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Preface

This document is a shorter version of a manual titled, *Puget Sound Pest Management Manual, A Guide for Protecting Our Water Quality,* developed under the direction of Washington State University (WSU) Cooperative Extension personnel. Craig MacConnell and a diverse advisory committee that represented various farm and other pesticide user groups, federal and state agencies, elected officials, research scientists, agribusiness, and environmental groups steered the report. The committee believed that if they explained and encouraged the adaptation of Integrated Pest Management (IPM) practices, actual pesticide usage would be reduced, which in turn would reduce the impact on groundwater from pest management practices. The public, the customer, and the government encourage and support the adaptation of IPM type approaches.

Whether you are a farmer, golf course manager, structural pest control operator, or any of several resource managers that get involved in pest control, you have probably heard about IPM. Perhaps you have formed an opinion about IPM as it relates to your particular situation. This document is an introduction to the "nuts and bolts" of IPM, so that you will understand this technology and will consider parts of IPM that suit your particular situation. Too often, presenters have described IPM as "complex and multi-disciplinary," which translates to managers as high-tech, new, and unattainable. Pest management is a dynamic process; we do not have all of the answers. The challenge is to use what we know about IPM by implementing it into practical solutions.

Following a brief overview of groundwater, this publication discusses the details and logic of IPM as a strategy to prevent groundwater contamination from pesticides.

Groundwater

Groundwater plays an important role in the lives of millions of people nationwide. In the United States, about half of the total population and 90% of the rural population depend on groundwater as their drinking water source. Generally, groundwater is a safe and reliable source of water. Increasing evidence shows that human activities affect this resource.

Many people think of groundwater as underground lakes, rivers, or streams isolated between layers of impermeable material. Although this does occur in some cases, groundwater more often exists as subsurface water filling spaces between particles of sand, soil, or rock beneath the earth's surface. When references are made to groundwater sources, people use the term aquifer to describe the saturated area. Aquifers usually are 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. At its base, another layer of materials having low permeability forms a seal. Confined aquifers are resupplied with new water (referred to as recharge) only at the point where the formation meets the surface or where it ends underground. Recharge does not come from overlying land surfaces. The natural forces recharging confined aquifers make them much less vulnerable to contamination than unconfined aquifers.

The water table is usually the top of the unconfined aquifer, and recharge comes from overlying land surfaces. Unconfined aquifers do not have an impermeable layer protecting the water source as confined aquifers do. As a result, unconfined aquifers are at a much greater risk of groundwater contamination than are confined aquifers. A significant portion of the population in western Washington obtains water either through individual wells or community wells. The source of this water most often is an unconfined aquifer.

Threats to Groundwater from Pesticides

Federal, state, and local agencies have undertaken numerous studies to determine the extent of groundwater contamination from pesticides. Most areas selected for study had relatively high groundwater vulnerability and high pesticide use. Many of the pesticides sampled are no longer in use. The U.S. Environmental Protection Agency (EPA) completed the National Pesticide Survey (NPS) in 1990. This 5-year study provides the most comprehensive look at groundwater on a nationwide level. Based on the results of the NPS, the EPA estimates that 10% of community water systems and 4% of rural domestic wells in the United States contain at least one pesticide or element of a pesticide.

Pesticides primarily enter groundwater through the soil. This movement of pesticides through the soil is known as leaching. Pesticide leaching partially depends on the chemical and physical properties of the pesticide. Adsorptivity, the ability of a pesticide to bind with soil particles, influences the leaching potential of pesticides. A pesticide that binds tightly to soil particles is less likely to leach than one that does not. Another property of pesticides that influences leaching is the solubility of the pesticide. A pesticide that dissolves in water can move with water through the soil.

Soil factors that influence leaching include soil texture, amount of organic matter, and permeability. A sandy soil, which is much more permeable than a clay soil, and that has less organic matter, has a much greater leaching potential.

Pesticides detected in the groundwater in various western Washington counties include ethylene dibromide (EDB), carbofuran, dibromochloropropane (DBCP), 1,2-dichloropropane, and prometon. Researchers found 12 of 23 pesticides they were testing for in an aquifer that originates in British Columbia, Canada, and extends south into Whatcom County, Washington.

The primary concern with groundwater contamination is clean-up. Protection of the water supply is less expensive and more feasible than cleaning up a contaminated aquifer.

National Pesticide Survey

In 1990, the EPA completed its 5-year study of pesticides in drinking water wells. During the study period, the EPA sampled approximately 1,300 community water system (CWS) wells and rural domestic wells for the presence of 101 pesticides and 25 pesticide degradates. Statistically, the NPS represents approximately 94,600 drinking water wells at 38,300 community water systems and over 10.5 million rural domestic wells throughout the United States. The study was designed to ensure that samples were taken from wells located in areas that had a wide range of levels of pesticide use and groundwater vulnerability.

The pesticides found most frequently were DCPA and atrazine. DCPA is used extensively on home lawns, golf courses, and farms to control annual grasses and broadleaf weeds. Atrazine is used for general weed control on noncropped industrial land, for selective weed control in conifer restoration and Christmas tree plantations, and for nonselective control of vegetation on fallow land.

Other pesticides detected were alachlor, bentazon, DBCP, dinoseb, ethylene thiourea, hexachlorobenzene, lindane, prometon, and simazine.

INTEGRATED PEST MANAGEMENT

Integrated pest management represents a balanced approach to controlling pests. Although most IPM research has addressed agriculture, successful programs occur 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 part of most IPM programs and will likely continue as such for quite some time. IPM is not a threat either to the pesticide industry or to 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 protect groundwater from pesticide contamination. Pesticide use is optimized under IPM, generally reducing frequency of pesticide application and, therefore, reducing groundwater contamination. IPM also represents a mental shift in our approach to pest control. An attempt is made to understand the dynamic nature of interactions among environment, pest, and host, rather than to focus exclusively on the pest.

Definition

IPM is an ecologically based pest control strategy that relies heavily on natural mortality factors, such as natural enemies and weather, and that seeks out control tactics to disrupt these factors as little as possible. Regular, systematic monitoring of pest populations and natural control factors forms the basis for deciding whether pest control action is necessary. Ideally, an IPM program blends or integrates appropriate tactics including cultural practices, natural enemies, resistant host varieties, physical methods, and pesticides to suppress a pest population to a tolerable level, based on economic or aesthetic considerations.

Reasons For IPM

Three main points support further development and use of IPM in agriculture, forestry, turf and ornamental, and urban environments.

1. *Several disadvantages are associated with a heavy or sole reliance upon pesticides,* including pest resistance to pesticides, secondary pest outbreaks, pest resurgence, nontarget effects, and environmental contamination.
2. *Due to the pesticide reregistration process* initiated in 1988, we have fewer pesticides to choose from.
3. *We also have an increased knowledge of ecological principles,* the interrelationships between organisms and their environment.

Resistance
The more often growers use a specific pesticide, the greater likelihood exists that the pest will develop resistance. Resistance is expensive primarily because it requires replacing chemicals that are no longer effective. The cost of registering pesticides has increased dramatically over the past 30 years, and this cost is passed on to the user. 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.

Secondary Pest Outbreaks
Secondary pest outbreaks can result when chemical applications inadvertently disrupt natural control agents. Organisms that previously caused no significant damage reach pest status once their natural control agents have been destroyed. Secondary outbreaks are documented with the twospotted spider mite, a secondary pest of red raspberries in western Washington. A complex of beneficial insects and mites keep this mite below a problem level. Field studies from 1987 through 1989 showed that mites reached a problem level in fields that received frequent insecticide applications. This is particularly a problem in fields that have high populations of root weevils. Weevil control requires a preharvest application of a broad-spectrum insecticide that disrupts natural enemies of the twospotted mite.

Pest Resurgence
Pest resurgence occurs when a pesticide kills both a large percentage of the pest population and its natural enemies. The absence of natural enemies permits the rapid return and population explosion of the pest.

Other Nontarget Effects
Due to the broad spectrum nature of many pesticides and the potential for drift from the application site, pesticides can affect organisms that are not the intended target. Organisms affected include honeybees, plants, aquatic organisms, soil microbes, small domestic animals, wildlife, and humans.

Environmental Contamination
Chlorinated hydrocarbon pesticides are generally long lived and can accumulate in the food chain. DDT, which is no longer available in this country, is an example of this class of pesticides. Although we are moving to less persistent materials, environmental contamination is still a concern, as findings of pesticide contaminated groundwater show.

Pesticide Reregistration Process
Twenty years ago the EPA was created and given the responsibility for pesticide regulation. As of 1988, all pesticides registered before 1984 must be reregistered to meet current testing requirements. Reregistration represents significant additional expense to manufacturers and threatens continued registration and use. The process is slow and the backlog is so great that completion of the reregistration process is not anticipated until the late 1990s. Many registrations already have been dropped, and more losses are expected.

Increased Knowledge of Ecological Principles
Ecology is the study of interrelationships between organisms and the environment. Organisms do not live and operate in a vacuum. They depend on and also affect other organisms that share the same environment.

The challenge of IPM is to analyze and select tactics, including pesticides, that suppress the pest population below damaging levels while minimizing destruction of naturally occurring beneficials and other organisms.

Principles of IPM

The components of IPM that separate it from traditional pesticide intensive methods of pest control are discussed in detail below. These principles must be considered in any IPM program and are the foundation of IPM. What improvements can you make in your service or operation using IPM?

What is a Pest?

Pests are organisms whose population densities are high enough to cause economic, aesthetic, social, or medical losses. The term "pest" is subjective, a matter of opinion. What one person considers a pest may not be a pest for another. IPM recognizes that designating an organism as a pest depends on its situation rather than simply its species. Pests come in all shapes and sizes and can inhabit many different environments. The principles of IPM apply when managing the diverse group of organisms that can become pests. These include 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. Pests occur in agriculture, forestry, golf courses, public grounds, greenhouse, nursery, and in numerous urban settings.

Pest Biology and Life Cycle

To effectively manage a pest, you must understand its biology and seasonal development or life cycle. The first step is proper identification of the pest, which is often overlooked. Once you have identified the pest, determine its stage of development. Most pests are more vulnerable to control at a certain stage. Try to time control efforts with the susceptible stage.

The Local Ecosystem

It is helpful to understand a pest's place in the local ecosystem, whether it is a raspberry field, a forest or a house. What environmental conditions favor its development? What does it need to survive and increase in population? Are there organisms present that feed upon or parasitize the pest? Knowing the interactions among pest, host, and environment can reveal a multitude of strategies for managing the pest.

Key and Secondary Pests

IPM programs are constructed around the "key" or most important pests in any 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 are occasional pests. Key pests have the potential to cause the most damage and frequently are present from year to year.

Regular Monitoring

Regular systematic monitoring, often referred to as "field scouting" in agriculture, is the most important component of IPM. Monitoring provides the field- or site-specific information needed to make appropriate pest management decisions. Usually both labor- and knowledge-intensive, it is most often conducted by a pest management specialist.

The most common methods for monitoring insects are random sampling and trapping. When using random sampling, scouts take counts of pest numbers, damage, and natural enemy populations at random spots within a field or management unit. Usually they choose at least four spots distributed throughout a field and record results for each spot. The field scout also observes any unusual conditions while walking between spots. Various kinds of traps can detect the first appearance of mobile insects and track the pest's life cycle. Pheromone traps are very useful for predicting activity peaks for certain insects and predict the best timing of control actions. After the field visit, the pest manager completes a report showing site locations and sampling results. This is the basis for treatment and future monitoring decisions.

Monitoring Techniques

> Direct counting from plant foliage is one of the most common techniques in agriculture. Specialists can use a hand lens in the field, or collect leaves for later examination in the laboratory depending on the type of pest and desired accuracy. Insects also can be dislodged 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. Regular monitoring of actual insect damage, for example, defoliation estimates or fruit entries, can help relate population estimates to damage ratings and need for treatment. Presence of frass (fecal matter) or exuviae (shed skins) indicates insect activity, which in some cases (e.g., powderpost beetles) is very important.
>
> Due to the microscopic nature of plant diseases, field monitoring is often impractical. Environmental monitoring can be very important in disease management because treatments may be necessary before infection begins. Use a weather station placed in a field to continuously monitor parameters such as soil and air temperature, soil moisture, relative humidity, and leaf wetness. Measuring these weather parameters and correlating them to disease development can be the basis for mathematical models. Use these models to make accurate fungicidal applications based on environmental conditions. Disease predictors are available for managing late blight in potatoes and apple scab, both important diseases in the Pacific Northwest. Disease predictors also are available for managing certain golf course turf diseases.

Monitoring Program

> Once suitable techniques are identified for a given system, integrate them into a practical regular monitoring program that will form 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. Others are evaluated perhaps only once or twice a year. Intensity of monitoring is driven primarily by economic considerations and required accuracy.

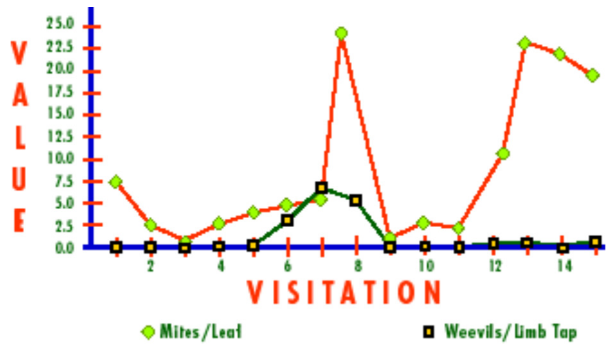
Decision Making

Decision making in IPM is information intensive, giving consideration often to economic, aesthetic, social, and legal factors. Although virtually a zero tolerance exists for cockroaches in restaurants, pests can be tolerated at some density in most situations. The goal in IPM is to manage pests below a density that allows unacceptable damage.

Economic Threshold

> The economic threshold (ET) is generally synonymous with the term "action threshold." Once a population reaches or is certain to reach this threshold level, control action is required. ET levels are determined for several insect, mite, and nematode pests of western Washington crops, including twospotted mites on strawberries and raspberries, flea beetles

on potatoes, and corn earworm on corn grown for processing. Levels are useful as rough guidelines for deciding when to apply pesticides or other methods. The following chart illustrates this concept for mites in raspberries.



This chart summarizes 1990 mite and weevil populations in a field of Willamette raspberries in Whatcom County. Sampling began on 4/12 and ended on 8/20. Mites escaped natural control in this field and began to increase rapidly in mid- to late June. The population, controlled rapidly, began to increase following a preharvest spray for weevils, which destroyed mite predators as well. A final mite spray in early August suppressed the population below the economic threshold of 25 mites/leaf.

Experience

Although the principles of IPM are universal in a geographic sense, pest dynamics are site specific. 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 important in evaluating action thresholds and potential disruptive effects of pesticide applications.

Posttreatment Follow Up

Continue monitoring to determine the effectiveness of the treatment and possible nontarget effects. Allow adequate time after treatment before evaluating control. For example, certain miticides are very fast acting and control can be measured within 3 to 5 days. Other materials may take a week or two before effects can be accurately evaluated. Posttreatment monitoring may indicate the need for a second follow-up application, inadequate control due to several possible factors, or effective control with minimal immediate nontarget effects. Recordkeeping, the final step in the process, forms the basis for future pest management decisions.

Evaluation and Selection of Control Strategies

Consider different strategies and tactics that are appropriate for the particular situation. The following section outlines different IPM methods or strategies and specific tactics. IPM programs employ a variety of tactics to achieve effective control in the least disruptive manner possible.

General IPM Strategies

Strategies fit into 6 classes: cultural practices, biological control, physical control, narrow spectrum biorational, genetic, and pesticides.

Cultural Practices

Cultural control refers to the adjustment of procedures to reduce pest abundance and minimize, or prevent pest damage. The environment is altered in such a way that it becomes less favorable for the pest. Strategies include site selection and preparation, sanitation, use of pest-free planting material and certified rootstock, crop rotation, trap cropping, mixed cropping, and timing of planting or harvest. Cultural tactics can be preventative as well as curative.

Site Selection and Preparation

Choosing and preparing a site is a critical consideration when growing perennial crops such as strawberries or raspberries. To prevent damage from plant parasitic nematodes and soilborne disease organisms, monitor these pests before planting to avoid planting into infested fields. Treat infested fields before planting or avoid them entirely if that is an option.

Sanitation

Sanitation reflects the food, water, and harborage in an environment. Modifying these components can prevent pest build up in many agricultural and urban settings. 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.

It is equally important in managing plant diseases. For example, removal of cull piles of potatoes and potato volunteer plants is one of the most important steps in managing potato late blight. These sanitary measures can reduce carryover of the disease from one season to the next and help delay and reduce the frequency of fungicide applications.

Pest-free Planting Stock

The Washington State Department of Agriculture Plant Services Division oversees certification programs on nursery plants grown for agricultural and ornamental use. These programs ensure that the buyer is receiving material that meets tolerances for certain important pests. Compromising by not using certified planting stock can result in chronic plant health problems and overuse of pesticides in an attempt to salvage the plantings.

Crop Rotation

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

Long-term crop rotation is a key in managing the fungus disease, club root, a serious pest of crucifers in western Washington. Rotate fields that have a history of disease out of susceptible crops for a minimum of 5 years. Rotation, combined with application of lime to make the soil more alkaline, can help reduce disease severity.

Trap Cropping

Trap crops are plant stands grown to lure pests from commercial fields or to enhance biological control by attracting natural enemies. 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. Europeans used trap trees over 200 years ago to control the spruce bark beetle. Although trap cropping is not widely used now, many important agricultural pest species are likely candidates for this technique.

Timing of Planting or Harvest

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

Damage from the fungus Rhizoctonia on potatoes can be reduced if growers delay planting until soil temperatures reach 45°F. In practice, this can present logistical problems to the grower who has a limited amount of time to plant a crop and a short growing season. If the crop is not planted by a certain date, it may not reach full maturity. Growers will often start planting as soon as physically possible, having little regard for disease implications. Delayed planting may be workable in some cases and impractical in others, but the managers need to consider this option.

Maintain a Healthy Host

Plants that are stressed are generally more susceptible to pest damage. Examples of this occur in agriculture and in lawn and turf management. Mowing height and frequency, fertilization amount and timing, irrigation scheduling, and thatch management can all affect turf pest problems.

Habitat Manipulation

Like all living organisms, pests have certain habitat requirements. By altering habitat, we can create conditions that are less favorable for the pest. This can be an effective method to prevent, suppress, or control pest populations. Management of deathwatch beetles provides a good example of this tactic.

Deathwatch Beetles

Wood infesting Anobiid beetles (deathwatch 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. 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 that could subsequently infest the structure.

Biological Control

Biological control relies on natural enemies: parasites, predators, and pathogens to reduce pest populations or damage to tolerable levels. When successful, biological control can provide a relatively permanent, harmonious, and economic solution. Biological control comprises three areas of activity; importing exotic natural enemies (classical biocontrol), increasing the number of natural enemies through mass release of laboratory-reared beneficials (augmentation), and maintaining numbers of natural enemies already present (conservation).

Classical Biocontrol

Many serious pests have been introduced into this country without their natural enemies. Lacking natural controls, they reach pest status. Classical biocontrol attempts the introduction of imported natural enemies, usually done on a large geographical scale. Classical biocontrol efforts peaked in the decade 1930-1940; many successes occurred during that 10-year period. Biocontrol efforts dropped dramatically after the development of synthetic organic insecticides following World War II.

In Washington, this technique has been most successful for controlling certain rangeland weeds.

Augmentation

Augmentation refers to increasing the number of natural enemies at critical times, usually through mass release in a field or greenhouse. Although some successful augmentation programs occur in agriculture in other areas of the country, this strategy has not received much attention in agriculture in the Pacific Northwest. Release of natural enemies is common in greenhouses in Europe, and an ongoing program in vegetable producing greenhouses in the Fraser Valley, British Columbia, has been successful since 1979.

Conservation

Conservation of natural enemies is a key objective of applied IPM. Growers often discover a better natural enemy balance when they replace calendar-based pesticide applications with threshold-based applications. Other pesticide management tactics that conserve natural enemies are improved timing of application, reduced rates, and selection of more narrow-spectrum pesticides. Regular monitoring of both pest and beneficial populations is critical in determining ratios of predator to prey. Naturally occurring biological control can be subtle, often escaping even the keenest observer. In raspberries in Whatcom County, twospotted spider mites are often suppressed by a small beneficial beetle, *Stethorus punctum,* commonly called the mite destroyer. Even when this predator is suppressing a mite population, it can be difficult to detect with regular field monitoring. Conservation of natural enemies by reducing the use and frequency of disruptive pesticide applications is the most widespread form of biological control. Careful monitoring and proper selection and use of pesticides can greatly enhance naturally occurring biological control.

Physical
People have employed physical methods for centuries to exclude and control pests. The most common household examples are window screening and the fly swatter. In agriculture, growers have experimented with floating row covers to protect cole crops from adult root maggots on a commercial scale in Skagit Valley. This tactic has been successful for excluding this insect from the crop, but it impedes and complicates cultural practices such as weed control. It has been most appropriate in smaller noncommercial plantings. In British Columbia, growers are trying a specially designed barrier fence to exclude root maggot flies from commercial vegetable fields. Use of a variety of physical barriers is appropriate for excluding urban insect and vertebrate pests from buildings. Common methods for controlling weeds include hoeing, mowing, burning, and machine tillage. Mowing has replaced herbicide use for managing vegetation in roadside ditches as part of Whatcom County's integrated vegetation management program. Hand hoeing, though labor intensive, is still a regular practice in high value crops such as strawberries. Hoeing removes weeds that escape control by herbicides. Land managers have practiced burning for several years for general weed control in noncropped areas, such as railroad rights of way and irrigation canals. Growers use flaming in strawberry fields in western Washington. A postharvest, late season tactic, it suppresses weeds and insects, particularly aphids that are capable of vectoring virus. Additional benefits may be adult weevil control and reduction of twospotted mites.

Greenhouse managers use heat and steam sterilization of soil to control soilborne insects, nematodes, and plant diseases.

Narrow Spectrum Biorational
Narrow spectrum insecticides are generally nontoxic to vertebrates and nontarget insects. The most common examples are the microbial insecticides (bacteria, fungi, and viruses), insect growth regulators, and pheromones. They have been developed for only a limited range of pests and often are more expensive than broad spectrum pesticides.

Microbials

Microbials are target specific compared with most conventional pesticides. This characteristic is advantageous in IPM. Greatest successes employ bacteria and viruses for insect control. Recently, entomopathogenic (insect-attacking) nematodes have joined the arsenal of microbial pesticides. Microbials are exempt from EPA tolerance levels and, therefore, can be applied even on 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 as applications to soil where they are protected from dessication and ultraviolet effects.

The bacteria, *Bacillus thuringiensis* (Bt.), is commonly used for leafroller control in raspberries in Washington and Oregon. Due to 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. Rapid control usually is not necessary in raspberries.

Entomopathogenic nematodes show potential for controlling a broad spectrum of soil insect pests without threat to groundwater contamination. This biological control agent is a possible alternative to soil-applied chemical insecticides, which are more likely to threaten groundwater. Various species of this nematode are commercially available for controlling soil inhabiting insect pests in lawn and garden, turf, cranberries, and ornamental nursery and greenhouse markets. Entomopathogenic nematodes have been used commercially in cranberries for black vine weevil control in southwestern Washington since 1989. Field experiments in small fruit crops such as strawberries in western Washington have not shown adequate control to date. The major practical limitation of this tactic is that soil moisture requirements necessary for the nematode's survival are difficult to maintain in large scale field situations.

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 kill insects but can suppress populations by reducing reproduction. One type of IGR, hydroprene, has been effective for controlling German cockroaches. Materials like this may be most useful when managers combine initial treatments with insecticides. The insecticides control the adult stage, and the IGR cause the immature stages to become sterile adults. IGR use is sensible as a component of an integrated approach for cockroach control that includes insecticides, boric acid, sanitation, and physical exclusion.

Pheromones

In nature, sex pheromones are chemicals released by the female to attract a mate. Their uses in pest management include insect population monitoring to aid in decision making, trapping out for direct control, and confusion or mating disruption to suppress populations.

Monitoring

Pheromone trapping to monitor codling moth in tree fruits is the best example of this tool in commercial agriculture in Washington. It is a critical component of IPM in tree fruits. Trap catch data determines whether the insect is present, its population density, and seasonal development. The combination of trapping results and temperature data guides the pest manager in timing and adjusting rates of insecticide applications. This program is based on years of codling moth biology and management research.

Trapping Out

Pheromone traps have had some success in reducing insect populations, but this strategy is not cost effective on a large scale. "Removal trapping" has been effective for controlling low density gypsy moth populations on the periphery of the insect's range. Foresters have made significant efforts to manage bark beetles in commercial forestry by mass trapping. This tactic is appropriate only when combined with sanitation measures in selected forest areas that are sensitive to infestations.

Mating Disruption

The confusion or mating disruption technique draws considerable interest. Larger than natural amounts of synthetic pheromones are released into the environment to disrupt the orientation of male insects to their mates. If successful, the number of matings is reduced and the population is lowered. In the past several years, scientists have achieved commercially acceptable levels of control with this technique on several pests in the United States and elsewhere.

Genetic

Genetic methods of pest control either alter the host plant to resist or tolerate a pest (host resistance) or manipulate the pest to lower its reproductive potential and survival (sterile male release).

Resistant Hosts

Growers use resistant plants or cultivars (varieties) to manage many important plant diseases. For example, The PNW Plant Disease Handbook lists approximately 40 agricultural, nursery, and ornamental plants that are resistant to Verticillium wilt, and about the same number that are susceptible. Host resistance also can manage certain insect, mite, and nematode pests.

Use of resistant hosts in pest management has several advantages. Plant resistance deals with key pest species and offers minimal environmental disruption. It provides longer term control than many methods and is compatible with normal production practices.

Sterile Male Release

Researchers release laboratory-produced sterile males in great number into the management area. Females mate with these sterile males to produce sterile eggs. Sterility programs require specialized knowledge and often are implemented over a large area. If successful, long-term control can be achieved with minimal environmental impact. Researchers used this technique to control codling moth in the Similkameen Valley of British Columbia in the mid-1970s. It is being considered for controlling the same pest on a larger scale in that province.

Pesticides

Synthetic pesticides are still the mainstay in pest control. If used based on actual need, they should continue as a useful tool for many years, as an important part of IPM programs.

Advantages of Pesticides

On average, pesticides are highly cost effective. In U.S. crop production, they return $3 to $4 for every $1 invested. When used properly, pesticides control target pests quickly and effectively. The broad spectrum activity of many pesticides often controls several potential pest species with a single application. However, as pest resistance occurs and the role of beneficials and other factors becomes clear, we realize that the broad spectrum nature of many pesticides is not always desirable.

Considerations When Using Pesticides

Pesticides continue to be important in IPM. IPM stresses the consideration of less disruptive methods, but where pesticides are appropriate, they should be used on an as-needed rather than on a calendar basis. When using pesticides, select the most appropriate material based on several criteria. Include

1. potential for groundwater contamination
2. acute mammalian toxicity
3. efficacy
4. disruption of natural enemies
5. resistance management

In addition to selecting the most appropriate material, make every effort to optimize *timing of application and rate and method of application.*

Selection

Pesticide Properties

The potential for a pesticide to reach ground and surface water depends to a great extent on its properties. The most important properties to consider are persistence, adsorptivity, solubility, and volatilization.

The chemical structure of a pesticide determines its persistence, which is usually reported as its half-life. This is the amount of time following application for half of the pesticide to break down. Avoid pesticides with a half-life greater than 3 weeks. These fall in the high category for leaching potential.

Adsorptivity is the retention of pesticides by soils. It is determined by the chemical properties of the pesticide and soil properties, particularly organic matter content. A pesticide's adsorptivity is expressed by its adsorption coefficient, or K value. The higher the number, the greater its adsorptivity. Adsorption coefficients less than 500 are in the high category for leaching potential.

The greater the *solubility* in water, the greater is the risk for leaching and chance for groundwater contamination, particularly in sandy soils. Pesticides with solubilities below 30mg/L have relatively low potential for leaching. Those above 30 mg/L may have high leaching potential, depending on their persistence and adsorptivity.

Volatilization occurs when a liquid turns into a gas. Volatilization of pesticides increases with higher air temperature and air movement, low relative humidity, and when spray droplets are small. Avoid applying pesticides when conditions favor volatilization.

Acute Mammalian Toxicity

Pesticides are classified into four categories based on their acute mammalian toxicity or LD_{50} values. The classifications are (I) most dangerous, (II) dangerous, (III) less dangerous, and (IV) least dangerous. These classes provide a useful index to relative acute toxicity of different pesticides. Select less toxic pesticides to minimize threats to the applicator and to other nontarget organisms.

Efficacy

One of the most obvious considerations is efficacy, or effectiveness. Herbicide efficacy tables on specific weeds are available as a tool to help select the most appropriate herbicide. 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.

Disruption of Natural Enemies

Where preservation of natural enemies is a factor, choose materials that are least damaging to natural enemies. Charts rate insecticides based on efficacy and toxicity to specific natural enemies. Charts are useful in crops that support a variety of pests and beneficials. A chart is available for apples in central Washington. In the absence of a chart, follow local experience to determine impacts of specific pesticides on beneficials. Where natural controls are significant, such as natural control of mites in raspberries, avoid broad spectrum pesticides that threaten mite predators unless no practical alternatives exist.

Resistance Management

The widespread phenomenon of pest resistance to pesticides has forced us to consider this factor in the selection process. Manage resistance by alternating pesticides, avoiding sub-lethal doses of insecticides, reducing frequency and extent of treatments, and reducing use of materials that have prolonged environmental persistence.

Timing of Application
By regularly monitoring pest and beneficial populations, growers can achieve the best timing and effectiveness of pesticide application. Better control means fewer applications and less opportunity for contamination of water. Growers can base timing on crop or host plant development, susceptible stage of pest, predator to prey ratios, environmental conditions, and established threshold levels.

Rate and Method of Application
Some pesticide labels give a range of rates as well as methods of application that will provide control under a variety of circumstances. Rates are based on effective averages. Exceeding recommended rates is illegal. In many cases, reduced rates and tailored methods of application can achieve adequate control. A goal of IPM is to reduce rates without compromising control. There are economic and environmental incentives for doing so. Reduced rates must be based on either university studies, supportive experience, or manufacturer's suggestions. Extension agents can keep pesticide users updated on this type of information.

Regardless of the pest, choose a method of application based on distribution of the pest in its environment. For example, mites feed on the underside of strawberry leaves, and populations are usually highest on lower leaves just a few inches above the ground. To place miticides on the underside of foliage, arrange spray nozzles so that spray is directed upwards from below the canopy.

Proper application will maximize effectiveness and minimize need for additional sprays. Rate and method of application can reduce the potential for a pesticide to reach either surface or groundwater.

IPM Implementation

IPM development has advanced most in agriculture, largely because of the research structure that has been in place for years. Forestry also has practiced IPM principles for years. IPM development in turf, ornamentals, and vegetation management in urban settings has been more recent. Greenhouse systems lend themselves to IPM because it is easier to alter and control a contained environment. They are particularly suitable for augmentation (increase of natural enemies) as evidenced by the success of this technique for mite and whitefly control in vegetable greenhouse production in the Fraser Valley of British Columbia.

Many IPM programs in agriculture were developed from Cooperative Extension Service demonstration projects in the late 1970s and early 1980s. Most were transferred to the private sector and delivered to users by consultants or grower and producer cooperatives. Individual growers often employ a full time pest management specialist.

Independent Consultants

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

Applying IPM techniques requires more labor to monitor and more specialized knowledge regarding pest biology. Consultants have become a major force in delivery of information to growers in many areas, including Washington State and British Columbia. At least six private consultants serve the tree fruit industry in the Yakima Valley, and at least two private consultants serve the fruit and forestry nursery industries in western Washington. Several pest management consultants in British Columbia serve agricultural and greenhouse operations, forestry, and urban systems.

Producers

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 State. 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.

Benefits of IPM

When compared with conventional pest control, benefits of IPM can include greater net return, improved risk management, marketing advantages, and reduced environmental disruption.

Economics

Greater net returns result from lower pesticide costs, when fewer applications are needed. Urban IPM projects targeting homeowner landscapes, grounds maintenance supervisors, and urban arborists have documented significant savings from reduced reliance on pesticides. Similar savings have been realized on golf courses. Improved timing and partial pesticide treatment have brought better control and reduced pesticide use. In greenhouse vegetable production in the Fraser Valley of British Columbia, growers have virtually replaced pesticides with biological control.

In most cases, the savings are due to reduction of calendar-based pesticide applications. Regular monitoring allows the manager to base decisions on need rather than a predetermined schedule. Improved timing of application gives better control and, therefore, lengthens the interval between applications. Spot treatment rather than total area treatment also reduces pesticide use and cost.

Risk Reduction

Contrary to perceptions, IPM is a risk reduction system. 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 a knowledge- and labor-intensive program. As long as decision-making guidelines are established, implementing knowledge will reduce risk of pest damage.

Marketing

IPM also has been used to gain marketing advantage. In response to public concern for food safety, some grocers have used IPM as a marketing tool. Considering the public concern regarding pesticide residues on food, expect an increase in advertising IPM-grown products. Ocean Spray Cranberry, Inc. mentions its use of IPM in promotional literature.

Marketing advantages can go beyond the farm. A golf course developer in Vermont agreed to practice IPM to satisfy state environmental requirements. In this case, IPM implementation sold the community on the merits of golf course development over other development uses of the property.

Environmental

Reducing the amount of pesticide used and frequency of pesticide applications through IPM means less opportunity for pesticides to contaminate groundwater and the environment in general.

Examples of IPM in Western Washington

Raspberries

Growers are practicing IPM on a small percentage of raspberry farms in western Washington. Economic benefits of IPM use in Whatcom County have not been studied, but IPM practices have reduced pesticide use in many fields. This is due to the elimination of some pesticides, improved timing of application, and reduced frequency of application. Conservation of mite predators has enhanced naturally occurring biological control.

IPM in raspberries includes preplant field selection to manage nematode and soil disease problems; pheromone trapping, weekly to biweekly systematic pest and beneficial insect monitoring, and diagnostic sampling to evaluate leaf nutrition, soil and root nematode populations, and root disease.

Roadside Vegetation Management

Whatcom County Department of Public Works received the 1991 national award for excellence in county vegetation management. The department manages vegetation along county roadways and adjacent ditches. They have recently switched from a herbicide-intensive program to" Integrated Vegetation Management," based on IPM principles.

Specifically, in managing vegetation within ditches along roadways, the department has shifted from a dependence on broad spectrum herbicides to using a combination of mowing and species selection to maintain a desirable mix of vegetation in these areas. This approach allows adequate water flow but minimal erosion of ditchbanks. Another major benefit of vegetation-lined ditches is their ability to filter potential contaminants and, thus, minimize surface and groundwater contamination.

Golf Course Turf

Pests that threaten golf course turf are being managed by some course superintendents through the integration of several tactics. The most important turf pests in this area are fusarium root disease, european crane fly, moles, and broadleaved weeds, particularly clovers. Managers have reduced pesticide use on courses as a result of monitoring, use of resistant varieties, and altering cultural practices, particularly irrigation scheduling.

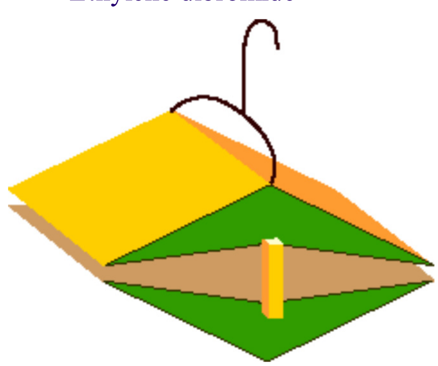
They select turf species based on tolerance to fusarium and suitability to local environmental conditions. Drought tolerance is an important trait for golf course turf. A plant that can remain healthy under drought conditions can also tolerate more damage from insects and disease. In addition to the use of tolerant varieties, managers control fusarium by fine-tuning irrigation scheduling and frequency, regular monitoring of highly susceptible areas, and use of preventative fungicide applications in the late fall and mid-winter based on air temperature. They monitor crane flies in the spring and use insecticides to spot-treat areas that exceed threshold levels. Managers can achieve adequate control using reduced rates and usually a single application. Weed control is primarily directed at clover, confining herbicide application to problem areas. Some courses manage moles exclusively by the use of traps rather than poisoning.

Conclusion

IPM does truly represent a balanced and sensible approach to pest management. It can provide benefits to both the producer or resource manager and to the public as a whole. The challenge to pest managers and resource managers is to examine current practices to see where improvements can be made. Consider the principles of IPM and the various strategies presented here to minimize dependence on pesticides and to select and use pesticides for optimal results and minimal environmental disruption. Groundwater is a precious resource; we all have an obligation to protect it. Once "broken" through pesticide contamination, it cannot simply be "fixed." Finally, the goal of this document has been to increase awareness of IPM and to stimulate the adoption of the IPM philosophy or approach to pest management.

Abbreviations

EPA	U.S. Environmental Protection Agency
CWS	Community water system
IPM	Integrated Pest Management
NPS	National Pesticide Survey
IGR	Insect growth regulators
DBCP	Dibromochloropropane
DCPA	Restricted-use pesticide
EDB	Ethylene dibromide



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