. Alachlor is an example of this class of herbicides along with napropamide, metolachlor, and pronamide. In general, these herbicides are readily leached in sandy soils and moderately leached in loam or clay soils. Napropamide (Devrinol) resists leaching. In general, the soil persistence of this group of herbicides is relatively short, 1 to 3 months, and they are essentially non-toxic to mammals (Anderson). They are widely used in western Washington primarily as pre-emergence herbicides in small fruits, Christmas trees, established nursery stock bulbs, and certain vegetable plantings as well as other situations. Both alachlor (Lasso) and metolachlor (Dual) are restricted use herbicides for groundwater protection in Washington state.

Phenylureas, chemically similar to the amides, have a wide range of water solubilities but have not been found in groundwater (CAST). Diuron (Karmex, Krovar), the most important commercial phenylurea, is only slightly mobile in water. In spite of this, its use is restricted in Washington state for groundwater protection. It is used as a selective pre-emergence herbicide in caneberries, blueberries and some bulb crops in western Washington. Linuron is another example, which is used in carrot seed crops and certain vegetable crops in western Washington. It is not recommended for use on sandy or low organic matter soils (PNW Weed Control Handbook).

Dinitroanilines are another major herbicide. Examples of this herbicide include trifluralin (Treflan) and oryzalin (Surflan), both of which are commonly used in western Washington. This class of herbicides are characteristic of low water solubility and high soil adsorption. These characteristics imply low downward movement of the herbicide, therefore, would suggest a low potential for leaching to ground water. Short-range vapor phase movement is important for the effectiveness of many dinitroanilines, and prompt incorporation into the soil is usually practiced to avoid excessive volatilization losses.

Uracils are another class of herbicides. An example of this class is bromacil which is used on non-cropland as a broad spectrum weed sterilant. It is moderately soluble, persistent, and mobile, and has been reported in groundwater. Bromacil is a restricted use pesticide in Washington state under WAC 16-228-164. Terbacil (Sinbar) is registered for use in small fruits (raspberries, blueberries, strawberries) in western Washington. It is generally not recommended on sandy soils or soils low in organic matter in these crops. The uracil herbicides are not readily adsorbed to soil (Anderson). This characteristic would present a greater risk to ground water as a result of potential leaching through soil.

Bipyridyliums, such as paraquat and diquat, are highly soluble and persistent but nonmobile because they are strongly adsorbed by soil clay. (CAST) They are broad spectrum foliar applied contact herbicides which are fast acting in the presence of sunlight. Diquat is used primarily to control submerged and floating weeds in certain aquatic settings, but also as a contact herbicide in general maintenance around ornamental plantings. Paraquat is used for weed control in several vegetable and bulb crops prior to crop emergence, and as a directed contact herbicide in established small fruit, Christmas tree, and field grown nursery stock plantings. Relative to most herbicides, paraquat is high in toxicity (LD_{50} : 157 mg/kg) and special precautions are required in its use.

NEMATOCIDES

Of the relatively small number of nematicides, at least four have, under certain circumstances, leached to groundwater. They include the carbamates aldicarb and oxamyl, which are restricted use pesticides in Washington under WAC 16-228-164 for protection of groundwater; and the halogenated aliphatics EDB and DBCP which are no longer in use. Soil fumigant nematicides which are available include 1,3-Dichloropropene (Telone), methyl bromide, and metam (Vapam). All are restricted use pesticides and Telone is restricted within Washington state for groundwater protection. It is available for pre-plant application for potatoes, turf, small fruits, and field grown nursery and ornamental plantings. These three fumigants are used only as preplant treatments. Their selection, and rate of application varies considerably with each situation depending primarily on pest complex and soil conditions. Most fumigant nematicides are applied in the late summer or fall when soil temperature is high and moisture is moderate. Timing of fumigation can be critical to success of control.

Non-fumigant nematicides include aldicarb, carbofuran, oxamyl (Vydate), phenamiphos (Nemacur), and ethoprop (Mocap). Nemacur is used in western Washington as a band application in established raspberry plantings and at time of planting for iris and narcissus bulbs. Ethoprop is occasionally used prior to planting commercial potatoes in parts of western Washington (Hawkins) and as a spring pre-plant in seed potatoes in Whatcom county. Downward movement via water is more likely with carbofuran and aldicarb

compared to ethoprop which is usually restricted to the zone of soil incorporation. All of these non-fumigant nematicides are highly toxic.

RODENTICIDES

In addition to damage to crops, rodents can cause damage to buildings and other structures as well as acting as carriers of diseases. Rodenticides are commonly used in the control of this pest. There are basically two types of rodenticide poisons: 1) single dose rodenticides and 2) multiple dose rodenticides. Rodenticides are usually offered in bait formulations.

Single dose rodenticides act quickly after feeding due to the high acute toxicity of the chemicals used for rodent control. As a result of the toxic nature of many of these chemicals, the possibility of secondary poisoning exists with their use. For example, a cat or bird feeding on a poisoned mouse may also adversely affect that animal.

Multiple dose rodenticides, which are generally anti-coagulants, require a number of days of feeding before death occurs. Anticoagulants reduce the clotting ability of the target organisms blood resulting in death from hemorrhages. Anticoagulants are generally safer than the single dose rodenticides.

BIOCIDES

Biocides include categories of pesticides not previously mentioned which may be formulated for very specific purposes to act on a narrow group of target organisms. An example of this is Avitrol which is specifically designed to control birds that are considered pests (PSWQA). Biocides are also broad-spectrum pesticides used to control nematodes, insects, soil-borne diseases and weed seeds. An example of a general biocide is methyl bromide. General biocides are most commonly used as pre-plant soil fumigants. Soil fumigants are discussed in greater detail under the section of this chapter addressing nematicides.

GROWTH REGULATORS

Growth regulators are used for both insect and weed control. They act by inhibiting or stimulating growth causing a disruption in their normal development. For example, by mimicking the action of hormones normally found in insects, growth regulators interrupt normal development causing the insect to die before becoming a reproducing adult. Growth regulators as a means of pest management are discussed in the IPM chapters of this manual in greater detail.

DISINFECTANTS

Disinfectants are commonly used against plant pathogenic bacteria, fungi, and viruses. They are relatively safe to use and are generally readily available. The three most useful disinfectants have been chloro- and phenyl- phenols, quaternary ammonium compounds and hypochlorite. The most widely used disinfectants are the ammonium compounds and chlorine bleach. (Pimentel, et.al., 1981)

In recent years, pesticides have been developed under tougher standards and improved safety testing. Some of these new generation pesticides are effective at very low concentrations (ounces per acre rather than pounds per acre) and show few indications of causing health problems. Problems may still exist however, with regard to impacts on wildlife and other nontarget species. In addition, the new generation pesticides are also more expensive which has led chemical companies to develop relatively few of them. (Webber).

PROCESSES AFFECTING PESTICIDE FATE

Pesticide fate is simply what happens to a pesticide once it is applied. As we have seen through earlier discussions, pesticides may be transported to both target and nontarget areas through a number of different mechanisms. Pesticides may effectively serve their intended purpose or they may leach to ground water or enter surface water through runoff. How much meets each of these fates depends on a number of factors including:

- management practices such as IPM (refer to Chapters Two and Three),
- pesticide properties,
- properties of the application site,
- other environmental factors, and
- pesticide application technique and timing.

PESTICIDE PROPERTIES

The properties of a pesticide are what make the pesticide effective in managing pests. However at the same time, properties are also important in determining the potential for pesticides to reach ground and surface water. With respect to potential impacts to ground and surface water, the most important properties to consider are: 1) persistence and degradation rate; 2) adsorptivity; 3) solubility; and 4) volatilization.

PERSISTENCE AND DEGRADATION RATE

The chemical structure of the pesticide determines its persistence and stability. The rate of breakdown decreases as the complexity of the molecular structure of the pesticide increases. Generally pesticides which have a benzene ring structure as part of their molecular structure are much more difficult to break down than chain structures. Also chain structures with halogen atoms (chlorine, bromine, fluorine) are more difficult to breakdown than structures with hydrogen atoms.

The degradation rate is the time it takes for a pesticide to breakdown into another chemical. Methods of degradation include reactions involving bacteria and fungi (microorganisms) in the soil (microbial degradation), reactions with water (hydrolysis), and reactions with sunlight (photodegradation).

Microbial decomposition is the primary means of breaking down pesticides by fungi, bacteria, and other microorganisms which use the pesticide as a food source. Most microbial decomposition occurs in the soil. The rate at which it occurs varies with the chemical structure of the pesticide and the conditions of the soil. The soil conditions

include the amount of pesticide present, the availability or absence of oxygen, temperature, water content, pH, prior use of pesticides, and supply of nutrients.

Chemical degradation is the breakdown of a pesticide by a process which does not involve living organisms. The rate at which the chemical reactions occur is influenced by the adsorption of the pesticide to the soil, the pH of the soil, soil temperature and moisture content. One of the most common chemical degradation reactions is hydrolysis which is the breakdown process where the pesticide reacts with water.

Photodegradation breaks down pesticides through the action of sunlight. The stability of pesticides applied to foliage, the soil surface, or structures varies when exposed to natural light. Factors influencing pesticide photodegradation include the intensity of the sunlight, properties of the application site, the application method, and properties of the pesticide.

When selecting pesticides, the soil half-life of a pesticide should be considered. The half-life measures the length of time it takes for half of the pesticide to break down after application. Half-lives greater than about three weeks indicate soil persistence sufficient to allow a high potential for leaching (EPA).

ADSORPTIVITY

Adsorption is the retention of pesticides by soil. Retention of pesticides by soil particles may decrease the concentration of pesticides in solution and thus decrease its availability for downward movement to ground water. The chemical characteristics of pesticides generally associated with greater adsorption include those with 1) a high molecular weight, 2) a tendency to form positively charged pesticidal ions (cations) in water, and 3) the presence of chemical groups that increase the affinity of the pesticide molecules for soil surfaces. The tendency of a pesticide to be adsorbed to soil is expressed by the pesticide's adsorption coefficient (K_{oc}). High K_{oc} values indicate a propensity for the chemical to be adsorbed to soil particles rather than remain in the soil solution. Adsorption coefficients less than 500 indicate a considerable potential for pesticide loss through leaching. (van Es, et al).

Adsorptivity is directly influenced by soil properties. The soil property of greatest importance with regard to adsorption of pesticides is the organic matter content. The greater the organic matter content, the greater the adsorption. Generally, in western Washington the areas with the highest organic matter are in shallow basins and depressions found in the low-lying areas along the major river systems. To some extent, the organic matter content of the soil can also be increased through various farming techniques.

SOLUBILITY

Solubility is the tendency of the pesticide to dissolve in water. This property is important in determining pesticide movement and its potential for leaching into ground water. Pesticides have a wide range of solubilities. Generally, the greater the solubility in water and the lower the adsorption or retention of the pesticide by the soil, the greater the risk for leaching. The greater the risk for leaching, the greater the chance for groundwater contamination. Pesticides with solubilities below the threshold value of 30 mg/L are considered to have relatively low potentials for leaching. Pesticides with solubility values higher than 30 mg/L may have a high leaching potential if the degradation rate and the soil adsorption are low (van Es, et al.; U.S. EPA).

Leaching potential is also increased when persistent pesticides that are highly soluble and have high adsorption coefficients are applied on permeable soil. In the upland areas of western Washington, the soils are derived from glacial drift (generally, the Everett Soil Series) and consist mainly of deposits of sands and gravels with occasional beds of silty clay. The subsurface soils in these areas are also sandy with a considerable amount of small gravel (Puget Sound Task Force and USDA). Given these conditions, the natural drainage would be excessive indicating a potential for leaching of a highly water soluble pesticide.

VOLATILIZATION

Volatilization occurs when a solid or liquid changes into a gas. Volatilization of pesticides increases with higher air temperature and air movement, higher temperature at the treated surface, low relative humidity, and when spray droplets are small. Pesticides also volatilize more readily from coarse textured soils and from medium to fine textured soils with high moisture content. (Ramsay, et al., 1990).

Application of a volatile pesticide should be avoided when conditions favor volatilization. This includes days that may be very hot and dry or it may be when the soils are wet. The chemical composition of the pesticide is an important factor in determining its potential for volatilization. The vapor pressure rating of the pesticide may help indicate the volatility of the material. The higher the vapor pressure, the more volatile the pesticide.

Labels on volatile pesticides may suggest incorporating the pesticide into the soil by tillage or irrigation during or shortly after application. This reduces volatilization by reducing the amount of exposed pesticide on the surface of the soil. (Brown and Hock). Substances used as fumigants must be relatively volatile in order for them to move in effective concentrations as gases through the material being fumigated. To prevent rapid loss to the atmosphere, the soil may be covered by plastic sheeting for a day or more to permit the fumigant to diffuse throughout the soil. When the sheeting is removed, the residual is gradually lost to the atmosphere where it is more susceptible to decomposition by sunlight. The total amount of pesticide that has the potential for reaching groundwater is reduced by the amount lost to the atmosphere. This is not to suggest however that highly volatile materials do not pose a threat to groundwater. EDB, which was found in ground water in Whatcom county, is a highly volatile soil fumigant.

Volatile pesticides can also contaminate surface water when airborne chemical vapors are transported from a treated area to another location where rainfall deposits them on land surfaces, lakes, streams, and vegetation. Redeposition of volatile pesticides to surface water has been confirmed in a study undertaken by the USGS in the Midwest and Northeast.

MODIFICATION OF PESTICIDE PROPERTIES

FORMULATION

Most pesticides are not applied to target areas as the active ingredient, but rather in a formulation. The formulation in which a pesticide is applied can affect leaching and other behavior in the environment. Formulations can also maximize or minimize application errors and pollution potential. For example, granular formulations may be more difficult to calibrate than other formulations thus leading to application errors.

Among the most common formulations for herbicides and insecticides are concentrated emulsions, dry flowables, and wettable powders. Other formulations include dusts, granules, liquid concentrates, soluble powders and aqueous solutions. Pesticide formulations vary in their cost, the application equipment and method required, and the potential risk to the water resources. When appropriate, pesticide formulation and application method should be a consideration when selecting pesticides.

ADJUVANTS

An adjuvant is a chemical that is added to a pesticide formulation or mixture to improve its performance or safety. In Washington state, adjuvants are considered pesticides and are defined as such under Washington pesticide laws (Ramsay, et.al.).

Many adjuvants include a surfactant which is a substance that alters the dispersing, spreading, and/or wetting properties of spray droplets. A spray droplet must wet the treated surface and spread uniformly over the treated area to provide maximum pest control. The surfactant serves the purpose of reducing the surface tension of spray droplets. Applications to plants with waxy or hairy leaves often require the inclusion of a surfactant to the spray mixture. Wetting agents and spreaders are the adjuvants most often used by pesticide applicators. Stickers, penetrants, and safeners are other adjuvants that influence the absorption, adherence or safety of a pesticide mixture on a treated surface. Buffers, compatibility agents, emulsifiers, and anti-foaming agents affect the mixing, handling, and longevity of a pesticide mixture. Foaming agents, drift retardants, and thickeners reduce drift during application. (Ramsay, et.al.).

INTERACTIONS

Sometimes individual chemicals are not toxic by themselves, but may become toxic when combined with other chemicals, minerals or trace metals. This is known as synergism and complicates scientific decision-making. Most research conducted on pesticides is performed on the active ingredient alone and does not take into account reactions that may occur when active ingredients are mixed in various formulations.

CHARACTERISTICS OF APPLICATION SITES

As previously mentioned, the characteristics of the application site are a factor in determining pesticide fate. The physical texture, mineral and chemistry of soils and other geologic materials affect the mobility of water and soluble pesticides. In addition, the topography of the application site and its proximity to surface water are important considerations as well.

Geological formations underlying the lands on which pesticides are applied can affect the potential for ground water contamination. Rock formations that are impermeable to water, prevent recharge and may protect an underlying aquifer. On the other hand, some formations contain large fractures, which may cause channeling of contaminated water to deeper aquifers (van Es, et al.). For example, shale offers good protection because it is almost impermeable and sandstone provides an intermediate level of protection. Fractured limestone and dolomite which are more common in other parts of the country, usually do not protect ground water because they have open cracks that are interconnected.

When considering the application site, the depth to the bedrock should also be considered. The depth to bedrock indicates the thickness of soil and surficial deposits in an area. This information is used to determine the relative importance of other resource factors. For example, where the bedrock surface is deep and the water table occurs above the bedrock the type of rock present is considered less important than when the depth to bedrock is shallow. When the depth to bedrock is shallow, the rock is more likely to influence a contaminant's ability to reach the ground water assuming the ground water source is a confined aquifer.

Soil characteristics and surficial deposits are considered to be the most important factors in determining the susceptibility of an area to groundwater contamination from pesticide application. Soil, which is the unconsolidated material occurring from the land surface to five feet below the land surface (Schmidt and Sturgul), is the first material through which water and accompanying contaminants seep to reach groundwater. Surficial deposits are geologic materials lying between the soil and top of the bedrock. Water contained in the space above the impermeable bedrock is considered an unconfined aquifer as defined in Chapter One. Shallow wells often draw water from this ground water source. Areas with sand and gravel are considered more susceptible to ground water contamination; areas with silt and clay are considered less susceptible.

Soils change in character vertically as well as laterally. As a result water can flow rapidly through some soil layers and geologic materials but slowly or not at all through other adjacent or enclosing layers. Once in groundwater, contaminants can spread in ways that are not predictable from the land's surface topography and drainage patterns. This means that areas with soils and other materials that tend to restrict downward leaching may still experience contaminated well-water because of lateral groundwater movement of contaminants from another part of the aquifer.

Soil characteristics that are important to consider prior to pesticide application are texture (amount of sand, silt, and clay), organic matter content, permeability, and water-holding capacity. Sandy soils are coarse and porous and therefore, permit rapid movement of water. Because of their small surface area, sandy soils have low adsorption and do not bind significantly with pesticides. Clay soils are finer-textured and therefore have greater surface area and more adsorptivity. They bind with pesticides better and limit pesticide movement to a greater degree than sandy soils. Coarse-textured soils generally have high potentials for leaching of pesticides to ground water but low potentials for surface loss to streams and lakes. Fine-textured soils such as clays and clay loams generally have low infiltration capacities, so surface runoff is relatively high compared to percolation. Soils with a high content of organic matter have the greatest potential for pesticide adsorption.

In western Washington, soil characteristics vary considerably. For example, large sections of Whatcom county consist of a compact mass of silt, clay and fine sand with a small amount of gravel with a silty texture. The subsoil in these areas is relatively impervious with poor drainage. Other sections of Whatcom county such as those in the level flood plain areas of the Nooksack River have soils that are sand and gravel with a uniformly sandy or gravelly subsoil. The natural drainage in these areas is usually excessive which indicates permeable soils. (Puget Sound Task Force and USDA). With the geologic conditions present in this area there is an increased risk potential for leaching of highly soluble pesticides to groundwater.

A similar situation is seen in Skagit county where silty textured soils are found in the alluvial flats and deltas near the mouth of the Skagit River. The silty soils found in these areas have relatively poor natural drainage. However, in the upland areas soil maps indicate areas where gravelly, sandy soils exist that have good natural drainage. (Puget Sound Task Force and USDA).

Soil surveys have been completed for each of the counties in western Washington and is available through the local Soil Conservation Service or the county Cooperative Extension Office. Matrices identifying the potential for soil leaching and runoff of various pesticides have also been developed by the Soil Conservation Service and WSU. Pesticide applicators are advised to check with one of these agencies for assistance in determining soil conditions at specific application sites.

Topography, refers to the shape and slope variability of the application site and is also a factor in determining pesticide fate. The topography helps determine the likelihood that a pesticide will runoff the site or remain on the surface in one area long enough to infiltrate (Aller, et al.). In areas where the topography is hilly or steeply sloped as is the case with the majority of commercial forestry land in western Washington, the potential for runoff is much greater than in low-lying areas where most of western Washington's agricultural land is found.

Proximity of surface water to the application site is an important consideration in determining pesticide fate as well. This is particularly the case where the site is sloped. In these situations, the risk of pesticides being transported to streams, lakes, and Puget Sound will increase as a result of runoff that may occur. Frequently the surface water source that transports pesticide containing runoff is as innocuous as a ditch that eventually finds its way to a larger body of water.

OTHER ENVIRONMENTAL FACTORS INFLUENCING PESTICIDE FATE

CLIMATE

Temperature inversions, wind and precipitation are all factors which influence pesticide fate. Temperature inversions occur when air at ground-level is cooler than the air above it. When this happens there is little or no vertical air movement. The most likely time for this event to develop is during the early evening, however, inversions may last into the night and through mid-morning. Studies have shown that drift residues from aerially and ground application of applied pesticides occur during periods when temperature inversions are being experienced (MacCollom, et al.).

Wind conditions during pesticide application may also result in pesticide drift. The extent of drift will depend on the application method, the pesticide being used, and wind velocity. Of all these factors, wind velocity is the most important in affecting drift losses. Depending on wind velocity, drift loss ranging from zero to 50 percent may occur (North Carolina Agricultural Extension Service). Restricting applications to windless days or, if no inversion is being experienced, to periods of the day when wind velocity is minimized (early morning, early evening or night) will reduce drift. As previously discussed, pesticide drift can result in deposition of pesticides to surface water sources.

Heavy precipitation prior to application will result in an increased potential for pesticide loss to ground or surface water due to saturated soil conditions. Whether the loss occurs to ground or surface water will depend on the type of soil present at the site. For example in sandy soils, heavy precipitation will lead to increased filtration rates and thus will allow for leaching of pesticides to groundwater. Clay soils, on the other hand, will result in increased pesticide loss through surface runoff due to the more impermeable nature of the soil. The solubility of the pesticide in water will also determine the fate of the pesticide in periods of heavy rainfall and saturated soil conditions. In western Washington, the combination of low soil pH, low soil temperature and high rainfall increase the chances for ground water contamination. This is due to the low level of microbial action that occurs under these soil conditions and the shallow depths to ground water experienced in much of the area.

APPLICATION TECHNIQUES

The careful selection and proper operation and maintenance of pesticide application equipment is an important step in the protection of water resources. It is important to follow all instructions in the manuals concerning calibration, pump pressure, and nozzles for field equipment. Preliminary calibration and checking of sprayers should be done with plain water. Check for leaks, clogged nozzles and other malfunctions. Drain and rinse spraying equipment after use.

There is a significant amount of literature available on equipment selection, types of equipment, and the maintenance and operation of each type of equipment. Pesticide applicators are advised to contact their local Extension Agent for advice and written material that will specifically meet their individual needs.

SELECTION AND TYPES

In general, equipment which optimizes drop size can greatly reduce drift losses. A spray boom with the nozzles directed downward, relatively close to the crops and ground and under relatively calm conditions, will place 90 percent or more of the spray in the target area (Pimentel, et al., 1991). However, if the spray is a mist of fine droplets (about 50 μm) and there is a 10 mph wind, then only 50-70 percent might reach the target. Covering the spray boom with a plastic shroud can decrease drift 85 percent (Pimentel, et al., 1991).

Boom injection sprayers are an alternative to mixing and loading pesticides at a single site (Schmidt and Sturgul). Rather than mixing pesticide and water prior to application, a separate tank of water and a container of pesticide concentrate are taken to the field. As water is pumped into the boom of the sprayer, the pesticide is injected, becoming diluted just prior to reaching the nozzles. Boom injection sprayers also eliminate the problems of excess pesticide spray mix or disposal of spray tank rinsate that may be encountered when operating conventional sprayers.

Electrostatic sprayers have recently added a method for using small (30 to 50 μm) easily dispersible drop sizes while minimizing drift. A negative charge is added to the spray droplet by a small electrode charging cap embedded near each nozzle tip. The negatively charged drop is attracted to the positively grounded target plant. A variation of the electrostatic sprayer is the recirculating sprayer in which droplets which are not deposited

on plant or soil surfaces are electrostatically recaptured by the sprayer. (North Carolina Agricultural Extension Service).

Ceramic spray tips are the most durable tip for highly abrasive chemicals such as atrazine and dacthal, as well as many fungicides and acid-based fertilizers. Such chemicals have the power to corrode and wear brass, plastic and stainless steel tips very rapidly leading to loss of calibration and over application.

APPLICATION TECHNIQUES

The three basic techniques for pesticide application are ground-based, chemigation and aerial.

GROUND-BASED

Ground-based application techniques generally involve application of pesticides with a tractor or spray rig which travels over the surface of the treated area. There are several ground-based methods for treating areas with pesticides.

Broadcast spraying involves uniform pesticide application over the entire field. It can be made either pre- or post-emergence. An alternative to this is banding which involves application of chemicals in a narrow strip beside or in the crop furrow. Treating only a band over or along the crop row rather than treating the whole field will reduce the total amount of pesticide applied and thus reduce the amount that might potentially contaminate surface and ground water. Band treatment can also be made either pre- or post-emergence.

Furrow treatment is another technique which may reduce pesticide use. In this treatment, the pesticide is placed in a strip in the soil directly over the seed at planting time. It was found that furrow-band applications of carbofuran reduce losses in surface runoff by about 50 percent compared to surface broadcasting (Heatwole, et al.).

When setting up the sprayer for banding, it is important to remember to calculate chemical mixing rates on the number of acres to be treated, rather than the total field acres.

Wicks, rollers and other wiping devices offer the best available method for effectively eliminating application of herbicides onto the soil. The rope-wick applicator has been used in soybeans with a reduced herbicide use of approximately 90 percent, and increase in soybean yields of 51 percent over conventional treatments (Pimentel, et al., 1991). However, these application methods require sufficient weed growth to provide contact of foliage and stems with the topical application. Due to variability in weed growth, several trips around the field may be necessary for control. (OTA).

CHEMIGATION

Chemigation is the method of applying pesticides through irrigation systems. Chemigation techniques have been shown to promote leaching of chemicals under certain conditions (OTA). Because heavy irrigation increases the potential for movement of the pesticide through the soil to the groundwater, considerable care needs to be taken to protect water resources and prevent ground water contamination.

Chemigation can lead to ground water contamination in a couple of ways. One is when

a pesticide treatment may be needed but the fields are already saturated from either a heavy rain or irrigation. Chemigation at this point may lead to leaching of water and soluble pesticides already present in the soil profile. A second way is through irrigation wells. Back-siphoning due to pressure loss could lead to significant contamination. Pesticides should be applied through irrigation systems only as directed on the pesticide label. The USDA has very strict regulations on chemigation equipment to avoid contamination of water resources.

AERIAL

In western Washington aerial application of pesticides is most common in forest management but occurs frequently in crop management. Aerial application can lead to water contamination through spray drift. Spray drift from aerial application of pesticides is about five times greater than from ground applications for row crops (Pimentel, et al., 1991). Aerial application to forests may result in greater loss than from application to field crops, because of the height from which the pesticides are sprayed. Drift from aerial application may adversely affect the aquatic environment of streams and lakes.

The most effective single management practice for reducing pesticide field losses may be switching from aerial to ground application wherever possible. Where a conversion to ground application equipment is not practical, there are a variety of methods for increasing the efficiency of aerial application.

- 1) Use the largest droplet size that still gives sufficient penetration and coverage of the target. Follow label recommendations on droplet size since it can vary with the intended target.
- 2) Assure the aircraft is providing an even distribution of pesticide to the target by positioning nozzles to allow for wind shear. Booms should be positioned behind the wing's trailing edge and nozzles positioned so that the spray swath is straight back. (ICI).
- 3) Release pesticides as low above the target as possible. An application that is made from too high can increase drift potential, but an application made from too low an altitude can alter the spray pattern. Generally, application height should range from one-quarter to one-half of the wing span which would be approximately eight to twelve feet. (ICI)
- 4) Prior to application, complete an on-ground survey of all water bodies including ditches and creeks. When application is made, avoid all identified water bodies by a safety margin.
- 5) Restrict application to days when heavy precipitation is not forecasted and wind conditions are mild. Drift is more easily controlled if wind speeds are a minimum of three mph but less than ten mph. Generally the lower wind speeds are required when applying volatile or acutely toxic materials, or if the application is being made near a body of water or if nearby fields have sensitive crops. (ICI)

CHAPTER FIVE

GENERAL SAFETY PRECAUTIONS

APPLICATOR SAFETY

Pesticides are approved by the EPA for specific uses. The pesticide's label, which must be registered with the EPA, explains where and how the pesticide may be used. The symbol on a label also indicates how toxic the product is to humans. The skull and crossbones is used on labels of highly toxic pesticides along with the signal word DANGER or the word POISON; ingestion of only a few drops of this material may be lethal. The signal word WARNING indicates that the material is moderately toxic. Low toxicity materials carry the signal word CAUTION. A number of pesticides are registered and labeled as "restricted use" pesticides and may only be purchased and used by certified applicators or individuals under the direct supervision of a certified applicator.

A Material Safety Data Sheet (MSDS) is available from the pesticide manufacturer for each registered pesticide. The MSDS contains important information which may not be included on the product label. It provides information on: 1) product ingredients; 2) chemical characteristics of the active ingredient; 3) fire and explosion hazard information; 4) health data including effects of overexposure and first aid procedures; 5) protective equipment for handlers such as dust masks, goggles, or respirators; 6) environmental data including waste and container disposal methods, and 7) requirements for shipping. Pesticide applicators must keep MSDSs for all products which they use in a designated, easily accessible spot known to coworkers or family members.

In addition to the precautions listed on the pesticide label, other considerations with regard to protective clothing should be taken when working with pesticide concentrates. Additional precautions include using a water-proof coat or apron and unlined rubber or neoprene boots. Gloves should also be unlined, made of chemically impervious material

and long enough to cover wrists. Pantlegs should be kept outside of the boots and shirt sleeves outside of gloves to keep pesticides from getting in. When using respirators always follow directions completely for proper use, care and when to change cartridges or canisters.

Applicators should wear clean clothes daily. If the clothes become wet with spray, the applicator should change them immediately and take a soapy shower or bath. Clothing should be discarded if a pesticide concentrate is spilled on them or if they get wet from a highly toxic spray material. Work clothing should always be washed separately from other laundry. Wash personal protective equipment thoroughly after every use. (Braun, et al.; Hock; Stone).

PERSONNEL PROCEDURES

Read and discuss the pesticide label with individuals under your supervision with regard to the hazards involved in handling and applying each pesticide used. Insist that everyone wear protective equipment as outlined above. Also, discuss first-aid procedures and how to identify the symptoms of pesticide poisoning. The Hazardous Communication Standard, which is part of OSHA's Worker Right-to Know Law, requires worker safety training. Although the OSHA regulations do not apply to operations with ten or less paid employees or operations employing only family members, a safety training program is still advisable.

PESTICIDE TRANSPORTATION

Concentrated pesticides should be transported on a steel truck bed with solid side walls and tailgate. Prior to loading the materials on the truck, sharp objects should be removed. Containers should be handled carefully to avoid punctures or rips. Also, inspect the containers for tightly closed plugs and caps. If it is necessary to stack containers, heavier containers should be on the bottom and the lighter ones on top. Never stack containers higher than the truck bed. Firmly secure containers against movement during transit and cover them with a tarp. Do not allow children, adults or animals to ride in the back of the truck when hauling chemicals. Also, never haul feed, fertilizer or food in the vehicle with chemicals.

When transporting pesticides, be prepared for a spill by equipping the truck with spill cleanup materials. At a minimum, the materials should include personal protective clothing, a shovel, plastic sheeting, absorbent material, and empty containers larger than the pesticide packaging. If possible, carry a small supply of water and soap for washing hands. Keep a list of emergency phone numbers in the truck. The list should include police, sheriff, fire department, ambulance service, poison control center, family doctor, agricultural chemicals supplier, and the Washington State Department of Emergency Services. (Ramsay, et al., 1990)

The transport of pesticides is regulated by the Washington State Department of Transportation under WAC 16-228-160. Pesticide applicators are advised to review the code to ensure compliance when transporting pesticides.

PESTICIDE STORAGE

Pesticides should always be stored according to label directions in their original containers with labels intact, legible, and plainly visible. Reduce the need for storage by purchasing only what will be used in the near future. While stored, containers should be marked with date of purchase and inspected routinely and frequently for leaks or signs of deterioration. Never store pesticides with food, feed, seed, fertilizers, veterinary supplies, or protective clothing, respirators, and other personal protective equipment. At a minimum, the floor of the storage facility should be covered with a heavy plastic to catch any spillage from stored pesticides. The storage facility should also be located at least 100 feet from, and if possible, down slope from any water source (well, ditch, stream, etc.) to prevent spilled material from moving toward the water source.

If possible, pesticides should not be stored in areas where flooding is likely. In flood prone areas, water tight dikes should be built around the storage facility. The building should also be a minimum of 50 feet from other buildings for easy access by fire trucks and other emergency vehicles.

An emergency response plan should be kept in any facility that stores or handles pesticides. The plan should list actions to take and personnel to contact in the event of a spill or other accident. An up to date listing of the pesticides used or stored in the facility should be included in the emergency response plan. Keep an extra copy of the list in a separate location from the facility in the event the list is destroyed or inaccessible.

The facility should be clearly identified with a sign which indicates that pesticides are stored inside. Ideally, a storage facility should consist of four parts; 1) the pesticide storage room; 2) the mixing room; 3) the locker room; 4) and an outside concrete pad for a washdown area. The facility should be constructed with fire-resistant building materials. Explosion-proof electrical wiring, switches and outlets may be required depending on the size, location and materials stored. The storage areas should be securely locked to prevent accidental entry by children, pets, or livestock. (Meyer and Daum).

WELL PROTECTION

A well provides direct access to groundwater. Groundwater can become contaminated if pesticides enter a well directly from the surface, through openings or beneath the pump base, or through the soil adjacent to the well. Wells should be properly capped and sealed to prevent groundwater contamination. Even with properly constructed wells, the area immediately surrounding the well should be protected from contaminants that may flow to, around, or down the outside of the well to ground water. Pesticides should be kept at least 100 feet from the well. Mixing and loading of pesticides should be done as far from wells as possible. (Ramsay, et al.; Schmidt and Sturgul). Slope the area around the wellhead to keep runoff away from the well. Properly close all abandoned wells and never dispose of waste in unused wells.

DISPOSAL OF PESTICIDE CONTAINERS

Implementing the IPM strategies discussed in earlier chapters will reduce the need for pesticide use and the subsequent need for disposal of the empty containers. When disposal of pesticide containers does become necessary, carefully follow the instructions on the label. Generally, this includes triple rinsing the containers to remove pesticide residues. The containers should be rinsed immediately after emptying and the rinsate added to the spray tank. This avoids the problem of rinsate disposal at the end of the day or the season.

Use of mini-bulk systems can also eliminate the problem of container disposal because the containers are returned to the supplier. Generally, mini-bulk containers are defined as any container of over 55 gallons but less than 400 gallons capacity; typically ranging in volume from 110 to 375 gallons. Stainless steel containers can be returned to the dealers for refilling.

RECORD KEEPING

The Washington Pesticide Application Act addresses pesticide use in the state. The Act sets up specific record keeping requirements including specifics about the application (land location, name of the applicator, etc.), the name and amount of the pesticide used, and certain environmental conditions (such as wind direction and speed). As revised in 1989, state law requires all certified applicators and all persons applying pesticides to more than one acre of agricultural land to keep records on a form established by the Washington State Department of Agriculture. Three versions of the form are set-up for various types of agricultural applications with a fourth version for commercial, residential, ornamental, and lawn applications.

Even aside from the state requirement, record-keeping is recommended because without it, growers cannot systematically apply principles such as rotating herbicides or adjusting rates for specific soils or weeds. Information compiled in record keeping such as the date of application, environmental conditions the day of the application, and amount of rainfall following application is critical in evaluating pesticide failure or crop injury. As previously mentioned, duplicate records should be kept in separate locations in the event of loss or damage.

PESTICIDE MIXING AND LOADING

Pesticide mixing and loading sites are of concern because groundwater contamination resulting from these sources normally involves multiple contaminants at significantly higher concentrations. Another problem is that commercial mixing and loading sites are often located in or near small towns which increases the risk of broader citizen exposure via nearby municipal or private wells. (Schmidt and Sturgul).

PROTECTION OF WATER SOURCE

To protect surface and ground water from pesticide contamination, install permanent concrete pads or something of equivalent material at mixing/loading facilities. When planning, renovating, or retrofitting pesticide handling and storage facilities consider future use as well as present use. With open concrete mixing/loading pads, precipitation can be a concern because of the need to dispose of potentially large volumes of pesticide contaminated precipitation. To avoid this situation, roofed mixing/loading facilities are recommended. (Kammel, et al).

Applicators which use significant amounts of pesticides should consider constructing a pit lined with clay or concrete and filled with rock and soil (Michigan State University, 1988). Mixing and loading can then be carried out over the pit so that any spill is contained and the active ingredient is broken down without the possibility of leaching to ground water. A well designed pit can also be used when washing application equipment.

When mixing and loading pesticides, measures are required to be taken to prevent against back-siphoning into the water source. When adding water to a spray mixture, keep the fill hose above the water level in the spray tank. This maintains an air break between the water supply and the spray mixture which prevents back-siphoning of the pesticide mixture into the water source. Use an anti-backflow device on the fill hose, especially when siphoning water directly from a pond or stream. Wells should be constructed with check valves to prevent back siphoning. (Ramsay, et al., 1990; Schmidt and Sturgul).

Another option would be to haul water to the field and do all pesticide mixing there. Sprayers and equipment could also be rinsed in the field to avoid concentrating residues from repeated rinsing near wells (Schmidt and Sturgul). One way to rig the sprayer with on-board water is to purchase a commercial clean water system. These packages come complete with water tank, clamps and fittings for mounting hoses and an on-off valve for easy access. You can also assemble your own clean water system using a small enclosed tank or any watertight covered bucket that can be mounted securely to the sprayer frame. (Schmidt and Sturgul).

Boom injection sprayers were briefly discussed in Chapter Four. This system is an available option that avoids the problems associated with mixing/loading operations. With this system, a separate tank of water is taken to the field with a container of pesticide concentrate. As water is pumped into the boom of the sprayer, the pesticide is injected. This closed system reduces the risk of ground water contamination from accidental spills, back-siphoning, and eliminates the need for disposal of excess pesticide spray mix or spray tank rinsate.

PESTICIDE APPLICATION EQUIPMENT OPERATION AND MAINTENANCE

OPERATION AND MAINTENANCE

Check sprayers before every application day. Make sure spray patterns are uniform across boom. Operate sprayer with water over gravel or blacktop and then watch to see how patterns dry. Heavy or light streaks mean nozzles are not applying uniformly and can result in too much or too little pesticide applied, irregular distribution, or poor pest control. A study conducted in 1986 by the University of Nebraska found that two of every three applicators (private and commercial pesticide applicators) missed their intended application rate by more than five percent, either as a result of errors in calibration or mixing, or both. Errors in application rate ranged from 40 percent under application to 60 percent over application (Schmidt and Sturgul). Pesticides that are excessively applied may result in residue carry over and crop damage and increase the potential for ground water contamination.

Unless using the same chemical for the next application, rinse and clean the sprayer after each use. The rinsing and washing of the sprayer should be done at a site constructed specifically for that purpose. Do not wash equipment near well-heads, ditches, streams, or other water sources. The rinse water from cleaning the equipment can be sprayed on cultivated fields at a rate consistent with the intended use of the chemical in the rinse water.

SUMMARY

Nationwide, an increasing amount of attention has been focused on pesticide use. This attention is coming from the general public as well as federal and state regulators. One of the primary concerns which has resulted in this increased attention has been the detection of pesticides in ground water. Although the detected levels are often below the Environmental Protection Agency's health advisory levels (HAL), there have been incidences where certain pesticides have exceeded these levels. It is because of these detections and the fact that remediation of contaminated ground water is extremely difficult that regulators have increased their attention on pesticide use.

Undoubtedly, pesticides are an important tool in pest management. However in order to ensure that pesticides continue to be readily available, efforts will need to be made by pesticide users to minimize the potential impact of pesticides on vulnerable ground water resources. The material that has been presented in this manual is an attempt to provide professional pest managers and pesticide applicators in the Puget Sound region with practical information on pest management techniques and pesticide use that will work toward those efforts.

Many pest problems can be avoided by first considering a prevention strategy which may include cultural, physical, biological, genetic or chemical tactics. This manual has emphasized Integrated Pest Management (IPM) as a strategy because it represents a rational, scientifically based approach to pest control. Accurate pest identification and regular systematic monitoring is the basis for decision making. With this approach, pests can often be treated on an as-needed basis, rather than on a prophylactic or calendar basis. Most of the economic benefit derived for IPM is due to the elimination or reduction of prophylactic pesticide use. IPM is more advanced in some situations than in others for a variety of reasons. Data gaps do exist and will likely always exist, but this should not pose constraints to adoption of the IPM decision making process, which is a thought process. Continued development and implementation of IPM will not threaten pesticide availability; it will protect pesticides as an important pest control tool.

When review of pest management options result in a strategy involving pesticide use, the decision making process for selecting the pesticide should include potential risk to water resources in addition to other factors. By considering pesticide properties in conjunction with pesticide formulation, method of application, and the physical characteristics and condition of the application site, the risk to water resources will be greatly reduced.

RESOURCE GUIDE

GROUND WATER STUDIES AND RELATED INFORMATION

Agricultural Management Practices to Minimize Ground Water Contamination

Gary Jackson, Dennis Keeney, Dave Curwen, and Bruce 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

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
225 Touhy Avenue
Park Ridge, IL 60068
(312) 399-5700

Health Advisory Summaries

U.S. Environmental Protection Agency, 1989
Office of Water

National Pesticide Survey

"Summary Results of EPA's National Survey of
Pesticides in Drinking Water Wells"
U.S. Environmental Protection Agency
Office of Water and Office of Pesticides and Toxic Substances
Fall 1990

"Pesticide Movement in Soils - Ground Water Protection"

Publication 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
P.O. Box 47600
Olympia, WA 98504-7600
April 1992

**Survey of Pesticides Used in Selected Areas
Having Vulnerable Groundwaters in Washington State**

U.S. Environmental Protection Agency
Pesticides Section, Region 10
1200 Sixth Ave.
Seattle, WA 98101
July 1987

**Washington State Agricultural
Chemicals Pilot Study, Final Report**

D. Erickson and North
Washington State Department of Ecology
Olympia, WA 98504

Washington State Water Quality Guide

“Integrateing Water Quality and Quantity into Conservation Planning”
Soil Conservation Service, USDA, 1989

Water Management References Notebook

Cooperative Extension
Washington State University, 1988

INTEGRATED PEST MANAGEMENT (IPM)

Advances in Urban Pest Management

Bennet and Owens
Van Nostrand Reinhold
115th Ave.
New York, NY

Biological Control

R. van den Bosch and P. S. Messenger
New York: Intext Educational Publishers
1973 publication

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 publication

Entomology and Pest Management

L. P. Pedigo
MacMillan Publishing Co.
866 Third Ave.
New York, NY 10022
1989 publication

Growers Weed Management Guide

H. M. Kempen
Thomson Publications
P.O. Box 9335
Fresno, CA 93791

**Integrated Pest Management
for Turfgrass and Ornamentals**

U.S. Environmental Protection Agency
Office of Pesticide Programs
Washington, D.C. 20460

Introduction to Integrated Pest Management

M. L. Flint and R. van den Bosch
Plenum Press
233 Spring St.
New York, NY 10013
1981 publication

Nursery and Landscape Weed Control Manual

R. P. Rice
Thomson Publications
P.O. Box 9335
Fresno, CA 93791
1986 publication

Plant Pathology

G. N. Agrios
Academic Press, Inc.
New York, NY 10013
1969 publication

PNW Insect Control Handbook, 1991

Cooperative Extension publication of
Oregon State University, University of Idaho,
and Washington State University

PNW Plant Disease Control Handbook, 1991

Cooperative Extension publication of Oregon State University,
University of Idaho, and Washington State University

PNW Weed Control Handbook, 1991

Cooperative Extension publication of
Oregon State University, University of Idaho, and Washington State University

Public Health Pest Control Publication MISC 0151

Carol A. Ramsay and Gary L. Thomasson
Washington State University
Cooperative Extension

Silent Spring

Rachel Carson
Fawcett World Library
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<i>EB0491</i>	<i>"Crop Protection Guide for Tree Fruits"</i>
<i>EB0669</i>	<i>"Weed Control on Rights of Way"</i>
<i>EB0856</i>	<i>"European Crane Fly: A Lawn Pest"</i>
<i>EB0965</i>	<i>"Root Weevils in Berry Crops"</i>
<i>EB1049</i>	<i>"Club Root of Cabbage and Other Crucifers"</i>
<i>EB1398</i>	<i>"Small Fruit Pests, Biology, Diagnosis, and Management"</i>
<i>EB1491</i>	<i>"Pest Control Guide for Commercial Small Fruits"</i>
<i>EB1577</i>	<i>"Anobiid Beetles in Structures"</i>
<i>EM2788</i>	<i>"Integrated Control of Insect and Mite Pests of Apple in Central Washington"</i>

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W. P. Anderson
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New York, NY
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Weed Science, Principles and Practices

F. M. Ashton and T. J. Monaco
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John Wiley and Sons, Inc.
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PESTICIDE PROPERTIES

A Glossery of Pesticide Toxicology and Related Terms

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P.O. Box 9335
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Agricultural Chemicals Series

W. T. Thomson
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P.O. Box 9335
Fresno, CA 93791

"Book 1 - Insecticides", 1989

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"Book 3 - Miscellaneous Agricultural Chemicals", 1992

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Agrochemicals, Preparation and Mode of Action

R. J. Cremlyn
John Wiley and Sons, Ltd.
Baffins Lane
Chichester, West Sussex
PO19 1UD, England
1991 Publication

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
7 Research Park
Cornell University
Ithaca, NY 14853

"Pesticide Movement in Soils - Ground Water Protection"

Publication EB1543
Washington State University - Cooperative Extension
Pullman, WA

The Pesticide Book

George Ware
W.H. Freeman and Co.
1978 publication

The Pesticide Manual, A World Compendium

Edited by C. R. Worthing and S. B. Walker

Eighth Edition, 1987

Published by The British Crop Protection Council

Toxicity and Potential Health Effects of Pesticides

File No. IVKld R4M390

W. K. Hock and C. L. Brown

Penn State University

College of Agriculture

Washington Pesticide Laws and Safety

Publication MISC 0056

“A guide to safe use and handling for applicators and dealers.”

Edited by Carol A. Ramsey and Gary L. Thomasson

Washington State University

Cooperative Extension

College of Agriculture and Home Economics

Pullman, WA

Private Applicator Pesticide Education Manual Publication MISC 0126

“A guide to safe use and handling.”

Edited by Carol A. Ramsay and Gary L. Thomasson

Washington State University

Cooperative Extension

College of Agriculture and Home Economics

Pullman, WA

PESTICIDE APPLICATION AND HANDLING

Agricultural Management Practices to Minimize Ground Water Contamination

Gary Jackson, Dennis Keeney, Dave Curwen, and Bruce 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"

Publication PNW360
Washington State University - Cooperative Extension
Pullman, WA

Designing Facilities for Pesticide and Fertilizer Containment

Publication MWPS-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, 1987
Thomson Publications
P.O. Box 9335
Fresno, CA 93791

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 MISC 0126

“A guide to safe use and handling.”

Edited by Carol A. Ramsay and Gary L. Thomasson

Washington State University

Cooperative Extension

College of Agriculture and Home Economics

Pullman, WA

“Protecting Ground Water from Pesticide Contamination”

Publication EB1644

Washington State University - Cooperative Extension

Pullman, WA

“Soil Erosion and Sediment Control Under Irrigation”

Publication EB0712

Washington State University - Cooperative Extension

Pullman, WA

Washington Pesticide Laws and Safety

Publication MISC 0056

“A guide to safe use and handling for applicators and dealers.”

Edited by Carol A. Ramsey and Gary L. Thomasson

Washington State University

Cooperative Extension

College of Agriculture and Home Economics

Pullman, WA

AGENCIES TO CONTACT FOR IPM OR PESTICIDE-RELATED 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

Non-regulatory 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.

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