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Aquatic Pest & Sewer Line Root Control

Category 5

Missouri Manual 99

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Preface

This training manual provides you with the information you need to meet the minimum Environmental Protection Agency (EPA) standards for certification as commercial applicators in Category 5, Aquatic Pest Control. It also prepares you for an examination, based on this manual, given by the Missouri Department of Agriculture.

It does not provide all of the information you need for safe and effective use of pesticides. Examine the label for each pesticide you use. Labels must list directions, precautions and health information — all of which are updated regularly when a pesticide is registered in Missouri. If you notice information on a current pesticide lab l that conflicts with the information in this manual, follow the label.

Manufacturers will supply additional information about products registered for use in or near the waters of Missouri. Information is also available from the Office of Pesticide Coordinator, 45 Agriculture Building, University of Missouri-Columbia, Columbia, MO 65211, (573) 884-6361.

Missouri's Pesticide Applicator Training Program is a cooperative effort. The Missouri Department of Agriculture is the state lead agency. University Extension, the University of Missouri-Columbia, is responsible for the content of the Pesticide Applicator Training Program. The Missouri Departments of Health, of Conservation, of Natural Resources and the EPA also contribute to the development of educational materials and participate in the training program.

(**A note on this manual:** Terms highlighted in bold type throughout the text also are found in the glossary, beginning on page 36.)

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The information in this manual is supplied with the understanding that no endorsement is implied or discrimination intended.

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Section I: Aquatic Pest Control

Aquatic plants are an essential and necessary part of Missouri's fishing lakes, ponds, streams and rivers. In these waters, microscopic plants produce the majority of dissolved oxygen in water for use by aquatic animals. Aquatic plants also serve as escape areas for young fish, ensuring that some survive and mature to produce additional young. Plants stabilize shorelines, prevent wave erosion, and may produce flowers or unique leaf patterns that add to our enjoyment of the outdoors. They can also provide important foods and nesting areas for frogs, waterfowl and shorebirds.

Plants can become problems when they interfere with the intended use of a lake, pond or other body of water. There is often a thin line separating plants and **weeds**. A particular plant may be desirable in one situation but may disrupt management objectives in another.

Surface water also is a vital and important resource. The demand for this resource for all uses is increasing. Approximately 60 to 70 percent of Missouri's population relies on surface water for its personal needs. Surface water supplies 70 to 80 percent of the water used in agriculture. Many aquatic pests can interfere with our use of surface water. Proper aquatic pest control is essential to provide for efficient water use while maintaining water quality.

Effects of aquatic weeds

The economic impact of aquatic weeds in terms of dollar loss is difficult to estimate. Because aquatic sites usually are noncropland sites and are not commercially harvested, crop yields and losses due to weeds can't be determined. But some of the monetary losses due to aquatic weeds have been estimated by calculating the amount spent for their control. Specific problems caused by aquatic weeds include the following:

1. Aquatic weeds restrict or prevent recreational activities such as swimming, fishing, water-skiing and boating.

2. Aquatic weeds can be hazardous to swimmers and water-skiers, who can become entangled in the weeds and drown. When covered with algal growths, ladders, rocks and rafts in lakes or ponds become slippery and hazardous.

3. Aquatic weeds cause foul tastes, unpleasant odors and discoloration of drinking water stored in reservoirs and ponds. Treating water with copper sulfate and passing it through filters to kill and remove odor-causing algae are standard water quality improvement procedures that must be used in many municipal and private water supply reservoirs.

4. Fish are affected adversely by excessive weed growth. An overabundance of plants can lead to overpopulation and stunting of fish, and death and decomposition of vegetation can cause fish kills.

5. Aquatic weeds block the flow of water in irrigation and drainage systems, causing flooding of fields and highway culverts.

6. A major cause of water loss is evaporation from the leaf surfaces of free-floating or shoreline plants. With water hyacinth plants, for example, three to four times more water is lost from their leaf surfaces than is lost from a free water surface by evaporation alone. Certain shoreline plants called **phreatophytes** not only **transpire** surface water but also draw from ground water supplies. Trees such as cedar, cottonwood and willow actually cause ground water levels to drop measurably during the day while they are actively transpiring.

7. Aquatic weeds catch debris and sediment, causing waterways to fill in at accelerated rates. If permitted to continue without correction, the accumulation of plant materials and sediments in ponds, lakes and canals eventually can produce bogs, marshes or dry land.

8. Navigation of rivers and waterways is difficult when they are clogged with aquatic weeds. Weeds impede boat movement, become entangled in boat propellers, and can cause extensive damage when they plug the cooling systems of motors.

9. Aquatic weeds provide habitat for harmful insects such as mosquitoes. Weed growth prevents normal wind and wave agitation of the water surface, thus providing undisturbed sites for the development of mosquito larvae. Other undesirable organisms sometimes found on aquatic vegetation include leeches and snails.

10. When infested with certain types of microscopic blue-green algae blooms, water can become toxic and quickly kill livestock, pets and wildlife that drink the water. The most frequent outbreaks of toxicity have occurred in several of the central states (Arkansas, Iowa and Minnesota).

11. The growth of unsightly, foul-smelling weeds in a body of water greatly lowers the aesthetic appeal of waterfront properties, thus lowering property values. Aquatic weeds detract from the appearance of golf course ponds, ornamental and reflecting pools and home aquariums. The recent emphasis on the construction of ponds and lakes as major landscaping features for housing developments, apartment complexes and office and industrial parks has greatly

increased the frequency of aquatic weed problems. When these bodies of water are shallow and surrounded by well-fertilized fields, lawns and greens, controlling aquatic weeds becomes a major maintenance consideration.

Aquatic plant identification and management

One of the most important steps in aquatic plant management is the correct identification of the problem plant. Drawings and photographs of plants can be very helpful to aquatic pesticide applicators. The following section discusses some of the common nuisance aquatic plants and algae found in Missouri.

Algae

Algae are generally classified as planktonic, filamentous or **macrophytic**. All types of algae obtain energy from sunlight. **Algae** are simple plants without true roots, leaves or flowers. They reproduce by cell division, plant fragmentation or spores.

Planktonic algae are individual algal cells that are suspended in the water or form a film on the surface. Planktonic algae are responsible for low water clarity and can cause allergic or toxic reactions in sensitive people. The most common group of nuisance planktonic algae is the blue-green algae. These species may turn the water a deep blue-green color. The blue-green algae can form green or dark green surface scum. They accumulate on the downwind sides of lakes, forming unsightly gelatinous masses on shorelines.

The blue-green algae are also noted for creating odor and taste problems in drinking water supplies where they accumulate. Some species are toxic and have been responsible for livestock illness and death. Natural die-off of algae may cause summer-kill of fish due to oxygen depletion.

Several **filamentous algae** genera have become significant nuisances. Filamentous algae can be split into two groups depending on growth habit: attached and free-floating. Both types can be persistent and difficult to manage. The attached algae are found on docks, seawalls, boats and other hard surfaces. The texture of these algae varies from slimy to coarse, resembling wet cotton or hair.

The free-floating filamentous algae may form mats on the sediments, continually increasing in size and layers. As new layers grow on top of old layers, the algal mat becomes increasingly dense and the lower layers become shaded and die. Gases are produced as the dead algae decompose. As these gases combine with those normally released from bottom sediments, they are trapped below the algae mat. These gases can actually buoy the mats upward to the water's surface. These unsightly surface mats of algae trap debris and are commonly referred to as "pond scum."

The macrophytic algae (Chara and Nitella) resemble vascular plants, which grow from sediment. Although they do not have roots, they do have hold-fast structures that anchor them to the bottom. Macrophytic algae are considered valuable in maintaining water quality. They cover the sediments and absorb nutrients that are released. This aids in preventing the establishment of the other nuisance algal groups and other undesirable plant species.

Control of the various nuisance algae can be achieved by several similar techniques, though application rates and methods vary. One approach is to broadcast an algaecide over the entire algal surface. Large mats of algae should be broken up with a boat propeller or high-pressure stream of water to maximize the treatment effectiveness. Directly spraying the floating mats and attached filaments will give the best results.

Control of macrophytic algae is not usually recommended, where control is desired, use a granular algaecide because the pellets sink to the bottom and maintain contact with the algae. Chara can be difficult to control, particularly in hard water. Two or more treatments with contact herbicides may be necessary, and best results are obtained when the plants are young and uncalcified.

Take care when using copper-based algaecides. Certain doses, even very low doses, of copper are toxic to fish and aquatic organisms, especially in low alkalinity water.

Aquatic flowering plants

Aquatic flowering plants can be described according to their growth habits as follows:

Submersed plants. Plants grow completely below the water surface, or nearly so, and depend on the surrounding water for support of the plant body.

Emersed or emergent plants. Plants are rooted in the sediments, extend above the water surface and are self-supporting.

Free-floating plants. Plants are not attached to the sediments and float on the water surface or just below it. Most have roots that extend into the water for nutrient uptake.

Rooted floating plants. Plants are attached to the sediment and have leaves that float on the water surface. These plants may or may not be self-supporting.

Many of the aquatic weeds occurring in Missouri are known as **exotic species,** that is, plants that are native to other regions, countries or continents.

Many aquatic weed species are capable of choking out native and beneficial plants. Some exotic plants, such as watermilfoil and curlyleaf pondweed, form dense mats of near-surface vegetation and cover expansive areas. These mats are nearly impenetrable by watercraft. They not only make fishing, boating and swimming difficult, but may also adversely affect the chemistry of underlying waters, degrading the habitats of fisheries and fishfood organisms.

In contrast, many of our native aquatic plants exhibit a more open growth habit with patchy distribution. This type of growth habit is more favorable for other aquatic organism needs. Native plants fulfill necessary and beneficial roles in the aquatic ecosystem. They serve as food, habitat or shelter for other aquatic organisms. They serve as stabilizing features for the substrate, and they filter storm and run off water as it moves through the aquatic area.

Submersed plants

Watermilfoils. This group is composed of plants that grow submerged or grow at the surface and may have small flower stalks that extend above the water surface. Most watermilfoils are native plants requiring minimal management because they are rarely present in nuisance proportions. In Missouri, the watermilfoils reproduce mainly by vegetative means, which include **fragmentation** and **stolons**. The major watermilfoil of concern in the United States is the exotic Eurasian watermilfoil, *Myriophyllum spicatum.* Eurasian watermilfoil was introduced to the United States in the 1940s. The species was very adaptable and quickly moved into areas that had been disturbed or changed. Because of this adaptability and their rapid growth rate, they can become established more quickly than other species. They easily grow to nuisance proportions in shallow and relatively deep water. Eurasian watermilfoil is of limited value to wildlife or fisheries because of its undesirable dense growth habit. Eurasian watermilfoil frequently chokes out native plants.

Eurasian watermilfoil is susceptible to some **systemic herbicides**. Certain systemic aquatic herbicides can be used as **selective herbicides** to remove Eurasian watermilfoil. Selective herbicides are effective only against certain species and are able to control unwanted plants without serious injury to desirable species. Because Eurasian watermilfoil grows faster than most native species, the consistent use of **contact herbicides** favors the continued reestablishment of this plant. Contact herbicides kill only tissue that they touch, allowing regrowth from the roots. Harvesting is not recommended for managing Eurasian watermilfoil because this results in its spread by fragmentation. Long-term harvesting, like the consistent use of contact herbicides, encourages Eurasian watermilfoil's displacement of native or more desirable plant species.

Pondweeds. The pondweeds are a very diverse group of aquatic plants. Identification of pondweed species can be difficult because structural differences among species are often small. Also, environmental factors often influence the growth form of a species, and hybridization between species is common. The growth form of a species may be related to current velocity, depth, clarity, temperature of water, time of year, nutrients, bottom type and so forth.

Most pondweeds are beneficial native species that provide excellent habitat and food for fish, aquatic invertebrates and migrating waterfowl. One species, curlyleaf pondweed *(Potamogeton crispus)*, is an exception. Like Eurasian watermilfoil, this species is an exotic. It was brought to North America in the mid-19th century. Curlyleaf pondweed has since spread throughout the continent and become a pest in many locations.

Curlyleaf pondweed gets its name from its wavy leaf margins. This species can grow in depths of 6 feet or less and may spread by rerooting of plant fragments. Curlyleaf pondweed emerges early in the spring. It flowers and sets seeds from May through September in Missouri.

The other pondweeds can be classified as either narrow-leaved pondweeds, which have thread- or ribbonlike leaves, or broad-leaved pondweeds, which have leaves wider than ½ inch. Members of these two general classifications can be used for food, cover and shelter by wildlife and fish. Pondweeds are among the most important waterfowl foods in the United States.

Pest species of pondweeds can be controlled in a variety of ways. Applying certain herbicides early in the season can selectively remove curlyleaf pondweed without affecting either group of beneficial pondweeds, which sprout later in the season. Most pondweeds can be mechanically harvested.

Naiads. The naiads (*Naias* sp.) are sometimes desirable and at other times are considered a serious nuisance. They are desirable when found as low-growing, lake-bottom covers and are valuable to wildlife and fish. Naiads often grow in thick clumps, and they can be short, lake-bottom dwellers or grow to heights that will reach the surface. When they grow to the surface and create impenetrable masses of vegetation, they become a nuisance.

The naiads differ from other aquatic species in that they are **annuals** that overwinter as seed. Most other submersed aquatic species overwinter in a vegetative condition or produce special overwintering structures. The naiads are adapted to fluctuating water levels, possibly because of the seeds' hardiness. As a result, naiads may become serious nuisances in shallow areas where repeated drawdowns occur.

Naiads can reproduce from fragments as well as by seeds. If control is necessary, harvesting is not usually an effective option because these plants grow low to the ground and fragment easily. Selective herbicides are available for control of naiads.

Other submersed aquatic species

Most other native submersed aquatic plant species require little management. It is important to consider these nonpest plants in the overall lake management goals and recognize that some plants provide desirable features. Therefore, plan for areas that can serve as plant preserves. If a group of plants becomes a nuisance, they must be managed cautiously and with consideration for their many positive qualities.

Coontail *(Ceratophyllum demersum)* is distributed throughout most of Missouri, mostly in relatively quiet and deep water. It is usually less than 3 feet long. It has clusters of finely forked leaves that appear bushy (like a raccoon's tail) at or near the ends of the stems. Leaves have small teeth along one side and are sometimes stiff with a coating of lime. Coontail harbors significant amounts of food for fish and waterfowl because its many fine branches are available for colonization by small aquatic animals. Coontail breaks into fragments easily and spreads in this manner. For this reason, both harvesting and water draw-downs may increase coontail populations. There are several herbicides labeled for control of coontail.

Elodea or waterweed *(Elodea canadensis)* is rarely a nuisance. It provides cover for fish and supports insects that are valuable for fish foo d. It has slender stems 7 to 9 feet long. It grows completely below the water surface. Leaves are bunched in whorls of three toward the ends of the stems, where new growth occurs. Older leaves usually break off from the lower stems. Elodea grows best in soft sediments and cool water. Elodea may rapidly colonize an area and then decline in abundance within 5 to 7 years. If necessary, it can be managed with herbicides or harvested. Fragments of the plant should be removed from the water to prevent new plants from generating.

Free-floating plants

Duckweed and watermeal. Several species of each of these aquatic weeds occur in Missouri. Duckweed (*Lemna* sp. and *Spirodella* sp.) is a tiny, green, floating, oval plant often mistaken for algae. Roots may or may not extend from the underside. Duckweed reproduces by division and is common in quiet water such as ponds and backwaters.

Watermeal (*Wolffia* sp.) is the smallest of flowering plants, granular in size and usually very abundant when present. These tiny, floating, green plants do not have roots extending from the underside and are often mistaken for seeds. Because duckweed and watermeal are floating plants, both obtain their nutrients directly from the water, not a substrate.

Duckweed and watermeal are noted for their rapid reproduction. When they become a nuisance, usually harvesting is not a feasible option. Effective herbicide control depends on chemical contact with as many of the plants as possible. This includes those washed up along shorelines or trapped in backwater areas. The minute size of these plants makes it very easy for water to wash the herbicides off. Addition of a sticker (adjuvant) is recommended by most manufacturers to aid in maintaining herbicide contact.

Rooted floating plants

Waterlilies or lilypads (*Nymphaea* sp. and *Nuphar* sp.) are valued for fish cover and for their showy flowers, and they are often best left alone. Flower colors vary, depending on species or hybrid. Leaves range from 6 to 16 inches in diameter and may be heart-shaped or round with a cleft (a cut about halfway to the midvein of the leaf). Lily pads are common in shallow water and prefer muck or silt bottoms. Waterlilies spread horizontally from thick, fleshy rhizomes. Waterlilies may be intentionally planted for their beauty and their contribution to fish habitat. Some species are quite prolific and can become a nuisance. If management treatments are necessary, use the same strategy as for cattails (see below). Because of the toughness of the lilypad leaf, it may take some time for the plant material to decompose.

Watershield *(Brasenia schreberi)* plants are similar in appearance to lilypads. They are found in shallow, acid waters throughout the eastern United States. Watershield has oval to elliptical leaves with smooth, unlobed edges. The petiole is attached to the middle of the leaf. The leaves may be 2 to 5 inches long. A slimy, gelatinous coating covers the underside of leaf and stem, particularly on mature plants. A dull, reddish purple flower is produced in early summer. If watershield requires herbicide treatment, it should be treated early in the season before development of the gelatinous coating.

American lotus *(Nelumbo lutea)* grows in shallow areas and slow-moving water throughout Missouri. It occurs in greatest abundance in oxbow lakes in the flood plain of the Mississippi and Missouri rivers and their tributaries. Plants have large, circular leaves up to 2 feet in diameter that extend above the water surface. The stem is attached in the center of the leaf, which is frequently cup-shaped. The seeds of this plant are a valuable food for waterfowl; the starchy rhizomes are also edible. Lotus plants provide shade and cover for fish.

Emergent or emersed plants

Cattails (*Typha* sp.) are highly regarded wetland plants that provide food and shelter for many species of wildlife and fish. Several species of cattail occur in Missouri. Cattails in general have long, slender, grasslike stalks up to 10 feet tall. These plants are common in wet lowlands and in water less than 4 feet deep.

Cutting mechanically or by hand during the growing season gives temporary relief but requires repeated treatment throughout the season. Cutting off cattails at ice level during the winter sometimes reduces their stands the following year. Effective herbicide management options for cattails require either applying certain contact herbicides before seedheads form or using a systemic herbicide before or after seedheads form.

Purple looses trife *(Lythrum salicaria)* is an exotic species that has spread because of people cultivating it as an ornamental plant. In Missouri, it is legally described as a noxious weed species. Its purple flower spikes are attractive; however, the plant is very aggressive in its growth habit and is of little value to wildlife. Infestations should be controlled as soon as they are discovered to prevent beneficial vegetation from being choked out. Systemic herbicides applied prior to seed formation are the best options for purple loosestrife control.

Conditions for aquatic weed growth

Two of the major factors regulating plant growth are sunlight and nutrients. In aquatic habitats, the depth of light penetration determines the depth to which underwater plants will grow. The amount of nutrient determines the amount of vegetation that can be produced. Other important factors that promote growth include adequate growing temperatures and, for rooted plants, a stable substrate and protection from wave action. These factors usually are optimal in shallow water, so many aquatic weed problems are limited to shallow sites. The potential for a body of water to develop an aquatic weed infestation can be estimated by evaluating the availability of each of these growth-regulating factors.

Light

Aquatic plants do not grow in water that is so turbid or deep that all light is blocked; however, they can grow at very low light intensities, even as low as 1 percent of the surface light on a midsummer day.

The portion of a body of water in which enough light can penetrate to support aquatic plant growth is called the **photic zone**. The bottom of the photic zone generally is defined as the depth at which the light intensity is equivalent to 1 percent of full sunlight. In silty ponds, the depth of the photic zone may be only a few inches; whereas in extremely clear bodies of water, the photic zone can extend to a depth of 300 feet. The more shallow the body of water, the more likely it is that the photic zone will extend to the sediment bottom, where rooted weeds can grow.

Another factor that influences water clarity is water hardness. Most people are aware that hard water requires large amounts of soap to lather or forms a deposit on the container when it evaporates. Technically, water hardness is a measure of calcium and magnesium content. Ions of these elements can bind with suspended colloidal particles such as clays and organic matter and cause them to precipitate, thus removing particles that normally would reduce the penetration of light. Soft, acid waters with low calcium and magnesium concentrations are often stained with organic substances that prevent good light penetration. Hard waters (hardness values greater than 60 to 75 parts per million of $CaCO^3$) tend to be clearer and therefore support more weed growth.

Nutrients

Bodies of water that drain fertile watersheds suitable for agriculture ten d to support heavier growths of aquatic weeds than do waters located in poorly developed soils that are low in organic matter and nutrients.

Besides being released from the underlying parent, soil-forming materials, nutrients can enter aquatic systems from precipitation, streams, springs, ground water and run off from urban and rural areas. In general, the larger the area draining into a body of water, the more plant growth the water will produce.

Run off is a major contributor to nutrient enrichment, so it is not unusual to see the most prolific weed growths occurring in shallow shoreline areas where the run off is first received. Specific nutrient contributors from urban watersheds include sewage effluents, storm sewer drainage, and septic field seepage. A major agricultural source is run off from fertilized fields and feedlots.

The nutrients that most often regulate aquatic plant growth are nitrogen and phosphorous. Of the two, phosphorous is generally agreed to be the more important. Because the nitrogen content of most natural fresh waters exceeds that of phosphorous 10 times or more, phosphorous is most likely to be the first nutrient to limit plant growth. Therefore, the addition of small amounts of phosphorous to phosphorous-depleted waters produces extremely large increases in the volume of living plant material. Phosphorous is most important in the growth of plants that obtain their nutrients directly from the water (that is, phytoplankton filamentous algae, and free-floating flowering plants).

Sediment fertility appears to be a more critical factor than water fertility in regulating rooted plant growth because rooted plants obtain most of their phosphorous and other nutrients from the sediments through root uptake. This probably is one reason why dense stands of submersed weeds can sometimes be found growing in clear, clean waters that do not have a high nutrient content. Continuous inputs of nutrients to the water, however, still may have an important impact on rooted plant growth because these nutrients eventually become incorporated into the sediments.

Fertilization of ponds and lakes

Fertilizing a pond or lake offers advantages in certain situations but is recommended only for commercial fish production. Fertilizing a pond or lake has the same effect on fish as fertilizing a pasture has on cattle — it makes them grow faster and larger. However, there are more “in between” steps in fertilizing for fish than in the fertilizer-forage-cow system. Fertilizing a pond causes a growth of microscopic plants called plankton. These tiny plants are food for small water animals that live suspended in the water or on the bottom. The small plants and animals are food for larger pond organisms that serve as food for bluegill and bass. Finally, the bluegill are eaten by the bass.

A mineral fertilizer is best for the pond or lake. Organic fertilizers, such as manure, hay or leaves, encourage pond scum. A 16-20-0 formula of water-soluble commercial fertilizer is recommended for Missouri ponds and lakes.

The right way to fertilize is to maintain a greenish color, or “plankton bloom,” throughout the spring and summer. If a brown or reddish color develops, chances are there is a shortage of nitrogen. This condition can usually be cleared up by adding 10 pounds of sodium nitrate per acre.

Start the fertilizing program when the water warms to 65 degrees F. Usually this occurs in the first two weeks of March. When starting the program, apply two bags of 16-20-0 per acre at one-week intervals or until a good color develops in the lake. After the proper color has been obtained, make additional applications of one bag of 16-20-0 fertilizer per acre every four to six weeks, or often enough so that a bright object goes out of sight about 20 inches under water. When the water clears so that deeper than 24 inches can be seen, add more fertilizer. Fertilization should be discontinued around October or when the water temperature drops to about 65 degrees.

Fertilizer is sometimes applied by placing it on one or more submerged platforms. These platforms, made of wood and anchored about 12 inches below the water surface near the shore, should be large enough so that they will hold the amount of fertilizer needed for each application. Wave action and water currents will dissolve the fertilizer and distribute it throughout the pond or lake.

Owners of ponds and lakes three years old and older can fertilize with phosphate, provided the pond has (1) been properly fertilized the past three or more years according to recommendations, and (2) there is no concentration of weeds.

Rates for these lakes are 40 pounds superphosphate or 18 pounds triple superphosphate per acre per application, beginning around mid-March (if there are no excess overflows) and continuing until the first of October.

Ponds with these conditions will probably no longer need nitrogen and potash. However, if a pond that falls in this category fails to show dark water coloration after one or two applications, return to the usual complete fertilizer. Cost of fertilizing with phosphate is about $5 or $6 per acre per year, compared with about $15 to $20 per acre per year with a complete fertilizer.

Unless fertilizer is applied as prescribed, it is useless to fertilize. The carrying capacity of fish ponds is more than doubled when a pond is adequately fertilized. If fertilization is discontinued, the pond will have more fish than it can support, and an overcrowded population results.

Additional benefits of fertilization include fewer water weeds and better fishing in general. The additional fertilizer causes the production of millions of microscopic plants (plankton). These plants color the water enough to prevent sunlight from reaching the pond bottom. Without light, submerged water weeds cannot grow. Fishing success can also be improved since the fish will not be as easily frightened as they would be in clear water.

Some ponds should not be fertilized. These include ponds that are

- muddy most of the time,
- infested with undesirable fish,
- infested with weeds,
- not fished heavily,
- subject or excess run off,

or ponds in which most of the bluegills caught are small.

Temperature

Most aquatic plants grow best in the warm waters of late spring and early summer and reach their maximum size in midsummer. Shallow water tends to warm up more quickly than deep water, so these areas usually are the first to show growths of aquatic weeds. Shallow waters provide aquatic plants with long growing periods, even in areas where the growing season normally is short.

Temperature is a major determining factor in the life cycle and geographic distribution of aquatic plants. In temperate zones, the onset of cold water temperatures in the fall causes most aquatic plants to die back to the sediments. Some underwater plants that live in deep water can survive through the winter under an ice cover with little loss in biomass. Such plants include largeleaf pondweed and elodea. Other plants grow best in late summer and early spring. These include curlyleaf pondweed and certain filamentous algae such as Spirogyra. In natural lakes in the Midwest, curlyleaf pondweed appears in late summer, persists over the winter, and reaches its maximum size in late spring. The plant dies down in midsummer, to be replaced by other submersed plants such as watermilfoil; it then begins new growth in the fall.

Substrate

A stable substrate is required for the attachment of rooted aquatic plants. Because sand tends to shift, it is a poor substrate in flowing waters or along shorelines of large lakes that are exposed to strong wind and wave action. In small bodies of water and in the protected areas of streams and lakes, sand as well as silt and clay interspersed with some organic matter provides an excellent rooting medium for most aquatic plants. Rock and large gravel substrates do not promote the growth of rooted flowering plants because they provide few fertile sediments for nutrient uptake.

Run off and erosion of terrestrial sediments cause a buildup of soil along shorelines and at the mouth of inflowing streams. Shallow areas with gradually sloping bottoms also are prime locations for weed infestations. On the other hand, bodies of water that are deep and have steep sides provide few sites for plant attachment.

Nonchemical aquatic vegetation management techniques

Careful site evaluations are important information-gathering activities for pest managers. A successful management program for a body of water includes an accurate assessment of the types and numbers of plant species found in the area. Various plants serve different purposes and may or may not be nuisances.

Identifying the components within an aquatic plant community is necessary for short- and long-range planning. How each type of plant will fit into the long-range goal must be considered. Plant groups may be contained, eradicated, encouraged or restored. The management strategies used influence the composition among plant communities.

Using a particular method will favor the production of some plant species or species groupings because it gives these species a competitive advantage over other species. Other species may be contained or eradicated by the application of a certain method or strategy. Some plant species will show little response to certain strategies. Many factors interact to influence the outcome of a particular management strategy in a particular body of water.

Ideally, the aquatic pest manager has discussed short- and long-range expectations of the site with persons and associations responsible for the aquatic environment. Management plans should specify what plants will be maintained and establish priorities to achieve the stated goals. Not only is it possible to integrate several methods or strategies into the short- and long-range management plans, but it is usually necessary.

When evaluating aquatic weed problems, consider all methods of control: preventive, mechanical, cultural, biological and chemical.

Preventive control

Preventing aquatic weed spread. Aquatic plants seem to appear quickly in new ponds or lakes, even though they may be isolated from other bodies of water. Algal spores can be carried by wind. Plant propagules — spores, seeds, tubers and plant fragments — can be carried on the feet or feathers of waterfowl or the fur of mammals. People are also primary movers of aquatic weeds, transporting plant propagules on boats and boat trailers. Using aquatic plants to provide packing or shade for bait minnows or worms, and disposing of aquarium plants through sewer systems are also believed to contribute to the spread of aquatic plants. It is nearly impossible to prevent the spread of aquatic weeds by animals, wind or water, but many human activities that spread weeds can be prevented.

If a small clump of a particularly objectionable aquatic weed species appears in a pond or lake channel, it should be removed immediately, either by hand or with chemical spot treatments. Control these plants before they flower and form seeds. This is particularly important with exotic species such as Eurasian watermilfoil and curlyleaf pondweed.

Nutrient management. A major emphasis during recent years has been placed on the management of nutrient loading to streams and larger waterbodies such as lakes and reservoirs. The addition of nutrients increases production of plants and algae and causes the lake's ecosystem to age and deteriorate. This process is called **eutrophication**. Phosphorous is the nutrient of most concern, though nitrogen loading has also received significant attention and abatement measures largely because of public health concerns over nitrate levels in drinking water. Carbon also enhances aquatic plant production. Carbon supplies sufficient to support extensive plant growth can enter water from the atmosphere in the form of carbon dioxide or in water as dissolved bicarbonate (HCO_3) compounds.

Nitrogen is available from many sources, including rain, lightning, ground water, the fixation of atmospheric nitrogen by blue-green algae, agricultural practices and lawn fertilization. For many lakes and streams, however, the major inputs of nitrogen and phosphorous are from **point sources** (single locations of discharge or release) such as sewage treatment plants, septic tanks and feedlots. Most of these sources can be identified and appropriate steps initiated to control their release of nutrients. For example, phosphorous can be partially removed through tertiary treatment at sewage treatment facilities, drainage from feedlots can be controlled, sewer systems can be installed in place of inadequate septic systems, and the use of phosphate detegents can be minimized.

Not all water bodies obtain nutrients from point sources. When nutrient inputs or other contaminants are from **nonpoint sources**, control is much more difficult. Nonpoint source pollution results from land run off, precipitation, acid rain or percolation rather than from a discharge or release at a specific, single location. Watershed alterations and management practices to reduce nutrient and other contaminating inflows include the following:

1. Installing vegetation or grass sod along drainage areas and around receiving waters to prevent run off and absorb nutrients (wetlands play a key role in this type of nutrient filtering).

2. Discontinuing turfgrass fertilization in a 10- to 20-foot strip around the body of water or, if this area requires fertilization, using only fertilizers without phosphorous on a limited basis. Fertilization of high-maintenance lawns and golf courses can be a major source of nutrients in ponds and lakes.

3. Preventing livestock from entering the body of water. Animals not only fertilize the water but tear down banks and increase soil erosion.

4. Practicing conservation tillage methods in areas that are subject to severe soil erosion.

5. Constructing a settling pond to receive nutrients before the flow reaches the main body of water (in cases where nutrients may be entering by means of sediments in an inflowing stream).

6. Constructing wetlands. These may be a series of small ponds and areas planted with emergent wetland vegetation. When properly engineered, constructed wetlands can effectively remove nutrients, such as phosphorous, from inflowing water.

7. Avoiding adding fertilizers to a body of water. In fact, except in certain commercial fish production operations, fertilizers should seldom be added to a body of water.

8. Checking for hidden sources of nutrients such as septic fields and drainage tiles. Septic systems can be checked using dyes available from state or local health boards.

9. Planting deciduous trees far enough from water bodies so that leaves will not fall into the water and accumulate.

Techniques to reduce nutrients in a body of water have been most effective for controlling organisms, such as phytoplankton, that receive nutrients from the water. Even though every effort should be made to reduce nutrient inputs into water, most evidence suggests that these efforts are unlikely to decrease the growth of established rooted plants. Reducing nutrient inputs to control rooted plants may be helpful in the long term for older lakes but is probably most effective in lakes where sediments have not become heavily loaded with nutrients.

Engineering shallow areas. New ponds and lakes should be constructed to avoid extensive areas less than 3 feet deep. Shoreline edges should be deepened to at least 3 feet to reduce sites for rapid establishment of plants. The only exception should be swimming areas, in which sharp drop-offs may be hazardous.

Shallow areas in existing ponds or lakes can be deepened with dredges or draglines to create a slope of 3:1 to a depth of 6 to 8 feet. Removing sediment also removes nutrients and plants. A dumping site away from the water's edge must be available for the removed hydrosoils.

Mechanical control

Mechanical methods to remove existing stands of aquatic weeds include hand pulling, raking, and using mechanized equipment.

Removal by hand can be effective, but it is extremely time consuming and laborious. Regrowth from seeds and underground plant parts can be expected.

Mechanized equipment includes a variety of dredging machinery and weed cutters. Draglines are used to remove vegetation and sediments from irrigation and drainage ditches. Draglining is an effective weed control method, but it is expensive and usually needs to be repeated every 3 to 4 years.

Weed cutters cut underwater rooted vegetation 4 to 6 feet below the water surface. They are used primarily on large lakes or rivers. Most machines also remove, or harvest, the cut material from the water body. Cutting/harvesting has several advantages. All types of aquatic vegetation, including filamentous algae and vascular plants, can usually be removed by this method. The technique can be practiced under most nonwindy conditions, and there are no restrictions on the size of the area to be cut or the use of the water after treatment.

Weed cutters that do not harvest the plants are not recommended because cut plant fragments can live for long periods of time floating in water. These plant fragments develop roots and can invade other areas. The cut fragments may also collect along shorelines and create a considerable mess along lakefronts and in swimming areas.

Aquatic weed cutters that harvest the cut plant material prevent it from decomposing in the water. Removing plant material reduces the risk of fish kills due to suffocation caused by decomposing plant material and the resulting oxygen depletion. To some degree, it also removes nutrients.

Only a small portion (2 to 3 percent in some cases) of a lake's total nutrient content is contained in the aquatic weeds. Over a long period of time, harvesting may lower the nutrient content of a body of water, if new nutrient inputs are prevented from entering the lake and nutrients are not recycled from the sediments.

Several factors should be considered before investing in a mechanical harvester. Purchase and maintenance costs can make these machines an expensive form of weed control. Mechanical harvesting is like mowing a lawn — plants continue growing from the uncut portions, so harvesting must be done several times during the season to maintain open water. Mechanical harvesters are not suitable for removing vegetation in water less than 1 to 3 feet deep, so many bodies of water will be too small for the large commercial equipment currently manufactured. Another consideration with mechanical harvesting of aquatic weeds is the disposal of vegetation. A du m ping area must be available from which vegetation cannot wash back into the body of water. Harvested aquatic weeds can be used as mulches or fertilizers in gardens and fields.

A disadvantage to weed cutting and harvesting is that the initial process is **nonselective**. All plant types growing among the weeds, both nuisance and desirable species, are removed. When harvesting is used over several years, some highly undesirable plants such as Eurasian watermilfoil may become the predominant species and more desirable plants may be excluded. Fish and small organisms that live in the weeds are also commonly victims of harvesting. Wise use of several management techniques will avoid the nontarget impact and long range selectivity of potentially undesirable species.

Finally, the plant stubble that remains after harvesting may release nutrients into the water. It is not uncommon for water clarity to decline immediately following a harvesting operation because of sediment suspension or algal blooms. This condition is usually temporary and water quality is typically restored within a few days.

Cultural control

Cultural weed control can also be used at aquatic sites. It involves altering the environment in which the weeds are found. Altering the habitat where weeds prefer to grow will discourage their establishment or reproduction. Examples include the following practices:

1. The shoreline can be lined with rocks (called riprap) to prevent both erosion and establishment of aquatic weeds.

2. Winter drawdowns are effective for controlling many submersed and rooted floating weeds. This technique involves exposing the shallow areas to drying and freezing conditions. Drawdown can be achieved with structures built to control water flow into the pond, lake or ditch; the installation of siphoning systems to lower the water level; or by natural means as a result of receding shorelines during periods of low rainfall. One of the benefits of a partial drawdown is to concentrate the fish in a small, deep area away from the shallow weed zone. Concentration enables more effective predation of small fish by large fish, which may result in an improvement in fish quality. Another benefit is the drying and consolidation of the sediments, which slightly deepens the water body. Drawdowns may also restructure the species com position of the lake flora. Naiads and milfoil may become dominant as a result. The following list summarizes the effect of winter drawdowns on a variety of aquatic plant species.

Susceptible to drawdown:
- Largeleaf pondweed *(Potamogeton amplifolius)*
- Waterlily *(Nymphaea tuberosa)*
- Watershield *(Brasenia schreberi)*

Moderately tolerant to drawdown:
- Leafy pondweed *(Potamogeton foliosus)*
- Water smartweed *(Polygonum natans)*

Tolerant to drawdown:
- Bulrush *(Scirpus validus)*
- Cattail *(Typha latifolia)*
- Coontail *(Ceratophyllum demursum)*
- Sago pondweed (*Potamogeton pectinatus*)

Predominance enhanced by drawdown:
- Naiads *(Najas* sp.*)*
- Milfoils *(Myriophyllum* sp.*)*
- Curlyleaf pondweed *(Potamogeton crispus)*

3. Covering bottom sediments with black plastic, landscape fabric or other light-blocking materials can be useful on a small scale for controlling submersed weeds. Several bottom-covering materials are commercially available. They are also called **benthic barriers**. The best benthic barrier is gas permeable and opaque and cannot be penetrated by plant roots or vegetation.

Areas suited for this technique include boat dock areas and swimming beaches. The material may be installed during impoundment construction, drawdown or ice cover and weighted with sand or gravel. Benthic barriers must be securely fastened to a substrate to prevent their being buoyed upward by the gases naturally produced in the underlying sediments. Plastic will become brittle over time and may break apart and float to the water surface. These pieces of plastic or other benthic barrier material are unsightly, may create a swimming hazard and can damage boat motors if they become entangled in the propellers.

4. Nontoxic dyes, which act as light screens, can be used to inhibit submersed plant growth. An example is a blue dye that absorbs light that plants would otherwise use for photosynthesis. This dye can be applied easily, disperses readily in a body of water and reduces plant growth. The dye concentration must be maintained throughout the growing season, so its use is limited to ponds with very little outflow. Also, dyes must be applied before weeds emerge in the spring. Once weeds reach the water surface, the dye has little effect. Some dyes are registered as pesticides; others are not. Only dyes approved for use in ponds should be used.

5. Aeration may control algae but does not affect macrophytes. If this process is not done correctly or thoroughly, the aquatic algae problem may increase. Aeration can increase aquatic plant problems by bringing nutrients that were trapped in the colder, deeper water to the surface, causing an algae bloom. To date, the benefits derived from controlling aquatic weeds or algal blooms by this technique in small ponds and lakes have not adequately been demonstrated. The primary benefit of aeration may be to prevent oxygen depletion during the summer or winter and thus, to prevent fish kills. In deep, thermally stratified lakes, aeration and destratification methods and devices have reduced phytoplanktonic algae production and shifted the species dominance from blue-green algae to more desirable species. Destratification techniques can alter nutrient and gas concentrations in the water column.

Biological control, or biomanipulation

Biological controls include strategies that introduce or enhance the production of organisms that restrict pest species. **Biological controls** may be introduced to encourage or artificially increase plants and animals that are parasites or predators of a pest. Biological controls have been used to manage insects, mites and some weeds in terrestrial settings. In Florida, several insects have been successfully introduced and provide varying levels of control of aquatic weeds such as alligatorweed, water hyacinth, hydrilla and water lettuce. The use of snails, manatees, ducks, crayfish and water buffalo for biological control of aquatic weeds has also been attempted. Most of these practices are not practical in Missouri.

Aquatic weeds have been controlled by several species of herbivorous (plant-eating) fish. Grass carp or white amur have successfully controlled weeds in many parts of the United States, but they are not legal for use in all states. Grass carp *(Ctenopharyngodon idella)* is an Asian member of the minnow family and is recommended for controlling some plants in Missouri. These fish are capable of eating two to three times their weight in plants each day and may gain 5 to 10 pounds in a year.

Herbicide technology and application considerations

Aquatic herbicides can be used to manage aquatic vegetation effectively and cost efficiently. A herbicide formulation consists of an organic (carbon-containing) or inorganic active ingredient, an inert carrier and perhaps adjuvants. Every herbicide must be registered for use in the United States by the Environmental Protection Agency, and a registration fee must be paid to the Missouri Department of Agriculture before it can legally be used here. At present, there are fewer than 10 herbicides labeled for use in aquatic sites in Missouri. The reason there are few aquatic herbicides is that the aquatic environment limits the number of compounds that will be effective for controlling aquatic plants and at the same time meet the rigid environmental and toxicological criteria necessary for registration. Aquatic herbicides must have the capacity to be taken up from the water by plants quickly and in sufficient amounts to be toxic to target plants and have sufficiently low toxicity to humans and to other organisms in the aquatic environment.

Several herbicides are packaged in a number of formulations, most of which are not registered for aquatic use. Always use the product labeled for aquatic sites — only these products offer low risk and effective control and have labels with the appropriate use information for aquatic settings. Applying unlabeled products or products that do not specify aquatic sites violates both federal and state laws and regulations and may severely damage the environment and possibly harm the user.

Aquatic herbicides and algaecides come in various formulations and can be used in a variety of situations. With careful selection and proper application rates and timing, aquatic herbicides are a selective lake management tool. Selectively removing exotic and other nuisance species can shift lake flora to more desirable native species that provide better habitat for fish and invertebrates.

Herbicide selection

Several factors need to considered in planning a successful aquatic herbicide program:

1. Proper identification of the weed or weeds.
2. Uses of the water to be treated.
3. Goals outlined in the lake's management plan.
4. Timing of the treatment.
5. Water characteristics, including temperature, hardness, alkalinity, percent saturation of dissolved oxygen, and water flow.
6. Method of application.
7. Probability of retreatment, potentially within the same year.
8. Impact on nontarget plants and animals.
9. Weather.
10. Cost.
11. Permits and permission from appropriate agencies and property owners or managers to perform the treatment.

Absorption characteristics

Contact herbicides. Contact herbicides act quickly and are generally lethal to all plant cells that they contact. Because of this rapid action or other physiological reasons, they do not move extensively within the plant and are effective only where they contact plants. For this reason, they are generally more effective on annual herbaceous plants. Perennial and woody plants can be defoliated by contact herbicides, but they can regrow from unaffected plant parts. Because contact herbicides do not kill the entire plant, retreatment is necessary, sometimes two or three times per year.

Systemic herbicides. Systemic herbicides are absorbed into the living portion of the plant and move within the plant (translocation). Systemic herbicides are absorbed at varying degrees by various plant parts. Systemic herbicides that are absorbed by plant roots are referred to as soil-active herbicides; those that are absorbed by leaves are referred to as foliar-active herbicides.

When applied correctly, systemic herbicides act more slowly than contact herbicides. They must move to the part of the plant where the control action takes place. Systemic herbicides are generally more effective than contact herbicides for controlling perennial and woody plants. Systemic herbicides generally have more selectivity than contact herbicides.

When using systemic herbicides, use only the amount necessary for control. This amount will never exceed label rates but may be lower than label rates under some situations. Exceeding label rates is not only illegal but may cause the foliage to burn off before it can absorb and translocate the herbicide throughout the plant and into the root system. This leaves the roots intact and able to generate new top growth. This situation may lead to the undesirable need for additional treatments later in the season.

Plant processes and herbicidal activity

Cell division. Plants grow by increasing their number of cells and replacing old cells. This process is called cell division. If a herbicide can stop cell division by affecting one of the many complex processes involved, it can stop the plant from growing. If cell division is sufficiently affected, the plant will die. Herbicides that affect cell division are most effective when they are applied **preemergence** (before weed seeds germinate and begin to grow) or during early growth.

Tissue development. During tissue development, plant cells become specialized and organized into units that perform particular functions in the plant. When a herbicide causes abnormal tissue development, abnormalites such as twisting of stems and leaves may be evident. If sufficient abnormalities occur, plants can die. Herbicides that act in this manner are often called plant growth regulators (PGRs). 2,4-D is an example of a herbicide that interferes with tissue development.

Photosynthesis. Photosynthesis is the process by which plants use carbon dioxide, water, and sunlight to produce molecules that are building blocks for other complex molecules that make up the plant body. Photosynthesis is a very complex process, and various herbicides disrupt it in different ways. Plant death may be slow when the photosynthesis process is disrupted.

Respiration. Plants produce compounds such as sugars and carbohydrates during photosynthesis. Plants then use these compounds through a series of processes known as respiration. Many herbicides affect respiration, although these are probably secondary reactions.

Nitrogen metabolism and enzyme activity. Nitrogen is an essential plant nutrient and is involved in many plant processes. Its absorption and incorporation into plant compounds is referred to as nitrogen metabolism. Complex nitrogen-containing compounds called enzymes are essential to plant processes. Many herbicides affect plants by interfering with the enzymes associated with these processes.

Selectivity

Broad-spectrum herbicides. Broad-spectrum (sometimes referred to as nonselective) herbicides are used to control all or most vegetation. Glyphosate is an example of a broad-spectrum herbicide.

Selective herbicides. Selective herbicides are those that are used to control certain plants but cause little or no injury to others. An example is 2,4-D, which can be used to control broad-leaved weeds with minimum impact on grasses. Herbicide selectivity is based on various plants' susceptibility or response to herbicides. Many related physical and biological factors contribute to a plant's susceptibility to a herbicide. Physical factors that contribute to selectivity are

- Herbicide placement
- Formulation
- Rate of application

Biological factors that affect herbicide selectivity are

- Physiological factors
- Morphological factors
- Stage of plant growth

Selective application can be as simple as carefully placing the herbicide on target plants and avoiding nontarget plants. For example, when small amounts of purple loosestrife are growing among cattails, an experienced applicator using a hand-held sprayer can control the loosestrife with minimum impact on the cattail community. This is an example of selective weed control by herbicide placement.

Herbicide formulation can also affect the selectivity of foliar-applied herbicides by increasing the herbicides' ability to enter the plant. The manufacturer may add adjuvants to one formulation and not to another. These additives can increase a herbicide's ability to pass through the cuticle (the waxy coating on leaves) or aid in bypassing leaf hairs by reducing surface tension.

Selectivity can be affected by the amount of herbicide applied. For example, low doses of certain herbicides may selectively control exotic species while inflicting only minimal damage on native species. The salt of endothall has been used at very low rates for the control of curlyleaf pondweed, and 2,4-D used at low rates has effectively controlled Eurasian watermilfoil with little or no impact on nontarget species. Higher rates of the same herbicide may control a much broader range of plant species.

For a herbicide to be effective, it must first contact or enter the plant tissue. Morphological characteristics such as thick cuticles, waxy coatings or hairs can affect a plant's susceptibility to herbicides by physically preventing entry of the herbicide into the plant. Likewise, leaf shape and angle can affect the entrance of herbicide into the plant. Broad, horizontal leaves will intercept and retain a greater amount of herbicide than narrow, upright leaves such as those of grasses and cattails.

A herbicide must be absorbed directly into cells or move through the plant (translocated) to the site where it is active. Herbicides may be bound on the outside of some plants or bound immediately after they enter the plant so that they cannot move to their site of activity. Some herbicides affect very specific biochemical pathways in plants. Therefore, they may be selective against a particular group or groups of plants because they are the only ones that have that particular pathway. In addition certain plant parts may be susceptible to a herbicide while others parts of the same plant are not affected.

Growth stage can affect susceptibility in several ways. Young, actively growing annual plants that have not developed a cuticle or leaf hairs are more susceptible than mature plants to foliar-applied herbicides. The physiology of perennial plants changes during an annual growth cycle. During early stages of growth when upward transport of food reserves and other plant compounds is rapid, soil-active herbicides are readily absorbed and moved upward to the growing points and sites of herbicide activity. Conversely, foliar-active herbicides (e.g., glyphosate) are least effective during this time, allowing some plants to tolerate the treatment.

During late and postflowering periods, perennial plants are completing that year's growth cycle. At this time, they are translocating materials downward to the roots and are most susceptible to foliar-active herbicides, which move downward to the roots with the plant materials.

Environmental factors that affect herbicide application

Weather conditions, water movement, soil chemistry and water chemistry can greatly affect the success of aquatic herbicide applications. The applicator has little or no control over some of these factors but can control or compensate for some others.

Weather conditions. Rainfall has an obvious effect on a herbicide application because of the potential for washing off foliar-applied herbicides. This is a particular problem with slowly absorbed systemic herbicides such as glyphosate. It is also possible that rain can enter a water body at a rate that dilutes a herbicide to an ineffective concentration. The applicator should be aware of potential weather conditions and should schedule applications accordingly.

Windy conditions can cause poor foliar application coverage. Wind can also indirectly affect the ability of leaves to absorb herbicides. Windy conditions favor herbicide drift, so applications should not be made when wind is strong enough to cause drift. Wind can also affect the efficacy of herbicide applications for submersed plant management. Wind can affect the efficacy of submersed weed control applications by causing water movement that carries the herbicide away from the target plant. For herbicide effective ness, sufficient concentrations must be present for sufficient periods of time.

Temperature affect s herbicide efficacy indirectly by affecting plant growth. At less than optimum temperatures, plant growth decreases, and this may decrease herbicide absorption and activity. It has been suggested that temperature gradients within the water column have been a primary factor in the exchange of water between the shallow and open water regions of lakes.

Most herbicides used for submersed aquatic weed management must be absorbed from the water into the target plants. A sufficient amount of herbicide must be available in the water long enough for the herbicide to be effective. It is difficult to manage submersed aquatic weeds in rapidly flowing water where the herbicide is carried away from the plants with the water flow. Special techniques must be used even in slow-moving water.

The following methods may be used when managing aquatic weeds in flowing water:

- Use of trailing hoses to aid sinking the herbicide and getting it to adhere to the plants.
- Use of special herbicide formulations for flowing water, such as slow-release pellets.
- Use of rapidly absorbed herbicides.
- Use of sequential applications or injection equipment to increase contact time.

Water chemistry factors that influence herbicide efficacy include pH, turbidity, and hardness. The applicator has little control over these factors; however, the applicator can decide which herbicide to use or adjust the rate of application according to conditions. More important, the chemistry of dilution water can affect herbicide performance and the applicator can sometimes make adjustments for this. A pH measurement indicates whether something is acidic or basic on a scale from 0 to 14. A pH value of 7 indicates neutral conditions, while values less than 7 indicate acidic conditions and values above 7 indicate basic conditions. The pH of water can affect the rate at which plants absorb some herbicides. Knowing how the herbicide reacts in a given pH range will help in selecting the appropriate rate to apply. Some herbicides have increased activity in acidic waters, therefore lower rates may be applied to obtain adequate weed control.

Turbidity is a measurement of water's ability to transmit light. This measurement is affected by suspended particles. The suspended particles can be biotic, such as plankton, organic or inorganic (clay, minerals). Organic or clay particles are of most concern to the applicator because they can inactivate herbicides by binding to them. Particulates in diluent water can also affect herbicide performance and even render chemicals ineffective. Diluent water that is as clean as possible should be used and care should be taken to keep the suction end of the filler hose far enough from the lake bottom to avoid drawing in sediments.

Knowledge of water hardness is important because it can have important effects on herbicide performance and environmental considerations. Certain herbicides can react with hardness components in water. This may cause them to become inactive or precipitate (come out of solution). This can happen either in lake water or in the spray tank. Consult with your chemical representative for details specific to each pesticide product. If possible, using softened or distilled water might aid in the efficacy of certain treatments — glyphosate applications, in particular.

The herbicidal properties of copper are very sensitive to hardness compounds in water. Inorganic copper algaecides are much more potent in soft water (less than 50 parts per million calcium carbonate). Application rates must be adjusted downward accordingly to avoid nontarget impacts, especially to fish. When using copper in hard water, chelated forms of copper are much more effective because they stay in solution longer, are more readily absorbed by plants and are less toxic to fish.

Water chemistry is an important factor in the performance of herbicide applications. The applicator has some influence over some of these factors, especially the source of diluent water for tank mixes. The following precautions should be taken when obtaining water for applications:

- Use the cleanest water available. Avoid sediments.
- When using herbicides that are known to be inactivated by hard water, use the softest water available. If possible, use softened or distilled water; lake water is the next best choice.
- Minimize the amount of time that herbicides remain mixed in tanks.
- Read the label for special precautions or instructions.

Effects on fish and other organisms. When used properly, aquatic herbicides are not toxic to fish, birds or other aquatic organisms. They are also short lived in the environment and do not accumulate in organisms. Under certain circumstances, however, fish kills occur as a direct or indirect result of aquatic herbicide applications. Fish kills are likely to occur as a direct effect of herbicide application only if a herbicide formulation known to be toxic to fish is applied in an enclosed water body. This type of herbicide should never be used where fish cannot escape toxic concentrations. When coves are treated, application should begin near shore to give fish an opportunity to escape. Most aquatic herbicides have very low toxicity to fish, and the concentrations that occur after application of recommended rates are far below concentrations that are toxic to fish. Rates of copper sulfate recommended for difficult-to-control filamentous algae can be toxic to fish in enclosed ponds, however, and care should be taken when making this type of application.

The most common reason for fish kills due to aquatic herbicide application is the indirect effect of lowered dissolved oxygen in the water. When performing any herbicide treatment, it is vital to limit the amount of vegetation killed at any one time. When a herbicide application kills large amounts of aquatic vegetation, the decaying vegetation and lack of oxygen production may cause dissolved oxygen to become so low that fish cannot survive in the water. If a herbicide that is effective on higher plants is used, and phytoplankton is present, the potential for a fish kill is reduced because the phytoplankton will continue to produce oxygen. Review the product label statements — they may limit the percentage of the lake area treated during one application.

The danger of fish kills is less in cooler water because it can hold more oxygen than warm water. For example, oxygen-saturated water at 65 degrees F contains 9.2 parts per million oxygen, whereas water at 85 degrees F contains only 7.5 parts per million oxygen.

To minimize the potential of fish kills, avoid herbicide applications to large areas of weeds, to warm water, during prolonged periods of cloudiness, and in areas where fish movement is restricted. Manage large weed populations by a series of applications to portions of the water body, or treat during the spring when water temperatures are lower. As a general rule, no more than one-third of the water's surface area should be treated at one time. If more than one-third of the area needs treatment, follow with a second application two to three weeks later.

Herbicide-related fish kills, either direct or indirect, are not likely to occur as a result of partial area applications in large water bodies because if they can, fish will move to other parts of a lake to avoid adverse conditions. Nevertheless, all precautions should be taken to avoid conditions that could lead to fish kills when applying aquatic herbicides.

Water use restrictions

The introduction of most aquatic herbicides into an aquatic environment requires restricting the use of the water until the herbicide has degraded, become inactivated or dissipated. Consequently, deter mining the present and potential uses of a body of water is one of the most critical steps in choosing an aquatic herbicide.

Restrictions on water use after a pesticide treatment are imposed for several reasons. Based on data required for pesticide registration, residue tolerances, residue data and environmental fate, water use restrictions or precautions for drinking, swimming, fishing, irrigation, watering livestock and domestic uses may be placed on the label (See Appendix Table 1 for specific restrictions on the use of various herbicides). This process ensures that the public will not come in contact with a herbicide at potentially harmful concentrations.

Water use restrictions also prevent people from disturbing the lake water and sediments, which could reduce the effectiveness of the treatment. Compounds must be absorbed by the plants in large enough quantities to kill them. If swimmers enter the treated area before the plants absorb enough of the active ingredient, the sediment that they kick up may bind with the herbicide and render a treatment ineffective.

The period of restriction, which varies among herbicides, depends on the dosage and the persistence of the compound in the water. Some restrictions extend for only a few days, and others may last for 12 months.

Other herbicide restrictions involve the type of water body to be treated. In many cases, a herbicide is restricted to a certain type of site, such as an irrigation canal (vs. a drainage ditch), a ditch-bank (vs. open water treatment), or nonflowing (vs. flowing) water.

If the restrictions are not clear, then the Missouri Department of Agriculture and the Missouri Department of Natural Resources should be contacted. Restrictions are usually imposed for streams, public or multiple-use lakes, and reservoirs. Always consult herbicide labels and state agencies for detailed information.

Algaecides

Chemicals used to control algae are known as **algaecides**. Timing their application to obtain desirable results is critical. Copper compounds should be applied on bright, sunny days when algae are actively functioning and releasing oxygen. Early in algal bloom development, the algae may be dispersed throughout the water, whereas later the bloom may form a surface scum. Low concentrations of chemicals can be used to thin algal populations during development. After a scum forms, treating only the upper 2 feet of the water with an algaecide is required. When treating algal scum, the amount of chemical needed for the upper 2 feet should be calculated . The treatment should be applied to the water surface or injected just beneath the surface. This method can be used only with copper compounds. Because a rapid kill of algae can cause oxygen depletion, early season treatment when waters are cool and well oxygenated and algal populations are low is preferable to later treatments.

If treatment of attached algae is needed and the growth is underwater, the algaecide should be dispersed in the water. If mats of attached algae are floating, at least some of the com pound should be dissolved in water and sprayed directly on the mats. Algaecides containing copper must come in direct contact with the algal cells to be effective.

Pesticide fate

Aquatic pesticides have many potential fates. The most desirable fate is **absorption** by the target pest. If plants are the target pest, pesticides can be absorbed by the leaves, stems, flowers or roots. Generally, if they're not absorbed, the compounds will naturally degrade, either by microbial action, chemically, photochemically, or by being chemically bound to sediments and then broken down.

Microbial degradation is mediated by microorganisms that either change the compound into something else or actually break it down to its elemental components. If changed into something else, the original compound may become more or less toxic.

Chemical degradation can occur through many pathways, the most common of which is **oxidation**. Photochemical degradation, or **photolysis**, can also transform or degrade a pesticide. The process involves sunlight, either through direct inter action with the pesticide, or indirectly by sensitizing another compound that degrades the pesticide through the process of energy transfer. **Adsorption** is the process by which the pesticide is physically or chemically bound to soil particles. This occurs most frequently in soils with high organic matter content.

Once it is adsorbed to particulate matte r or sediments, the pesticide can be broken down by one of the processes described above, either while still bound to the soil particles or after being released. Adsorption to bottom sediments causes a herbicide to be unavailable. This is undesirable if toxic concentrations to the target plant were not reached or retained long enough for an effective treatment.

Other undesirable fates of pesticides remove or lessen the amount of pesticide available for the intended purpose. Drift, through the movement of water or wind during application, not only can lessen the amount available but can potentially harm nontarget areas and species. Applicators are liable for damage caused by drift to nontarget sites. Some pesticides are **volatile**. The more volatile a substance is, the more likely it is to have vapors associated with it as it evaporates. Few aquatic herbicides are volatile.

Timing of treatment

Most aquatic herbicides are applied in mid- to late spring or early summer when the weeds are young and growing vigorously and before they have gone to seed. Herbicide penetration and translocation are usually greatest before plants reach maturity. Not only are the weeds more susceptible at this stage, but there are fewer weeds to treat than there will be later in the season.

Another reason for early season treatment is that cool water contains more oxygen than warm water; therefore, there is a greater margin of safety for fish. Most aquatic herbicides, however, should not be applied when the water is too cold (below 60 degrees F). Though plants grow at these temperatures, they may not be metabolizing rapidly enough to take in sufficient quantities of herbicide for the herbicide to be effective. Treatment should be delayed when there is a chance that heavy spring rains will wash the herbicide out of the target area or off the target plant. Consult labels for specific restrictions on the use of postemergence herbicides before rainfall.

Except when preemergence herbicides are being used, plant growth should generally be visible at the time of treatment. Evidence indicates that autumn treatments of some species of submersed weeds are effective. For most species, however, plants have produced seeds or algal spores by fall, from which new plants will grow the following spring.

Chemical application methods and techniques

Although the correct chemicals must be selected for treating aquatic weeds, the application technique you use will deter mine whether or not a chemical will be effective in controlling the aquatic weed population. Specific application techniques are available for different situations and should be used according to the particular type of aquatic weed problem that exists.

When treating aquatic weeds in situations where fishing is valued, partial treatment is recommended instead of total treatment of the body of water in one operation. Particularly in waters high in nutrients, a complete treatment may reduce the recovery capacity of the lake or pond or may cause a fish kill. Often in a complete treatment, the nutrients released by the decaying plants are recycled into undesirable types of algal growth.

Aquatic herbicides are formulated as liquids, powders and granules. The liquids and powders are usually applied in a water carrier, whereas granules are applied directly to the water or to exposed sediment surfaces. For more specific information regarding pesticide formulations, consult *Applying Pesticides Correctly: Missouri Core Manual* (MU publication MX328).

Volume treatments. Liquid treatments to a body of water can be accomplished in several ways. Pouring the herbicide directly from the container is the least desirable method because it does not ensure mixing. Liquids and powders are usually diluted in water to facilitate even distribution. Dilution ratios depend on which product is used, and the proper ratios are given on the label. When a water carrier is used, the solution is sprayed on the surface and allowed to sink to the bottom, or it is injected into the water a foot or two below the surface. Injection can be accomplished by siphoning the solution into the water with a boat bailer or by pumping the chemical into hoses that trail behind, attached to a boom. For applications with a boat motor, powered pumps may be adapted with a "Y" intake that will simultaneously pump water from the lake and chemical from the container. A hose fitted with a hand-held applicator, a boom, or a subsurface injector is used on the discharge side of the pump.

Bottom treatments. Herbicides can be injected into bottom water by connecting weighted brass pipes to 15- to 30-foot hoses that extend from a boom on the spray boat. The herbicide is released into the water through small holes bored about 6 inches from the end of the pipe. For best results, pipes should be no more than 3 feet apart. Application rates are based on the volume of the lower 2 feet of water. The technique is particularly effective early in the growing season when submersed weeds are still short. Best results are obtained in static bodies of water that have firm sandy bottoms; it is not recommended for flowing water or muddy bottoms.

Granular treatments. Granular pesticides are usually applied with a granule spreader or by hand. This formulation sinks to the bottom and then releases the active ingredient into the water. Granules have the advantage of being easy to apply in a uniform manner.

Spray treatments. Plants with most of their leaf area above the water surface (emergent, free-floating, and rooted floating plants) are usually sprayed with aqueous solutions of herbicides. In many cases, the addition of an adjuvant to the spray tank is recommended. Consult specific labels for recommended types and rates of adjuvants. Herbicide dosage is calculated on the surface area to be covered.

Treatment of water conveyance systems. Flowing water in ditches and canals requires control techniques different from those used in lakes, ponds or other static systems. Herbicide solutions are usually injected or allowed to drip into the water, and the water disperses the herbicide. In drip systems, constant flow metering devices slowly drip the chemical into the water. The dosage rate for this type of use with copper complexes may be given as the amount of herbicide per cubic feet per second (CFS) per hour. CFS can be determined using the following formula:

CFS = average width (ft) x average depth (ft) x velocity (ft/sec)

More detailed information and examples of these types and other calculations are given in the "Calibration" section of this manual.

Re-treatment. Most aquatic herbicides are contact materials and have a relatively short persistence. This characteristic can be desirable because restriction times on the use of water can be fairly short. However, it can also be undesirable because vegetation can reinfest an area soon after treatment, either from vegetation not killed by the treatment or vegetation that comes back from seeds, spores, or under-ground structures. This problem is particularly true of algae. Algae often must be re-treated several times per season, whereas flowering plants usually require only a follow- up treatment to catch missed or late- sprouting plants. Unfortunately, new weed species that previously were not problems sometimes appear later in the same season of treatment. A common weed shift is the appearance of chara after submersed flowering plants are controlled. Another is the bloom of microscopic algae after submersed plants are killed, or vice versa.

Retreatment in subsequent years is usually required because new species appear or weeds return from seeds, spores, or vegetative propagules. A successful chemical weed control program should be considered as a long-term program requiring continuing treatments.

Aquatic insects and their control

There are times when control of certain aquatic insects is necessary. Such instances involve the control of insect vectors of human and animal diseases or a temporary reduction in the nuisance effects of high insect populations in public areas and surrounding households.

Nonchemical means of control are preferred but are usually too slow in emergency situations. Insecticides are typically the recommended control measure because of the necessity for rapid pest reduction. The cost of pesticides and their usually quick but temporary control must be balanced with nonchemical methods that may provide much longer lasting reductions in pest populations. Initially, these nonchemical methods may be more expensive.

Nonchemical methods

Nonchemical methods of pest reduction should be built into each program from its conception. Then the design and methods should be carried through the operation of the program. These methods include the following:

- Design of water impoundment areas.
- Maintenance of water impoundments such as shoreline vegetation and algae control.
- Operation of water impoundment; do not overload; also maintain adequate aeration and circulation.
- Water management such as filling or draining wetlands, but only when absolutely necessary.
- Implementing good sanitation practices.
- Using mechanical methods of pest control.
- Using mosquito-eating fish.

The Mosquitofish

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Everyone knows about mosquitos, but few Missouri residents have encountered mosquitofish. These little fish are known for mosquito control and thrive in brackish and vegetated waters, where many mosquitos hatch. Mosquitofish females can grow to about 2.8 inches, while the males seldom grow larger than 1.2 inches long. During the summer mating season, which usually lasts 10 to 15 weeks in Missouri, males actively search for female mating partners, which they court with nudging and fancy swimming demonstrations. Courtship rituals are often visible to observers as flashing in the water. Mosquitofish are livebearers; they give birth to live young, instead of laying eggs. A few other livebearer fish are tropical mollies and guppies. Each birth of live young is called a brood, and broods usually consist of between 10 and 100 young. A female can have several broods per season. Mosquitofish prefer warm climates and only a few of the species survive Missouri's cold winters, but these few manage to sustain the population. More mosquitofish are showing up in central and north Missouri. Their spread is thought to be due to people stocking the fish for mosquito control. However, a few other native fish species also can control mosquitos and are better suited to Missouri's climate.

Insects and controls

Mosquitos. Mosquitos are usually the most common aquatic insect pest. They are a nuisance and a serious public health threat. Mosquitos serve as vectors of human and animal diseases. Between 50 and 60 species of mosquitos live in Missouri. Only six of these are known as vectors of human or animal diseases.

The life cycle of a mosquito has four stages: egg, larva, pupa and adult. The first three stages occur in water. Eggs are laid in the water, where they float individually or together in "rafts." Larvae are elongated and called "wigglers." Pupae are called "tumblers." These common names are characteristic of their movement.

In the water, mosquitos are beneficial by providing food for other aquatic animals. Even as adults, only the females of most species suck blood from their host(s). Females require a blood meal before they are capable of laying eggs. Each mosquito species has its preferred type of habitat as immatures or adults and may feed only on certain animals. Some species remain close to their immature habitat, flying only a few hundred feet. Other species are capable of flying ten or more miles.

The use of insecticides to control the larval stage is known as "larviciding." Proper species identification, knowledge of their habitat, and proper timing of application are essential for good control. The degree of pollution and amount of vegetation in the water influence the effectiveness of insecticides. Heavily polluted waters usually require more frequent treatment. Granular insecticide formulations are preferred in areas having heavy vegetation. Even low rates of some insecticides may be toxic to other aquatic organisms, birds, and honey bees. New pesticide labeling to protect federally endangered species may prohibit the use of some insecticides for mosquito control in certain areas.

Insect growth regulators are a chemical control agent that does not demonstrate classical toxicity but interferes with normal developmental processes, such as growth rate, molting or metamorphosis. These compounds are used to control immature mosquitos when applied to larval breeding sites.

The biological insecticide *Bacillus thuringiensis* var. *israelensis* (Bti) has proven to be a very effective larvicide. Research has indicated that this insecticide acts primarily as a stomach poison. Mosquitos are paralyzed when they eat the material, then die when their intestines rupture. The material is not harmful to humans, domestic animals, wildlife, beneficial insects, fish, or other aquatic life.

Midges. Midges of several species may become overpopulated in sewage lagoons, especially those that are allowed to become overloaded. A nuisance situation is created for surrounding residences when adult midges emerge from their aquatic habitat. The adult midges resemble mosquitos in size and shape, but they do not bite or suck blood, nor are they known to be vectors of diseases.

There are four stages in the life cycle of midges: eggs, larvae, pupae and adults. The first three stages occur in water. The blood-red larvae are found on or near the surface of sludge on the bottom of a lagoon. They are actually beneficial in that the larvae feed on and help break down the organic matter. Although some larvae can be found throughout the bottom of a lagoon, they prefer shallow water. This preference ranges from the shoreline out to a depth of about four feet. Also midges prefer a secondary lagoon and are seldom found in a primary lagoon that receives raw sewage.

Proper lagoon management normally keeps the midge population within desirable levels. Conversely, overloaded lagoons may develop an overabundance of midges anytime during the spring, summer and early fall. Bottom sampling of overloaded lagoons often reveals the bottom covered with larvae. Within some two to three weeks, a heavy adult emergence can be expected.

The objective in control of these nuisance midges is to reduce the larval populations temporarily through limited area applications of granular insecticides. The granules must readily sink to the bottom. The insecticide must be of short residual and biodegradable action. Very few insecticides are registered for this use. Abate® is currently registered for this use and is available in several granular formulations. The material should be broadcast from the shoreline out into the lagoon for a distance of 8 to 10 feet or to a water depth of 4 feet. Abate is toxic to other aquatic insects that normally occur in most secondary lagoons.

Unless an effort is made to correct the overloading situation, the midge problem will redevelop within one to three months.

Filter flies. Filter flies can be a problem at sewage disposal plants using trickle filters. Occasionally, heavy infestations of these small, mothlike flies develop. Adult filter flies are not known to be vectors of any diseases, nor do they bite or suck blood. However, the nuisance effect of an overabundance of these adult flies to disposal plant workers and to surrounding residences can be serious.

Four stages in the life cycle of filter flies. There are eggs, larvae, pupae and adults. The first three stages occur in or at the water level. An excessive number of larvae and pupae in a filter can cause what is known as "ponding of the filter." This is a condition whereby the filter rock becomes clogged, either throughout the entire depth or near the surface, which causes pools of sewage to stand either in or on the filter.

If the ponding condition is caused by sloughing of filter-fly larvae and pup ae, or the nuisance problem becomes obvious, it can be controlled by periodic flooding of the filter beds and manual removal.

Calibration

Most aquatic pesticides have specific label directions about the amount of pesticide to be applied per unit area or volume (acre, square feet, acre-foot). For example, "Apply 2 pints of Weedblaster in a minimum of 15 gallons of water per surface acre." Directions of this kind require the applicator to carry out some very important procedures. These procedures normally include

- determination and possible adjustment of the equipment's delivery rate,
- determination of how much area a mixed load of pesticide will cover, and
- in spray applications, determination of how much pesticide to add per tank load of mix.

The ability to carry out these kinds of procedures is one of the most important aspects of pesticide use. **Calibration** is the process used to determine the amount of material the equipment is applying per unit area. There are several good reasons why time invested in calibration is time well spent:

- It is virtually impossible to apply a pesticide at the prescribed rate unless the equipment has been calibrated.
- Pesticide applications exceeding rates listed on the label are illegal.
- Chemicals need to be applied at proper rates to be effective. Too little pesticide may not provide effective pest control. Too much pesticide may cause damage to the treated area, can result in illegal residues, and may cause adverse effects to the environment and to nontarget organisms.

Application equipment suppliers often provide charts and tables designed to help the applicator determine equipment configurations needed to obtain desired delivery rates; however, such sources of information will provide only an approximation of delivery rates. Charts and tables cannot account for equipment wear or inaccurate gauges or speed readings, for example. Consequently, more reliable determinations of equipment delivery rates are usually accomplished by calibrating the equipment.

Treatment types and calculations

Aquatic pesticides can be applied to four different zones in a body of water, depending on the location of the target pest.

Surface/ subsurface treatment. Surface treatments simply treat the water at the surface to control only those weeds and insects at the water's surface. Subsurface applications may also be made through injection hoses that a boat pulls through the water. Surface area measurements are the base for surface and subsurface applications. Applications can be made by air, ground or boat. These applications are usually made with boom sprayers. Surface and subsurface injection treatments are easier and more effective when large volumes of liquid carrier are used.

Example calculation: The label rate of a mosquito larvicide is 8 gallons of formulation per surface acre. The larval infestation in a shallow marsh pond covers an area 500 feet by 750 feet. How much product will be needed to make a complete application?

First, determine how many acres of surface you must treat:

500 ft x 750 ft = 375,000 sq ft

Convert square feet to acres.

375,000 sq ft ÷ 43,560 sq ft per acre = 8.6 surface acres

Note: 1 acre = 43,560 sq ft

If 8 gallons of product per acre are needed, then:

8.6 acres x 8 gallons per acre = 68.8 or 69 gallons of product

Surface area of odd-shaped ponds or lakes sometimes can be cumbersome. The area can be broken into smaller units from which area measurements are more easily made. See Figure 1.

Total water volume treatment. A whole body of water is sometimes treated for aquatic weed or insect control. When making total water volume treatments, the volume of water to be treated must be calculated. The water volume unit most commonly used on pesticide labels is the acre-foot. See Figure 2.

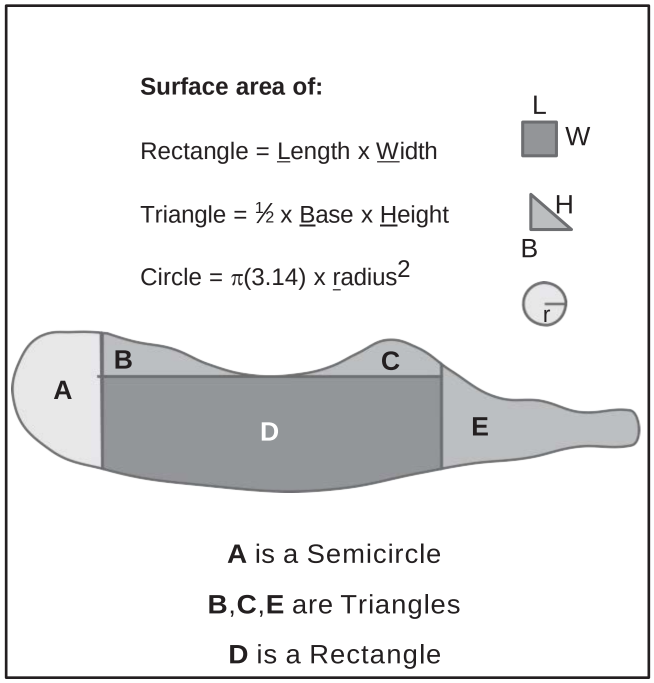

Figure 1. Calculate surface area for treatment.

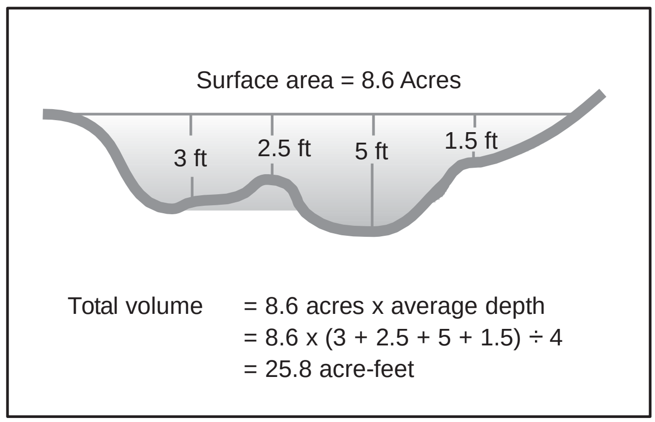

Figure 2. Calculate total water volume for treatment.

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acre-feet of water = surface acres of water x average water depth in feet

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Some aquatic pesticide labels require the user to calculate the amount of pesticide necessary to establish a lethal concentration in a body of water. The pesticide concentration is sometimes expressed in "parts per million" (pp m). The concentration is measured in terms of the weight of the pesticide vs. the weight of the water. For example, the required concentration for control of a specific pest is 2 ppm of the pesticide formulation. The pesticide product should be applied at the rate of 2 pounds of product to 1 million pounds of water in the area to be treated.

An acre-foot of water weighs 2.7 million pounds

Therefore, if 2.7 pound s of the product are dissolved in 1 acre-foot of water, there would be a concentration of 1 part per million (ppm) by weight. The following formula can be used to deter mine the amount of material needed to obtain a desired ppm concentration:

(2.7) x (ppm wanted) x (acre-feet) = pounds of product required

Example calculation: Assume a 5.6 acre pond having an average depth of 5 feet requires a weed control treatment. The concentration of product required is 0.5 ppm. How much product will be needed?

First, determine the volume of the pond in acre-feet:

5.6 acres x 5 ft = 28 acre-feet

Now, the formula from above can be used to calculate the amount of product needed:

(2.7) x (0.5 ppm wanted) x (28 acre-feet) = 37.8 or 38 pounds of product

Many labels provide a table that adjusts the rate depending on water depth and required pesticide concentration so that for total volume treatments, only the surface area needs to be calculated.

Bottom layer treatment. Treating the layer of water is especially useful in deep lakes, where it is impractical and too costly to treat the entire volume of water. Such treatments are generally made by attaching several flexible hoses at 3- to 5-foot intervals on a rigid boom. Each hose is usually equipped with some type of nozzle at the end and may be weighted to reach the desired depth. The length of hose and speed of the boat carrying the application equipment affect the depth of application. Successful bottom treatments are usually achieved by blanket herbicide applications in the lower 1 to 3 feet of water. Calculations for bottom treatments are similar to those for surface treatment, that is, amount of product per bottom acre.

Canal or ditch water treatment. Treating water flowing through an irrigation ditch depends on water volume and its rate of flow. Cross-sectional area is measured by the average width of the canal multiplied by the average depth of the canal.

cross-sectional area = average width of canal x average depth of canal

Water velocity is usually expressed as the distance water moves per unit of time, such as feet per second (fps) or feet per minute (fpm). The water flow rate is determined by multiplying the cross-sectional area by the water velocity.

water flow rate = average depth x average width x water velocity

Labels generally state the application rates in ppm, either by volume (ppmv) or by weight (ppmw). Several additional calculations are necessary to determine ppm equivalent application rates. First, convert flow rates from cubic feet per second (cfs) to cubic feet per minute (cfm) by multiplying by 60 seconds. Next, convert cubic feet of water per minute to volume (gallons) or weight (pounds) of water per minute, depending on whether the label is based on ppmv or ppmw.

One cubic foot of water is equal to 7.5 gallons. A flow rate of 1,000 cfm converts to 7,500 gallons per minute.

One cubic foot of water is equal to 62.4 pounds. A flow rate of 1,000 cfm converts to 62,400 pounds per minute.

The next step is to convert the application rate in ppm to its decimal equivalent:

desired 1,500 ppm = 1,500 ÷ 1,000,000 = 0.0015

Then, multiply this decimal equivalent by the flow rate in gallons per minute or pounds per minute to deter mine the amount of product that must be applied per minute to achieve the desired concentration:

0.0015 x 7,500 gal/min = 11.25 gallons of product per minute

or

0.0015 x 62,400 lb/min = 93.6 pounds of product per minute

Thus, at an application rate of 1,500 ppm and a flow rate of 1,000 cfm, 11.25 gallons or 93.6 pounds of product would be needed depending on whether the label was based on volu me or weight.

Example calculation: A pesticide label of a liquid formulation states that the product should be applied at a rate that will provide a product concentration of 500 ppmv. The label also states that this concentration must be maintained for 15 minutes. The application will be made to an irrigation canal (5 ft wide by 3 ft deep) that is flowing at a rate of 1 foot per second. How many gallons of this product must be applied per minute to achieve a concentration of 500 ppm, and how many gallons of the product will be needed to maintain the concentration for 15 minutes?

First, determine water flow rate in cfs:

5 ft x 3 ft x 1 fps = 15 cfs

Next, convert to cfm:

15 cfs x 60 seconds = 900 cfm

Next, determine the flow rate in gallons per minute:
Note: 1 cubic foot water = 7.5 gallons

900 cfm x 7.5 gallons = 6,750 gallons of water per minute

To achieve a concentration of 500 ppm in 6,750 gallons of water that flow past each minute, convert 500 ppm to its decimal equivalent and then multiply that factor by the flow rate:

(500 ÷ 1,000,000) x 6,750 gallons of water per minute = 3.375 gallons product per minute

This means that the product must be metered into the canal at a rate of 3.375 gallons per minute to achieve the 500 ppm concentration. Finally, determine how much total product will be needed for the 15 minutes:

3.375 gallons per minute x 15 minutes = 50.625 gallons

Example Calculation: A concrete lined irrigation canal has an average flow of 150 cubic feet per second. The label of a dry formulation directs the application to be made at 5 ppmw for 1 hour. How many pounds of product will be needed per minute over the 1 hour period?

First, determine the flow rate of water per minute:

150 cfs x 60 seconds = 9,000 cfm

Next, determine weight of water per minute:
Note: 1 cubic foot water = 62.4 pounds

9,000 cfm x 62.4 lb/cubic ft = 561,600 lb/min

To achieve a concentration of 5 ppm in 561,600 pounds of water that flows each minute, convert 5 ppm to its decimal equivalent and then multiply that factor by the rate of water per minute:

(5 ÷ 1,000,000) x 561,600 lb of water per minute = 2.8 lb of product per minute

Finally, determine how much total product will be needed for the 1 hour:

2.8 lb/min x 60 min = 168 lb/hour

Pesticide treatments of flowing water can be very complex. The problems are often compounded by the fact that the quality of instructions on aquatic pesticide labels is quite variable. Some labels provide complicated but comprehensive instructions, while other labels offer a minimum of instructions on application procedures. If uncertain, the chemical supplier should be consulted for specific directions concerning application procedures and rates.

Equivalents and Equations

Liquid measurements

1 gallon (gal) =	4 quarts or 8 pints or 16 cups or 128 fluid ounces (fl oz)
1 quart (qt) =	2 pints or 4 cups or 32 fluid ounces
1 cup =	8 ounces or 16 tablespoons
½ cup =	4 ounces or 8 tablespoons
¼ cup =	2 ounces or 4 tablespoons
1 tablespoon =	½ fluid ounce

Solid measurements

1 pound (lb) =	16 ounces (oz)
½ pound =	8 ounces

Unit and conversion equivalents

1 acre =	43,560 sq ft
1 acre-foot (ac ft) =	43,560 cubic ft = 325,762 gal = 2,720,000 lb
1 cubic ft/sec (cfs) =	450 gal/minute (gpm)
1 cubic ft =	7.48 gal = 62.4 lb
1 gal =	128 fl oz = 8.33 lb
1 ppm by volume (ppmv) =	1 gal/million gal of water
1 ppm by weight (ppmw) =	8.33 lb of chemical/million gal of water
1 ppmw =	2.72 lb of chemical/acre-feet of water
gal of liquid formulation required =	lb active ingredient (a.i.) required ÷ lb a.i./gal of concentrate
lb of dry formulation required =	(lb a.i. required x 100) ÷ % a.i. in formulation by wt

Formulas for applications to ponds or lakes

Surface area in square feet =	length in ft x width in ft
Volume of water in cubic feet =	surface area in sq ft x average depth in ft
Volume of water in acre-feet =	surface area in acres x average depth in ft
Volume of water in acre-feet =	volume of water in cubic ft ÷ 43,560
ppmv =	gal of 100% a.i. ÷ (volume in acre-feet x 0.33)
Total gal of chemical required =	acre feet x ppmv x 0.33
ppmw =	lb a.i. of chem applied ÷ volume in acre-feet x 2.72
Total lb a.i. required =	acre-feet x 2.72 x ppmw desired
Total gal liquid form required =	(acre-feet x 2.72 x ppmw desired) ÷ lb/a.i./gal concentrate

Formulas for applications to channels

cfs = cross section in area in sq ft x average velocity of water in ft/second (fps)
Cross section area of rectangular channel in sq ft = average width in ft x average depth in ft
ppmv = (gal of chemical x 1,000,000) ÷ (cfs x 450 x minutes applied)
gal of chemical/cfs = (ppmv x 450 x minutes applied) ÷ 1,000,000
Total gal of chemical required = (ppmv x 450 x cfs x minutes applied) ÷ 1,000,000
ppmv = (lb of chemical x 1,000,000) ÷ (cfs x 3,744 x minutes applied)
ppmv = (gal of formulation x lb a.i./gal x 1,000,000) ÷ (cfs x 3,744 x minutes applied)
lb of chemical/cfs = (ppmv x 3,744 x minutes applied) ÷ 1,000,000
gal of formulation/cfs = (ppmv x 3,744 x minutes applied) ÷ (lb a.i./gal x 1,000,000)

Section II: Sewer Line Chemical Root Control

Sewer line root control is a matter of using the right technologies. To be successful, the technology must be effective and must not adversely affect people or the environment.

The purpose of this training manual is to provide a sound foundation for studying the technical aspects of sewer line root control with emphases on the safe use and application of chemical products, especially those containing metam-sodium, a restricted use pesticide.

Roots in sewers

Root-related sewer problems

The intrusion of roots into sewers is probably the most destructive problem encountered in a wastewater collection system. Root-related sewer problems include

- Sewer stoppages and overflows
- Structural damage caused by growing roots
- Formation of septic pools behind root masses, which generate hydrogen sulfide, other gases and odors
- Reduction in hydraulic capacity, and loss of self-scouring velocities
- Infiltration where the pipe is seasonally under the water table

Sewer stoppages and overflows are the way that most municipalities and homeowners find out about their root problems. Structural damage on the other hand usually goes unnoticed until the damage is determined through television probing. In the long run, structural damage is probably more costly than sewer stoppages.

Sewers are underground, so root problems are not noticed until backups or overflows occur. Effective use of early, preventive root control can avoid costly and permanent structural damage. However, municipalities are unlikely to fund a preventive root-control program until a known problem alerts officials to the need for control.

Root growth

Roots have three basic functions: (1) they anchor the plant and hold it upright, (2) they store food for the plant, and (3) they absorb and conduct water and nutrients.

Roots are tenacious and long-lived. The top of a plant is more dependent on the root system for survival than vice versa. A plant can regenerate after it has been topped but may not survive the loss of its root system. A willow tree root system can survive for many years after the top has been removed and will continually try sending up new shoots through the stump or exposed roots. The root systems of some grasses of the American Great Plains are thought to have remained alive for thousands of years. Just how far roots will grow in search of moisture and nutrients is uncertain. In the Rocky Mountains in Colorado, live tree roots have been found penetrating a pipe in the Moffet Tunnel, 2,500 feet from the nearest tree.

Root systems. Plants may have either a fibrous root system or a taproot system. Plants with **fibrous root systems**, such as garden plants and grasses, occupy the upper layers of soil, extend outward and are not normally associated with sewer problems.

Plants with tap root systems are the trees and woody plants. The primary root of the plant grows directly downward into the soil. Taproot systems are well adapted to deep soils and soils where the water table is relatively low. Branches, or secondary roots, grow laterally from the primary root. Secondary root structures can grow several inches in diameter, and, if they invade sewer pipes, can exert enough pressure to spread pipe joints or break the pipe.

Feeder roots are fine, hairlike roots that may develop into secondary roots. The surface of feeder roots contains microscopic structures called root hairs, which greatly increase the total surface area available to absorb nutrients and water.

The leading tip of a root shoot, the **meristem**, “senses” minute differences in nutrient and moisture levels and grows in response to them. This growth in response to nutrients and moisture enables the root to grow into sewer pipes. Temperature variance between wastewater flowing within a pipe and the surrounding soil may cause condensation to form on the pipe. Also, loose pipe joints, cracks and pipe porosity allow water with a high nutrient content to seep from the pipe into the surrounding soil. This type of environment attracts and encourages root growth.

Factors affecting root growth. A number of different soil conditions around sewer lines influence root growth. Backfill used during sewer construction may provide more favorable soil than undisturbed soils. Water table levels will fluctuate with seasonal changes. During drier seasons the water table drops and tree roots will grow deeper in search of moisture. The tendency of roots to grow toward moisture is called **hydrotropism**. Sewer lines above the water table will draw roots in that direction. During colder seasons, especially where ground frost occurs, the warmer soil temperatures surrounding the sewer pipe may also cause the roots to grow in that direction. Moisture and warm temperatures surrounding a sewer pipe create an excellent environment for root growth. If the moisture level drops below a certain point roots will begin to wilt.

Microscopic openings only a few cells wide permit hairlike structures to penetrate pipe joints, cracks, connections, or any other opening. Heavy secondary root structures may grow along a sewer pipe for many feet, exploiting each opportunity to penetrate pipe joints.

Roots thrive in sewer pipes, a perfect hydroponic environment. Roots are suspended in a well-ventilated, oxygen-rich environment with a plentiful supply of water and nutrients.

Generally, root growth is greatest in fall, winter and spring before leafing. At this time, roots are either storing or distributing nutrients. Root growth is less active in the late spring and summer season when the above-ground portion of the tree is actively growing. Roots of most trees cannot grow or survive if constantly submerged. Therefore roots generally do not cause problems in sewers that are located below a permanent water table. With adequate water available, roots need not expend energy trying to penetrate the water table and sewer pipes. However, if the water table fluctuates, or if porous soil profiles permit rapid downward movement of rain water, roots can be found in saturated soil and can be a major cause of sewer infiltration. In this case, tree roots suspended in the atmosphere of the sewer can carry on metabolic activity while the woody, submerged portion of the root system serves as a pipeline for plant nutrients.

Roots must always grow because parts of the root system are constantly dying. If a root system stopped growing, the plant would die. When the nutrients or moisture in an area of soil is depleted, feeder roots die. Secondary roots elongate or stop growing, depending on the availability of additional nutrients. In time, bacteria in the soil break down the dead root tissue, helping to replenish the depleted nutrients.

Roots in the sewer environment. In urban environments, finding adequate sources of nutrients for tree roots may be difficult. Expanses of concrete and asphalt, removal of leaves and other organic debris from lawns and storm sewers draining away surface water cause roots to obtain nutrition at greater depths. Some roots may grow along building sewers well beyond the tree's drip line to the main line sewer.

Two types of root structures found in sewer lines are known as veil and tail. The **veil root structure** occurs in lines with steady flows, such as interceptor pipe and other lines with constant flow. The roots will penetrate pipe at the top or sides and hang from upper surface, like a curtain, touching the flow. Live roots are seldom found below the water line. The roots will rake the flow accumulating solids and debris. Grease and other organic materials will also accumulate. Eventually the root mass and accumulated material will cause a stoppage of flow, and gases may develop.

The **tail root structure** occurs in sewers that have very low or intermittent flow, such as in small-diameter collector sewers, building sewers and storm drains. The tail root structure looks like a horse's tail. The roots will grow into the pipe from the top, bottom, or sides, and continue to grow downstream filling the pipe. Tail root structures over 20 feet long have been removed from sewers. Such root structures may appear as solid tubes of tree root, possibly with a slightly flattened area along the bottom where submergence in sewer flows prevent root growth.

Roots that enter the sewers or are visible during a television inspection represent only a small percentage of total root structures in the vicinity of the sewer. Roots girdling the pipe on the outside are responsible for pipe damage as they swell inside joints and cracks.

Nonchemical methods of root control

Chemical, as well as several nonchemical methods of sewer line root control are available to root-control experts and public works officials. Although nonchemical methods generally do not provide the same level of results as chemical methods, they have an important place in sewer maintenance. For example, mechanical methods are best for opening plugged sewers and for removing roots from sewers that are at imminent risk of plugging. In some cases, chemical control methods should not be used, especially near treatment plants or when there are other environmental or safety considerations. Pipe relining, grouting and sealing may also deter intrusion by roots. Municipal planners may discourage future root problems by careful selection and planting of trees in the proximity of proposed sewer lines. A successful line root-control program will integrate a variety of root-control methods, namely, cultural, physical, mechanical and chemical.

Cultural control. Cultural control of roots in sewers is a routine management practice that can prevent tree roots from invading sewer lines. Cultural control must be implemented before roots have a chance to become a problem. Two major cultural methods are (1) careful installation and inspection of sewer lines during construction, and (2) control of the selection of tree species and planting sites. Sewer connections with air-tight joints and seams will make it difficult for roots to penetrate. Municipalities should carefully inspect connections where plumbers join building laterals to the main-line sewer. Also, homeowners should be advised of the potential for future root problems and should be discouraged from planting deep-rooted or fast-growing trees near sewer lines. Willow trees, in particular, have adventurous roots that consume relatively large volumes of water. Unfortunately, when a sewer root problem is detected, it is too late for cultural control.

Physical control. Physical pest control relies on devices or procedures that physically separate the pest from the target area. A mosquito net is a physical pest control method. Physical control of sewer line roots involves isolating the environment of the sewer pipe from the roots around or near the sewer pipe. Three examples of physical control are (1) tree removal, (2) pipe replacement, and (3) pipe relining.

Tree removal works best when removing a single troublesome tree, such as a willow whose roots have invaded pipes. However, it would be difficult to convince homeowners along "Shady Lane" that the municipality's public works department should remove their trees in the vicinity of sewer lines. This would not only be expensive but would not guarantee removal of the root problems. Roots may survive long after the death of the above-ground part of the tree, necessitating the use of mechanical or chemical controls for some time afterward. For tree removal to be most effective, the stump should be pulled or chemically treated with a basal herbicide application. Pipe replacement involves removing old, defective sewers and replacing them with new sewers. As discussed above, the new sewers must have air-tight joints and properly installed connections to prevent the roots from becoming a problem. Pipe replacement corrects structural defects as well as root problems. There are four major disadvantages to pipe replacement (1) cost, (2) disruption of traffic and property, (3) roots can still enter through building sewers, and (4) destruction of trees planted in the vicinity of the trench line. If the pipe is in danger of collapsing, or is in a state of structural failure, pipe replacement may be the best method of control. Pipe replacement is not warranted when the pipe is in sound structural condition.

Pipe lining includes various technologies for rehabilitating sewer pipe. Roots must be chemically or mechanically removed prior to installation. "Slip-lining" involves pulling a seamless pipe through the existing sewer and digging only where building laterals require connection. "Cured-in-place" lining involves inflating and curing a sock or plastic tube that conforms to the shape of the pipe. Robotic devices are then used to cut building connections into the liner.

Advantages of pipe lining are that it (1) addresses infiltration problems and some structural defects, (2) is less disruptive than pipe replacement, and (3) promises long-term control against root regrowth through joints. Disadvantages of pipe lining are (1) it is often more costly than replacement, and (2) roots can still re-enter the main-line sewer through building laterals. Even after relining the main-line sewer, chemical control may be required to prevent roots from penetrating the main-line sewer through service connections.

Mechanical control. Mechanical control is the most common method of root control and the most important nonchemical method for applicators to understand. Mechanical control involves use of tools or other devices to cut and remove roots from sewers.

Drill machines, also called coil rodders, are either hand- or power-driven, springlike, flexible steel cables that turn augers or blades within the sewer. They are most often used by plumbers to relieve blockages in house lines or other small-diameter sewers. They are seldom used in main-line sewers.

Rodding machines are flexible steel rods with attached rotating blade cutters, augers or corkscrews. Rodding machines are most effective in small diameter sewers, up to 12 inches.

Jetters are also known as flushers, flush trucks, jet rodders, jet trucks and hydraulic sewer cleaners. Jetters consist of a high-pressure water pump, water tank, hose reel, and ½-inch to 1-inch sewer cleaning hose. Orifices in the rear of the nozzle propel the hose through the sewer. The nozzle blasts through obstructions. As the hose and nozzle are retrieved, debris is hydraulically flushed back to the insertion manhole for removal. Jetters can also be equipped with root cutters that use the force of water to spin blades. Unfortunately, root cutters can easily get stuck in the sewer, especially where there are protruding taps or other structural defects. Bound cutters can be removed only by digging them out.

Winches, also called drag machines or bucket machines, are large, engine-driven devices that pull buckets, brushes, or porcupine-like scrapers through the sewer. Special tools are designed to cut roots. Winches are most often used on large- diameter sewers that cannot be cleaned efficiently with jetters. Winches are used in heavy cleaning to remove large volumes of solids.

The main advantage of mechanical control is that it is the only method of relieving a root blockage. Chemicals are ineffective and dangerous when used in plugged or surcharging sewers. Sewer stoppage is an emergency situation and the municipality should have some type of mechanical control device for correcting such problems.

The main disadvantage of mechanical control is that it provides no residual control or long-term effectiveness. Roots respond to injury by producing a hormone, abscisic acid, which hastens and thickens regrowth. Root masses grow back heavier each time they are cut. Taproot s continue to grow in diameter and, in time, place additional stress on sewer pipe. Good results are obtained if the roots are cut flush with the joints; however, offset joints and cut-in laterals can prevent the use of full-gauge cleaning tools.

Mechanical control is often used in conjunction with chemical control. An example is preparation of sewer lines for rehabilitation with pipe-lining and grouting.

Chemical root controls

Chemicals can kill roots for a distance beyond the point of contact, providing control of root growth outside the sewer pipe.

Pesticides are the fastest way to control pests. For root control they are practically the only tool available. Choosing the best chemical for the job is important. Metam-sodium is a nonselective, contact herbicide. Many chemicals such as bensulide, dichlobenil, endothall, metham, paraquat, trifluralin, 2, 4-D and copper sulfate have been tried for root control. Note: not all of these products may be registered in all states, or there may be special handling requirements not specified on the label. Applicators should check with local authorities before using these pesticides. Also, acid and basic compounds such as sulfamic or sulfuric acid and sodium or potassium hydroxide are commonly used as “pour down” products in residential settings. The following section discusses several available chemicals for root control.

Trifluralin. Brand names: Treflan®, Bio-Barrier®. Fabric or rubber impregnated with trifluralin pellets is a relatively new concept in sewer line root control. The impregnated fabric is placed between the sewer pipe and trees at the time of sewer installation. The fabric is porous allowing water to pass through. The trifluralin pellets are time-released, and the manufacturer claims that active ingredient leaches only a few inches before being trapped by soil particles. Impregnated rubber is used for joint gaskets. Trifluralin is very water insoluble, and unsubstantiated claims state that root control lasts for “decades.”

Three advantages of this method are (1) root control is long-lasting without need for re-treatments, (2) pesticides are not directly introduced into the sewer collection system, and (3) environmental risk is minimized.

The main disadvantage of this method is that installation is well in advance of roots actually becoming a problem. This method cannot be employed economically after a problem occurs.

Modern pipeline installation, if done correctly, can adequately deter root penetration making preventive chemical control unnecessary.

Copper products. Brand names: numerous. Although small amounts of copper are required by all plants for normal growth, excessive amounts of copper will damage tree leaves and could result in the death of the tree. Copper is a heavy metal that may not be removed by the normal treatment process. Not only can it be toxic to the treatment plant’s microbes, but it leaves the treatment plant as a pollutant in both the effluent and the biomass (sludge), thus becoming a potential environmental contaminant.

Copper sulfate has been used for many years for root control in sewers and as an algaecide. Some studies have shown that high concentrations of copper sulfate cause systemic injury without killing the roots. Nevertheless, copper sulfate products are still in widespread use by many plumbers and homeowners as a “pour down” application for controlling roots in building sewers. Copper sulfate is believed to be a relatively safe material to handle, and poses little health risk to the applicator.

The use of copper products may not be permitted in some states. Check with local authorities before use.

Metam-sodium and dichlobenil. Synonyms: Metam, Metam-sodium, Metham-sodium, Vapam®; Synonyms: Dichlobenil, Casaron®

Metam-sodium and dichlobenil have been used together as a root-control product in sewers for approximately 25 years. Metam-sodium is a fumigant, meaning it breaks down into a gas, methylisothiocyanate (MITC), which kills plant roots. It is non-systemic and does not move throughout the root system killing the whole plant. Metam is used in combination with dichlobenil, which is an effective growth inhibitor.

These two pesticides were originally applied together by spray or soak methods. Soaking entailed plugging the pipe, filling it with the chemical for a period of time, allowing the chemicals to penetrate any blockages as well as soaking out cracks and joints and killing further up the root system. An alternative method involved spraying the interior of the pipe with the chemical solution. Because of the large doses of chemical used and their apparent threat to wastewater treatment facilities, soak and spray methods are no longer recommended.

Current methodology uses metam-sodium products as a dry foam (similar to shaving cream). Specialized foam-generating equipment is used to produce the foam that is then applied to the interior of the pipe. Application is made by inserting a hose the length of pipe to be treated; the foam is pumped into the pipe as the hose is retracted. As the foam collapses (over a period of 1 hour or more), it adheres to the pipe and root surfaces.

Any product that does not adhere to the roots and pipe walls enters the wastewater in the pipe and is carried to the treatment facility. The dilution of the product in the wastewater and the instability or rapid breakdown (fuming off), of the metam-sodium allow a safety margin for the treatment plant.

Once the roots have been killed (within hours of application), bacteria and other microbes in the sewer begin to decompose the dead tissue. Total decomposition of the roots may take several months to a year or more. The decomposed organic matter enters the wastewater stream and is carried to the treatment plant for disposal. Root regrowth will start in a couple of years, which may necessitate retreatment at 3 to 5 year intervals.

Identifying which lines have root problems

Pest identification is usually the first and most important step in a pesticide control program. In sewer line chemical root control, pest identification is not an issue because it does not matter which species of tree produces the nuisance roots. All roots in sewers are pests; there are no beneficial species.

In sewer line chemical root control, the sewer applicator must determine which sewer lines have been infiltrated by roots. There are several indicators of root penetration.

Maintenance records will indicate sewer lines that have experienced a stoppage and the cause of the stoppage.

Sewer line television reports provide accurate evidence of a root problem.

Commonalties in root-prone areas are an important but general indicator. Sewer lines that were installed at the same time in the same area with similar tree-planting patterns near sewers will experience similar root problems.

Conditions that increase the likelihood of root problems in a particular sewer section are

- Sewers located near other sewers with known root problems.
- Sewer pipes located near the surface and closer to tree roots.
- Sewer lines located off-road in wooded easements, at a curbline, or near trees and roots.
- Sewer lines with many lateral connections per lineal foot, which affords greater opportunity for root intrusion.
- Sewer lines located in tree-lined streets and easements.
- Sewer pipe constructed with loose-fitting joints or outdated joint packing material (asbestos-cement pipe, orangeburg pipe, and clay tile sewers with oakum joints are very susceptible to root penetration, whereas pipe with air-tight rubber gaskets and seamless pipe are less susceptible).

In addition, residential areas are more susceptible than industrial areas.

A useful tool for planning root-control programs is the scattergram. This is a map of the sewer collection system with known root problem lines highlighted. As a root-related stoppage occurs, or if other evidence of a root problem is detected, the line is highlighted on the map. Over time, patterns begin emerging, indicating an area prone to root problems.

Wastewater treatment facilities

Raw wastewater varies among wastewater treatment facilities, as does the efficiency of treatment processes. This section will provide you with an understanding of the basic operation of a treatment plant and will help you determine the potential risks associated with the application of root-control chemicals with emphasis on metam-sodium. It is important that you not only understand the operation of sewer collection systems but also have a basic understanding of the treatment process.

Facilities for handling wastewater usually have three major components: collection, treatment and disposal. An understanding of the treatment process is important for the applicator, especially when introducing foreign materials, such as root-control chemicals or grease-eating bacteria, into the collection system. For example, the root-control chemical metam-sodium, is a general biocide so its potential for affecting the treatment process is directly related to the concentration reaching the treatment plant and the efficiency of that plant’s treatment process.

Collection systems

Collection and transport of wastewater from the source to the treatment plant is accomplished through a complex network of pipes and pumps of many sizes. Typically the sewer coming into the treatment plant carries municipal wastes from households and commercial establishments and possibly some industrial wastes. This is called a **sanitary sewer**. All storm run off is collected separately in a **storm sewer**, which normally discharges to a water course without treatment. In some areas, only one network of sewers has been laid out beneath the municipality to pick up both sanitary wastes and stormwater in a **combined sewer**.

The collection system consists of a series of interconnecting pipes of varying sizes (from 4-inch pipe to tunnels in which maintenance personnel can float in boats). The majority of the pipe footage in areas serving buildings is 8 to 12 inches in diameter. The system is designed to provide gravity flow from the point of collection to the treatment plant. Sanitary sewers are normally placed at a slope sufficient to produce a water velocity (speed) of at least 2 feet per second, or more, when flowing full. Usually this velocity will prevent the deposition of solids that may clog the pipe or cause odors. The gravity system is broken up into sections by manholes, which allow maintenance personnel access to the collection system. Design criteria usually place manholes at pipe junctions, changes of pipe grade or direction. Therefore, manholes may be spaced 150 to 1,000 feet apart.

Most treatment plants with flows of less than 0.5 million gallons per day have pipe sizes from 4 to 8 inches in diameter and occasionally 10 to 12 inches. As the plant's capacities increase, the pipe sizes increase as lateral flows are collected and approach the treatment plant.

Variables affecting root control

Pipe slope is a major design criterion of the collection system. The slope of a sewer is the ratio of the change in elevation between two manholes to the horizontal distance between the manholes. Pipe slope and flow velocity can affect the application and detention time of metam-sodium and therefore its impact on treatment plants. The design standard for slope is a minimum flow velocity of 2 feet per second with the preferred velocity of 2.5 feet per second. As the pipes are designed for more slope, the velocity increases. The presence of roots causes the velocities to decrease.

Grade is an important consideration when applying root control chemicals because of the effect treatment may have on buildings "below grade." The term "grade," although used at times in place of slope, is also used to indicate relative elevation. For example, a building sewer is termed "below grade" if the elevation of floor drains is below that of the subsequent manhole.

Flow characteristics can affect root growth patterns. Flow may dictate the appropriate treatment method, the rate of root decay after treatment, the rate at which chemicals drift toward the treatment plant, and the rate of dilution of chemicals in the wastewater stream. Flows can be influenced by ground water infiltration and peak periods of residential or industrial use.

The greater the velocity of sewer flows, the greater the rate at which root-control chemicals drift downstream. Foam should be injected above the flow surface to reduce the amount of chemical carried downstream. Pipes with particularly heavy or swift flows should be treated at night or during periods of low flow to improve the efficacy of treatment.

The applicator should be aware that heavy or swift flows are more problematic with respect to protecting the treatment plant, and should vary the application rates accordingly. The applicator should also be mindful of force mains upstream from the treatment area. When force mains above treated sections "kick in" after treatment, then can wash chemicals out of treated lines and downstream toward the treatment plant.

Characteristics of the collection system can affect the efficiency of a wastewater treatment plant and allow the root-control chemical to have an unusual influence on the plant. Large water users, such as industries that contribute waste to the collection system, may affect the efficiency of the treatment plant, especially if there are periods during the day or during the year when their waste flows are a major load on the plant. For example, canneries are highly seasonal, making it possible to predict large flows from them. Even in areas where the sanitary and storm sewers are separate, **infiltration** of ground water or stormwater into sanitary sewers through breaks or open joints can cause high flow problems at the treatment plant.

The time required for wastes to reach a plant can also affect a treatment plant's efficiency. Hydrogen sulfide gas (rotten egg gas) may be released by anaerobic bacteria feeding on the wastes if the flow time is quite long and the weather is hot; this can cause odor problems, damage concrete in the plant, and make the wastes more difficult to treat (solids won't settle easily). Wastes from isolated subdivisions located far away from the main collection network often have such "aging" problems.

Pump stations are normally installed in sewer systems in low areas or where pipe is deep under the ground surface. These pump stations lift the wastewater to a higher point from which it may again flow by gravity, or the wastewater may be pumped under pressure directly to the treatment plant. A large pump station located just ahead of the treatment plant can create problems by periodically sending large volumes of flow to the plant one minute, and virtually nothing the next minute. These fluctuating flows can be reduced by using variable speed pumps or short pumping cycles.

Dilution

The size of a wastewater treatment plant determines the amount of dilution of root-control chemicals in the wastewater. Concentrations of pesticides are expressed as a percent of active ingredient (a.i.) per unit of measure. One gallon of 100 percent a.i. mixed with 999,999 gallons of water represents one part per million by volume (1 + 999,999 = 1,000,000).

Laboratory tests indicate that the "no observable effect limit" (NOEL) for foaming root- control products containing metam-sodium and dichlobenil is a concentration of 10 ppm a.i. metam. Seven (7) ppm a.i. metam is used in order to provide a minimal

Example calculation: Estimate the maximum concentration of the active ingredient of a product, in parts per million, in wastewater as it enters the wastewater treatment plant. Label instructions say to mix 10 gallons of product (25% a.i.) with 200 gallons of water. This solution is converted into foam at a ratio of 20:1, foam to solution. This material is applied over the course of two hours to a sewer system with a flow of 380,000 gallons/hr.

Note: The 200 gallons of water used in the mix, and the foam expansion ratio, are irrelevant to the answer.

First, 10 gallons of the product containing 25% active ingredient are applied over two hours, so 5 gallons are applied in one hour. Therefore, a ratio can be used:

$$\mathbf{(5 \times 0.25) \div 380{,}000 \text{ gallons/hr} = \mathit{x} \div 1{,}000{,}000}$$

Finally, solve for x:

$$\mathbf{1.25 \times 1{,}000{,}000 = 380{,}000\mathit{x}}$$

$$\mathbf{1{,}250{,}000 \div 380{,}000 = \mathit{x}}$$

$$\mathbf{\mathit{x} = 3.289 \text{ parts a.i. per million gallons of water.}}$$

safety margin. By using what we have learned about sewer line flows, we can estimate the amount of active ingredient, or product, necessary to achieve a given concentration.

Note: No two treatment plants are alike. Two plants with the same flow may react differently to the same concentration of pesticides in wastewater flow. The biological process of one plant may be under more stress than another because of a lack of oxygen, chemical pollutants, excessive organic loading, operator error, for example. A second plant may not be under these stresses. A treatment plant operating under one or more of these stresses may react to a small concentration of a pesticide such as metam-sodium and become "upset" (adverse change in the biological decomposition process that can last from hours to days). The same plant, operating well and unstressed, may be able to tolerate several ppm of metam-sodium without effect. Treatment plants become upset for a number of reasons, only one of which may be traced to root-control chemicals. A well-run plant is usually more tolerant and resilient to pesticides.

Example calculation: An applicator learns from the treatment plant operator that average day-time flows are 5 million gallons and that this is spread evenly over the 8-hour day in which the applicator intends to work. What amount of a product that contains 25% a.i. can the applicator apply over the 8-hour day to stay under 7 parts per million?

First, determine the total amount of product per day which may be applied:

$$\mathbf{(5{,}000{,}000 \div 1{,}000{,}000) \times 7 \text{ ppm} \div 0.25 \text{ a.i.}}$$

$$\mathbf{35 \div 0.25 = 140 \text{ gallons of product}}$$

Finally, determine the amount of product per hour which may be applied:

$$\mathbf{140 \text{ gallons} \div 8 \text{ hr} = 17.5 \text{ gallons/hr of 25\% a.i. product}}$$

The applicator should keep in mind that manufacturers' recommendations should be used only as a guideline. The best source of information about a given plant and how it is responding to root control treatments is the wastewater treatment plant operator. All root-control activities need to be cleared and coordinated not only with treatment plant operators but with line maintenance and pretreatment personnel as well.

Disposing of excess chemicals — Effect on the plant

Dichlobenil and metam-sodium have certain physical properties that lend them to either absorption or degradation in the pipe section being treated. The foaming method of application retains the metam in the pipe section being treated for a period of time, allowing decomposition to take place, thus reducing the risk to the receiving treatment plant. Excess concentrate or mixed solution should not be "dumped" into the sewer lines as it may not have time to degrade enroute to the plant. The material may not dilute sufficiently before reaching the plant and may cause a temporary upset.

If the applicator has any unwanted concentrate or solution, the safest way to dispose of it is by applying it according to label instructions. Never dump concentrated chemicals or chemical/water solutions into the sewer system.

Metam-sodium root-control application

The three phases of applying the metam-sodium root-control chemicals are (1) mixing the chemicals or the chemical/water solution, (2) calibrating a 1 part chemical/water solution to 20 parts foam, and (3) calibrating the hose retrieval rate.

Mixing the chemical

Due to the differences in packaged products, specific mixing instructions must be obtained from the label of the metam-sodium root-control products being applied. Mixing instructions must also be obtained from the manufacturer of the specific application equipment being used.

The active ingredients metam-sodium and dichlobenil can be used only in combination with each other and with a foaming agent, according to the product label. Depending on the equipment being used, the ingredients may be mixed with the water in a mixing tank or may be mixed only with themselves in a small chemical tank to be automatically mixed with water at the moment of application.

Dichlobenil should be mixed with the other root-control ingredients vigorously before mixing with water. The mixed solution should not be allowed to stand, as mild agitation is necessary to keep the dichlobenil in suspension.

The chemical mixture should be used promptly after mixing and the applicator should not mix more solution than can be used in one day. To mix the proper amount of solution, the applicator must (1) determine the method of treatment, (2) determine the total footage of pipe by pipe diameter and method of treatment, and (3) calculate the chemical mix ratio and the amount of chemical/water solution to prepare depending on the pipe diameter and method of application.

Methods of treatment include the foam fill and foam spray. Pipe diameters less than 12 to 14 inches require filling the entire pipe with foam (foam fill). Larger pipes are more economically treated by surface coating on the root masses and pipe surface (foam spray). Other factors such as wastewater level, velocity of flow and root density may dictate the method of application.

Calibrating foam/solution expansion ratio

The applicator should know how to calibrate the application equipment to get the proper consistency and volume. This section provides general guidelines for equipment and foam calibration. Consult the equipment manufacturer for more specific calibration details.

Metam-sodium root-control products require a foam application. The ingredients are mixed with water, according to the package instruction, and then air is introduced with an air compressor. Foam quality, the proper chemical/water to foam expansion ratio, is an important factor in achieving successful root control. The proper expansion ratio is that 1 part, or gallon, of chemical/water solution will expand to 20 parts, or gallons, of chemical/foam solution.

The proper foam will be dense, have small bubbles, "cling" to the pipe surfaces, maintain its shape for a specified period, and contain the proper concentration of active ingredient per cubic foot of foam.

An expansion ratio less than 1:20 produces a "wetter" foam. A wet foam will be "runny" and not stick to pipe surfaces. It will also be "heavy" and quickly collapse, not holding its shape in the pipe. Additionally, wet foams will not fill pipe volumes at normal retrieval rates, or penetrate wye connections. An expansion ratio greater than 1:20 produces a "dryer" foam with large bubbles and will not carry a sufficient amount of active ingredient per cubic foot to be active on tree roots.

Variations in foam quality can be made by adjusting the water/chemical solution volume [gallons per minute (gpm)] versus the air volume [cubic feet/minute (cfm)]. Follow the equipment manufacturer's guidelines to make these adjustments.

The hardness of the water may affect foam quality. If this is a problem, check with the chemical manufacturer or supplier for technical assistance.

A simple test of foam quality is for the applicator to observe the foam discharging unobstructed from the hose into a manhole. A stream of good foam breaks into light balls and flakes about 2–3 feet from the point of discharge. Tests for foam quality or equipment calibration can be performed at a testing site by using the appropriate amount of wetting/foaming agent only, without adding the products' active ingredients. This reduces the exposure risk of operators performing the test. Wetting/foaming agents can readily be obtained from the product manufacturer. Contact the equipment manufacturer for detailed calibration procedures for specific equipment.

To measure the foam more accurately from the mound of created foam, fill a 2,000-ml graduated cylinder to the top. Place the filled cylinder in a location free of wind (wind causes unnecessary breakdown of the foam). When the foam has settled, a liquid remains. The desired result is to have the remaining liquid measure 100 ml, or 1⁄20th of the foam volume.

Each piece of equipment should be calibrated separately to determine its proper flow rate. If a piece of equipment shows wide variances in foam consistency, there may be a problem with the equipment. Service the equipment according to the equipment manufacturer's recommendations.

Calibrating the hose retrieval rate

To determine the hose retrieval rate the operator must know (1) how many gallons of foam are required per foot of sewer pipe, and (2) how many gallons per minute the application equipment is producing.

Then, divide the amount of foam produced per minute by the amount of foam required per foot to determine the hose retrieval rate in feet per minute.

The following table provides a quick method of determining retrieval rates when applying foam at 100 gallons per minute.

Pipe diameter	Foam fill	Feet per minute
4 inches	0.7 gal/ft	143
6 inches	1.5 gal/ft	67
8 inches	2.5 gal/ft	40
10 inches	4.0 gal/ft	25
12 inches	5.9 gal/ft	17

This same procedure can be used for surface coating techniques. For example, to apply a 3-inch surface coating of foam to 300 feet of a 24-inch pipe carrying 7 inches of flow requires 2,221 gallons of foam. This breaks down to 7.4 gallons of foam per foot. If the equipment is generating 90 gallons of foam per minute then the proper hose retrieval rate would be 12.16 feet per minute (90 ÷ 7.4).

Calculating pipe volume

Calculating the correct volume of a pipe to be treated is important. If pipe volume is overestimated, too much foam could be pumped into the line and forced up building laterals and into the buildings. An underestimation could result in an ineffective application. The following conversion table may help in your calculations.

Multiply number of	by	to obtain equivalent number of
cubic feet	1,728	cubic inches
cubic feet	7.481	gallons
gallons	0.1337	cubic feet
gallons	231	cubic inches

A pipe is a cylinder open on both ends. The calculation for volume of a pipe (cylinder) is the area of the circle (cross section of the pipe) times the length of the pipe. The area of a circle is the radius (½ the diameter) times the radius times π, or 3.14.

pipe volume = pipe cross-sectional area x length
area of circle = 3.14 x radius ^{2}

Example calculation: Find the volume of foam required to treat a pipe 10 inches diameter and 400 feet long.

First, find the area of the circle:

(Remember, radius = ½ diameter; therefore the radius is 5 inches)

$$\mathbf{3.14 \times (5^2) = 78.5\ inches^2}$$

Second, convert square inches to square feet:
Divide square inches by 144 (144 in^2 = 1 ft^2).

$$\mathbf{78.5 \div 144 = 0.545\ ft^2}$$

Third, determine the pipe volume:

$$\mathbf{0.545\ ft^2 \times 400ft = 218ft^3}$$

Fourth, determine the volume of foam in gallons required:

(Refer to the conversion table above)

$$\mathbf{218ft^3 \times 7.481 = 1630.85\ gallons}$$

If a pipe is partially full of water, the water also takes up volume. The applicator should be able to compensate for the reduced volume. Roots do not grow below the water level and chemicals are not effective when diluted in sewer flows. Proper application requires that the foam be discharged above the flow line. Under certain field conditions where a pipe has slow-moving flow, the applicator should compensate for the volume displaced by the water to avoid overcharging the pipe. In Figure 3, D is the diameter of the pipe and d is the depth of the flow in the pipe. The wetted perimeter is that portion of the circumference submerged with water and the dry perimeter is the portion of the circumference above the waterline.

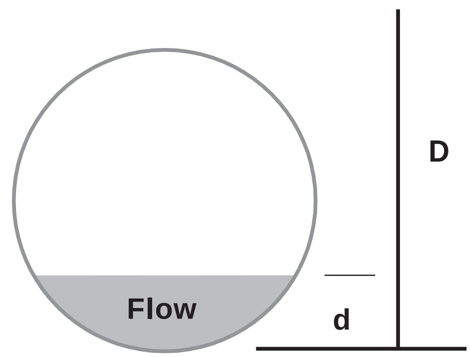

Figure 3. Sewer pipe with diameter D carrying flow of depth d.

By comparing the wetted perimeter of the pipe with the entire perimeter (circumference), the applicator can determine the percent by volume of the pipe filled with water.

The relationship between d/D and the wetted perimeter is illustrated in the following table:

Wetted perimeter	
d/D	**% of Circumference**
0.1	20
0.2	30
0.3	37
0.4	44
0.5	50
0.6	56
0.7	63
0.8	70
0.9	80
1.0	100

Determining effectiveness of root-control treatments

Determining the effectiveness of chemical root-control treatments is an important issue for contractors and public works officials. The results of chemical root control are sometimes difficult to assess because they cannot be seen by the naked eye.

Tracking results can also be a learning process for the applicator as well as the public works director by pointing out deficiencies in application methods. Conditions that may influence effectiveness include

- Improper application techniques, in particular, poor contact and exposure time.
- High sewer flows or surcharging conditions soon after application.
- Severe hydraulic sewer cleaning before or after treatment.
- Heavy grease deposits that interfere with chemical contact.
- Old or ineffective chemical, or improperly mixed chemical.

Because of the remoteness of root masses in sewer pipes, it is extremely difficult to assess accurately the percentage of the root kill. An important fact to remember is that treating roots with chemicals kills the roots; however, these treatments do not make the roots disappear. A complex of decaying organisms is constantly present in the sewer, feeding on the dead roots. In addition, the buildup of solids and the constant pressure caused by wastewater flows break the dead roots off, sending them to the treatment plant. This process may take weeks, months, or even years.

Note: If a sewer line is experiencing frequent blockages, chemically treating roots will not immediately eliminate the problem. These blockages need to be addressed with a good cleaning, preferably with a high-pressure jetter. Once the blockage is cleared, the long-term solution of chemically treating roots can be addressed.

As discussed in the section on how roots grow, root masses are made up of a central trunk dividing into a series of smaller and smaller branches, ending as microscopic hair roots. A specific root mass in a pipe may be the result of a single rootlet entering the pipe through a faulty pipe joint. This rootlet can grow and divide into more rootlets, which in turn divide and grow, forming a "root mass." As the root mass grows, the supporting branch (the original root hair entering the pipe) grows in size and is frequently protected by the surrounding root mass.

The most difficult part of a successful chemical root treatment is determining with any degree of accuracy the percent kill of a specific root mass or root masses in a specific section of pipe. When viewing the root masses in the pipe with the use of closed-circuit TV, a live root mass looks brown and dirty; because of equipment lighting, the root masses tend to reflect light, causing glare and "hot spots." The same closed-circuit TV of a dead root mass also looks brown and dirty with glare and hot spots. For this reason, the inspection requires judgment on the part of the inspector. With time, the root mass becomes smaller through decay and breakage. The contents of a dead root mass become soft or brittle and break off easily as the camera passes. These factors all become part of the assessment of the success of a specific chemical root-control treatment. The confidence level of these judgment calls can be significantly increased by removing a root mass from the pipe for a detailed visual inspection.

Like the trees above ground, roots grow in diameter by adding cells between the dead tissue in the center of the root and the dead bark on the outside. These healthy living cells create a light-colored, almost white layer under the bark. When a root is killed, this layer turns brown. By stripping the bark layer off the individual roots in a root mass, you can determine the effectiveness of a specific chemical treatment. When performing this visual test, you need to remember that you are examining only one of perhaps hundreds of root masses from the specific section(s) of treated line. What you find in one root mass may not be what you find in the next.

Perhaps the most reliable method of judging the success of a chemical root-control program is to determine the rate of reduction in sewer stoppages, overflows, emergency calls, and other root-related sewer problems. If a municipality experiences, say, 100 stoppages in the year before implementing a chemical program, and two stoppages in the following year, the program has shown positive results. The program could be justified by weighing the cost of the root- control program against the cost of relieving stoppages and the damage caused by the stoppages.

Although the ultimate goal of a root-control program is elimination of all root masses, in reality, a successful program is one in which the roots are managed at a level below which the cost and risk of application are less than the cost and risk of unwanted sewer blockages and damaged pipe.

Note: The application of foam into sewer pipes involves the use of various conversion tables. To use these tables, certified applicators must be capable of calculating volumes and performing basic mathematical functions such as multiplication, division and use of percentages.

Glossary

Absorption. The process by which a herbicide passes from the soil solution into plant root cells or from leaf surface into the leaf cells.

Adsorption. The process by which chemicals are held or bound to a surface by physical or chemical attraction.

Algae. Nonvascular chlorophyll-containing plants, usually aquatic.

Algaecide. A chemical used to control algae.

Annual weed. A weed that completes its life cycle in one year.

Benthic barrier. Bottom-covering material that cannot be penetrated by plant roots or vegetation.

Biological control. The use of living organisms to manage a pest population.

Calibration. Measurement of application equipment's delivery rate.

Combined sewer. A sewer designed to carry both sanitary flows and stormwater, either all or part of the time.

Contact herbicide. A chemical that kills primarily by contact with plant tissue, with little or no translocation.

Emersed plant. A rooted or anchored aquatic plant adapted to grow with most of its leaf-stem tissue above the water surface and not falling or rising with the water level.

Erect algae. Algae that have hold-fast structures (not roots) that anchor them to the bottom.

Eutrophication. Deterioration of a body of water because of increased production of plants through addition of nutrients.

Exotic species. Plants that are native to other regions.

Feeder root. Fine, hairlike root that may develop into a secondary root.

Fibrous root system. Root system formed mostly by lateral branching of the primary root.

Filamentous algae. Algae that occur as long strands of cells.

Fragmentation. Plant propagation from broken parts of the parent plant.

Free-floating plant. An aquatic plant that floats freely on or beneath the water surface.

Hydrotropism. Growth response toward moisture.

Infiltration. Ground water that enters sewer systems through joints or other defects.

Macrophytic. Referring to large plants.

Meristem. The active vegetative growing point of a plant.

Nonpoint source. Contamination arising from the normal or accepted use of certain materials over a large general area and extended length of time.

Nonselective. Pesticide that kills or controls any living organism or is toxic to a wide range of organisms.

Noxious weed. A weed specified by law as being especially undesirable, troublesome or difficult to control. Precise definition varies according to legal interpretations.

Oxidation. Chemical degradation caused by combining with oxygen.

Photic zone. Zone where light is sufficient for plant growth.

Photolysis. Chemical degradation caused by sunlight.

Phreatophyte. Plants, usually woody, that draw water from underground water supplies as well as from soil water.

Planktonic algae. Individual algae cells that are suspended in the water or form a film on the surface.

Point source. A single location of discharge of a contaminant.

Preemergence. Application of a herbicide prior to weed emergence.

Rooted floating plant. Aquatic plants rooted in the bottom sediments at water depths of approximately 1 to 5 feet. Their floating leaves originate from underground rhizomes.

Sanitary sewer. A sewer designed to carry only residential or commercial waste.

Selective herbicide. A chemical that is more toxic to some plant species than to others.

Stolon. A specialized horizontal stem that grows above ground.

Storm sewer. A sewer designed to carry only rain water, ground water or surface water.

Submersed plant. An aquatic plant that grows with all or most of its body below the water surface.

Systemic herbicide. A herbicide that is absorbed by treated plants and moves to most tissues.

Tail root structure. Roots that have grown into a pipe from the top, bottom or sides and resemble a horse's tail.

Transpire. To give off water vapor from the surface of plant leaves.

Turbidity. Cloudiness caused by suspended material in water.

Veil root structure. Roots that have grown into a pipe from the top or sides and obtain nutrients from hanging in the pipe's flow.

Volatile. Referring to a substance that is likely to give off gas vapors.

Weed. A plant that grows out of place.

Appendix

Appendix Table 1. Restrictions on water use (after treatment with an aquatic management product — number of days to wait).

ALWAYS REFER TO CURRENT LABEL FOR SPECIFIC REQUIREMENTS AND RECOMMENDATIONS.

Product	Active ingredient	% a.i.	Human			Livestock watering	Irrigation
			Drinking	Swimming	Fish consumption		
Aqua-Kleen®	2,4-D butoxyethyl lo-vol ester	27.6	Don't use	1	*	No Dairy	21
Aquashade®	Acid blue 9 & acid yellow 23	26.02	Don't use	0	0	0	0
Aquashadow®	Acid blue 9 & acid yellow 23	—	Don't use	0	0	0	0
Aquathol® (G)	Dipotassium salt of Endothall	10.1	7	1	3	7	7
Aquathol® K (L)	Dipotassium salt of Endothall	40.3	7 – 25	1	3	7 – 25	7 – 25**
Copper sulfate	Copper sulfate (pentahydrate)	99	0	0	0	0	0
Cutrine® Plus (G)	Copper chelate	3.7	0	0	0	0	0
Cutrine® Plus (L)	Copper chelate	9	0	0	0	0	0
Diquat®	Diquat dibromide	35.3	14	1	0	14	14
Hydrothol® 191 (G)	Monoamine salt of Endothall	11.2	7 – 25	1	3	7 – 25	7 – 25
Hydrothol® 191 (L)	Monoamine salt of Endothall	53	7 – 25	1	3	7 – 25	7 – 25
Lake Colorant®	Blue colorant	100	Don't use	0	0	0	0
Navigate®	2,4-D butoxyethyl lo-vol ester	27.6	Don't use	1	*	No dairy	Don't use
Norosac®	Dichlobenil	10	Don't use	0	90	Don't use	Don't use
Noxfish®	Rotenone (fish toxicant)	5	***	0	Don't use	*	Don't use
Reward®	Diquat dibromide	35.3	14	1	0	14	14
Rodeo®	Glyphosate	53.8	***	0	0	0	0
Sonar® (L)	Fluridone	41.7	#	0	0	0	7 – 30
Sonar® (P)	Fluridone	5	#	0	0	0	7 – 30
Stocktrine® II	Copper chelate	1.25	0	0	0	0	0
Weedpro® 4 Amine	2,4-D dimethylamine	46.6	21	*	*	*	21
Weedtrine® D	Diquat dibromide	8.53	14	1	0	14	14

*No restriction listed on label. **Exception: Do not irrigate bentgrass turf varieties. ***Do not apply within ½ mile upstream of potable water intakes. For Rodeo, applications can be made within that ½ mile restricted area if the water intake can be turned off for a minimum period of 48 hours. #Do not apply within ¼ mile of any functioning potable water intake.

Appendix Table 2. Weed susceptibility to aquatic herbicides.

Weed	2,4–D	Endothall – monoamine salt	Endothall – dipotassium salt	Copper complexes@	Diquat	Glyphosate	Fluridone	Dichlobenil
Algae								
Chara	–	G	G	E	G	–	–	E
Filamentous	–	G	G	E	–	–	–	–
Microscopic	–	G	G	E	–	–	–	–
Nitella	–	–	G	E	G	–	–	E
Emersed								
Alligatorweed	–	–	–	–	–	G	F	F
American lotus	E	–	G	–	–	G	G	E
Parrot feather	E	–	E	–	E	–	–	–
Pickerelweed	G	–	–	–	–	G	–	–
Slender spikerush	–	–	–	–	G	–	G	–
Waterlilies	G	–	G	–	–	G	G	E
Water pennywort	–	–	G	–	E	G	–	–
Water primrose	E	–	–	–	–	G	G	–
Watershield	G	–	G	–	–	–	F	E
Floating								
Duckweeds	G	–	–	–	E	G	E	–
Frogbit	E	–	–	–	E	G	–	–
Spatterdock	F	–	–	–	–	G	–	–
Water hyacinth	E	–	–	–	E	G	–	–
Submersed								
Broadleaf watermilfoil	–	–	E	–	E	–	G	E
Coontail	G	–	E	–	E	–	G	G
Elodea	–	–	–	–	E	–	G	E
Eurasian watermilfoil	E	–	G	–	E	–	G	–
Fanwort	–	–	E	–	–	–	G	–
Hydrilla	–	–	G	@	G	–	G	F
Naiads	–	–	E	@	E	–	G	E
Pondweeds	–	–	E	–	G	–	G	E
Marginal								
Arrowhead	E	–	G	–	G	–	–	–
Buttonbush	E	–	–	–	–	–	–	–
Cattail	G	–	–	–	G	E	G	–
Sedges and rushes	G	–	–	–	–	–	–	–
Smartweed	E	–	G	–	–	G	–	–
Willows	E	–	–	–	–	G	–	–

Rating scale: E = excellent; G = Good; F = Fair; – = no control or insufficient data available.

Note: These data are presented for informational purposes only. Use of these herbicides for control of these weeds is at the user's discretion. Performance is not warranted by the manufacturer or the University of Missouri.

@ Copper complexes include copper sulfate and various chelated copper compounds that are used primarily for algae control. Some chelates can also be used for hydrilla and southern naiad control. Consult individual product labels.

Aquatic herbicide selected information

(From: *Weed Control Manual*)

Copper Complexes

Copper sulfate and various chelated copper compounds are used primarily for algae control. Some chelates can also be used for hydrilla and southern naiad control. Copper sulfate is widely used but may not be effective in hard water; chelates are formulated to provide a longer lasting effect in hard water. Copper sulfate and chelates are the only compounds for which there are no restrictions on water use after treatment, except that they should not be used in trout-bearing waters. When used for filamentous algae, good distribution and contact with the mats is essential for optimal control.

2,4-D - Phenoxyherbicides

Granular and ester formulations are labeled for use on submersed weeds and are particularly effective on Eurasian watermilfoil. Liquid amine formulations are effective for water hyacinth control. Caution should be used when applying liquid ester formulations because they can cause a fish kill. Take precautions to avoid drift.

Dichlobenil

Apply during early spring as a preemergence herbicide, i.e., applied before weeds emerge, to exposed bottoms or through the water. Dichlobenil works best on submersed weeds. Note water use restrictions.

Diquat

Diquat is primarily used as a contact herbicide for submersed and free-floating aquatic weeds. It will provide a short-term top kill on emergent plants such as cattails. Surfactant or spreader should be added to the spray solution when treating free-floating or emergent weeds. This chemical binds to suspended soil particles; therefore, do not use in or dilute in muddy water. Diquat should be applied while weeds are actively growing but before weed growth reaches the surface of water. Note water use restrictions.

Endothall

Endothall is a contact herbicide used for submersed weeds (Aquathol®) or algae and submersed weeds (Hydrothol®). Fish are particularly sensitive to liquid formulations of Hydrothol, and open water should be left untreated to provide an escape for them. Aquathol is safe for fish, and liquid formulation is often tank-mixed with copper chelates to provide both algae and submersed weed control. Water use restrictions vary from 24 hours to 25 days (see Appendix table 1) depending on use and dosage applied.

Glyphosate

Glyphosate should be used strictly for emergent and floating weed control. Surfactants must be added to Rodeo® to aid in foliage penetration. Glyphosate has a broad spectrum of activity and its only restriction is within a half mile of potable water intakes. It is not effective on plants that are either completely submerged or have most of their foliage under water. The glyphosate product, Roundup ®, contains a surfactant that is harmful to fish.

Fluridone

Fluridone (Sonar®) is primarily used for submersed weed control. It can be applied before or soon after weeds emerge. Fluridone is slow-acting (30 to 90 days under optimum conditions); however, in some cases, treatment will provide more than one year’s control. It must be used as a whole pond treatment. Trees and shrubs growing in treated water may be injured. Note water use restrictions.

Suggested references for additional information

Aquatic Plant Identification and Herbicide Use Guide. Department of the Army, Department of the Army, Waterways Experiment Station, Corps of Engineers, P.O. Box 631, Vicksburg, MS 39180-0631.

Aquatic Plant Management in Missouri. Lawrence C. Belusz, Missouri Department of Conservation, P.O. Box 2180, Jefferson City, MO 65102. 1984.

Aquatic Weed Control in Missouri (Agricultural publication G04856). Andrew Kendig. Extension Publications, 2800 Maguire Blvd., University of Missouri, Columbia, MO 65211. 1993.

Biological Control of Weeds Handbook. Weed Science Society of America, Weed Science Society of America, 1508 West University Avenue, Champaign, IL 61821-3133.

Farm Chemicals Handbook. Meister Publishing Co., 37733 Euclid Avenue, Willoughby, OH 44094-5992.

Herbicide Handbook – 7th Edition. Weed Science Society of America, 1508 West University Avenue, Champaign, IL 61821-3133. 1994

SWSS Weed Identification Guides. Southern Weed Science Society, Weed Science Society of America, 1508 West University Avenue, Champaign, IL 61821-3133.

Weed Control Manual. Meister Publishing Co., 37733 Euclid Avenue, Willoughby, OH 44094-5992.

Emergency Telephone Numbers

Missouri Regional Poison Control Center 1-800-366-8888

For pesticide poisoning emergencies, the Missouri Poison Control Center is accessible through a toll free number. The center is located and administered by Cardinal Glennon Memorial Hospital in St. Louis. It is staffed 24 hours daily with medical professionals. The center is equipped to refer poisoning accident victims to a local poison control emergency facility.

Missouri Emergency Response Team (573) 634-2436

For pesticide spill emergencies, the Emergency Response Team handles pesticide spills anyw h ere in Missouri. For information, call (573) 751-7929. Contact: Environmental Emergency Response Coordinator, Missouri Department of Natural Resources, Division of Environmental Quality, P.O. Box 176, Jefferson City, MO 65102.

National Pesticide Safety Team Network (Chemtrec) 1-800-424-9300

The National Agricultural Chemicals Association has a telephone network. This network can tell the applicator the correct contamination procedures to use to send a local safety team to clean up the spill. An applicator can call the network toll free and any time.

National Pesticide Tele-Communications Network 1-800-858-PEST

Call the NPTN network toll free.

U.S. Environmental Protection Agency (EPA) (913) 551-7000

All major pesticide spills are required by law to be reported immediately to the U.S. Environmental Protection Agency, Region VII Office, 726 Minnesota Avenue, Kansas City, KS 66101. The following information should be reported:

1. Name, address, and telephone number of person reporting
2. Exact location of spill
3. Name of company involved and location
4. Specific pesticide spilled
5. Estimated quantity of pesticide spilled
6. Source of spill
7. Cause of spill
8. Name of body of water involved, or nearest body of water to the spill area
9. Action taken for containment and cleanup.

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