A Brief Introduction to Factors Affecting Water Quality, Aquatic Weed Control, Herbicide Labels, & Mixing Calculations

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Factors Affecting Water Quality

Water quality is affected by and can affect the surrounding landscape. Waterbody geomorphology (basin shape) plays a critical role in interactions between water quality in the basin and surrounding landscape. These interactions can influence the ecosystem of a waterbody; specifically, the plant and fish populations. To that end, waterbodies should be surveyed prior to management activities to get baseline measurements of bathymetry (area and depth), water temperature, dissolved oxygen (DO), water clarity (secchi depth), nutrient load (ammonium and nitrate), potential hydrogen (pH), and buffering capacity (alkalinity). Understanding these factors can make managing aquatic resources much easier.

Bathymetry – The bathymetry (or shape) of a waterbody is usually described by area, average depth, and/or maximum depth. The average depth and the area are used to calculate the volume of the waterbody (usually in acre-feet). These measurements are needed for any calculation of lime, fertilizer, or pesticide that will be used for waterbody management. Additionally, these measurements can be used to determine the appropriate stocking densities and feed rates of fish populations.

Water Temperature – Water temperature varies seasonally and with depth. Water in larger, deeper MS waterbodies typically stratifies in summer months with warmer water at the surface and colder water at the bottom; stratification may or may not occur in shallower waterbodies in MS depending on surrounding landscape and local weather patterns. In winter months, water in MS waterbodies tends to fully mix with no significant change in temperature from top to bottom; although, there are exceptions to this (i.e., ice cover on ponds and very deep reservoirs). Water temperature can affect the form of dissolved gasses and nutrients in the water column which in turn can affect the aquatic ecosystem. In summer months, water at the bottom of ponds has less oxygen than warmer, upper water, usually due to a lack of vegetation and algae in deeper water (due to light limitations) that produce dissolved gasses as these organisms undergo photosynthesis. In winter months, oxygen tends to be uniformly distributed throughout the water column and in higher densities than warmer months because cooler water can hold more dissolved gasses than warmer water.

Dissolved oxygen (DO) – Dissolved oxygen is a measurement of oxygen gas in the water column. This is the major oxygen source for all submersed aquatic flora and fauna. The DO of a water body can be affected by the aquatic plant community present. As submersed plants respire, they release DO into the water column that is then available for use by aquatic fauna. However, if a waterbody is overpopulated with nuisance vegetation that forms thick mats in the upper water column, the DO can drop as underlying plants are shaded out and die. The bacteria in the water column that break down decaying vegetation use DO in the decomposition process. Thus, the available DO is used up by bacteria to metabolize decaying plants and is unavailable for fish use. This drop in DO can suffocate fish causing their populations to decline or even crash if the plant infestation is severe enough to cause a rapid die off of underlying plants.

Water Clarity – Water clarity is usually measured as secchi depth using a Secchi disk. Water clarity is used to calculate the littoral zone of a water body. The littoral zone is that area of a waterbody that receives enough sunlight on the bottom for aquatic plants and algae to grow. The littoral depth is calculated as 2.5 secchi depths. However, as water temperature rises in summer months, phytoplankton (which include green algae, diatoms, and cyanobacteria) become more active/prevalent in the water column. These organisms are present in waterbodies year-round and tend to have similar life cycles as plants; that is, they increase in number as air and water temperatures rise (summer) and decrease in number as temperatures decline (winter). This leads to algal and bacterial reproduction which lowers water clarity as the algal community (sometimes called an algal bloom) gets more-dense in warmer months. As the bloom increases the water clarity decreases which can in turn decrease the size of the littoral zone of a waterbody.

Nutrient Load – Because algae and plants rely on nutrients in the water column, they are sensitive to changes in aquatic nutrients; specifically, the 3 primary plant nutrients found in commercial fertilizers like phosphorus (measured as phosphate or phosphate compounds), potassium, and nitrogen (measured as ammonium or nitrate). Plants and algae typically utilize inorganic nutrients (rather than organic) for growth; thus, most commercial fertilizers are composed of inorganic forms of these nutrients. However, the inorganic form of nutrients (specifically nitrogen) can fluctuate due to changes in bacterial communities which can be regulated by changes in water temperature and water potential hydrogen (pH). Unlike nitrogen compounds, there is no atmospheric form of phosphorous, thus its cycling process is less complex; however, because phosphorous compounds are rapidly absorbed to sediment, iron, and/or organic particles in aquatic environments, it is often the limiting nutrient for plant and algal growth.

Fertilizing a waterbody can cause nuisance plant growth and algal blooms to increase (lowering water clarity). Over-fertilizing (which is common in small ponds) can cause a rapid increase in algal bloom density that can have a similar effect as topped out nuisance vegetation. The algal bloom can become so dense that it shades out underlying vegetation and kills it. An algal bloom can also have a self-inhibiting effect; whereby, the bloom can become so dense that some of the bloom does not get enough sunlight and dies. As the dead portion of the algal bloom is metabolized by bacteria the DO drops. The resulting drop in DO can then cause a summer fish kill.

Most waterbodies in the southeastern U.S. have plenty of nutrients constantly introduced to them from the atmosphere, as rainfall washes debris (sticks, leaves, soil, dead animals) into waterbodies, and from sediment release. The addition of fertilizer is usually not needed to have a healthy and balanced fish community. However, if a larger and more dense fish community is desired then the addition of nutrients can be beneficial. This is usually accomplished through fertilizing or feeding fish. Both activities affect the entire food web of a waterbody, but feeding is more targeted to the fish community (top of the food web) while fertilizing targets the plant community (bottom of the food web). Actions that affect the bottom of a food web can have major effects on upper food web layers while actions that affect the upper layers don't usually affect the lower layers with the same intensity; especially if fish are harvested.

Feeding fish is usually easier to start and stop without having long term effects on the system because this method primarily targets the fish community rather than the entire aquatic ecosystem. Additionally, regular harvest of fish removes added nutrients from the ecosystem before they can by cycled to the lower layers of the food web. Once started, fertilizing has to be continued. If fertilization is stopped, the entire pond ecosystem may crash, which usually requires restocking of fish followed by 2 – 4 years of not harvesting fish while the community recovers.

Potential Hydrogen (pH) – Potential hydrogen is a measure of hydrogen ion concentration (acidity or basicity) in a water body and is measured on a scale of 0-14; with 0 being acidic, 7 being neutral, and 14 being alkaline. The pH of a waterbody is primarily influenced by the soils of the surrounding landscape. The pH can affect bacterial communities in water bodies which can in turn affect the form of nitrogen in the water. Most bacteria that can convert organic nitrogen to inorganic are found in waters close to a neutral pH. The pH of a water body can fluctuate drastically throughout the day as plants photosynthesize and respire. pH is lowest in the morning, rises during the day, then drops during the night. Water with less pH fluctuation away from neutral values (pH of ~5.8 – 8.0) should have a healthier microbial community to constantly convert nitrogen to the appropriate form for plant uptake. If water is too acidic, lime can be added to raise the pH closer to a neutral value.

Buffering Capacity – Buffering capacity is a measure of a waterbody to resist changes in pH. This is usually referred to as alkalinity and is controlled by ions (can be gasses and/or solids) in the water column that can bind to hydrogen before it can lower the pH of the waterbody. At a given point, the alkalinity is overcome, and the pH begins to change; although in a higher alkalinity water body this is slower than and not as drastic as a waterbody with less buffering capacity. These ions are measured as parts per million (ppm) in the water column. In addition to raising pH, lime can increase the buffering capacity (increased ppm) of water so that daily changes in pH are less drastic from baseline values. This will help to keep nutrients in a form plants and algae can use by keeping water pH in a range useful for bacteria to alter the form of nitrogen.

If any of these factors are altered too far, they can impact aquatic plant growth in negative ways that may need management actions to correct. For example, as a waterbody gets shallower due to sedimentation (altered *bathymetry*) it will hold less water volume which can lead to drastic seasonal shifts in *water temperature* due to less water to heat and cool from solar radiation and the surrounding atmosphere. This can lead to a cascading effect that can alter *dissolved oxygen*, *water clarity*, *nutrient loads*, *pH*, and *buffering capacity* in the same water body. In a similar fashion, these factors can affect and be affected by nuisance aquatic plant growth.

Introduction to Aquatic Weed Control

Aquatic weeds can be troubling to a broad demographic of citizens (farmers, recreational waterbody users, private landowners, commercial and private industry) in MS and surrounding states. Aquatic plants provide structure for feeding and breeding of fish species. Many aquatic crustaceans (i.e., snails) and insects use aquatic plants as a food source. These crustaceans and insects are in turn a food source for fish; primarily sunfish (a.k.a. bream) in small ponds. However, when aquatic plants become a nuisance, it is beneficial for landowners or resource managers to define the goals they have in mind for their waterbody and then develop a plan to help them reach those goals. For example, weed management in a trophy bass pond will be very different from management in an irrigation pond. The most effective management plans are those that are well thought out and pre-planned prior to implementation of any management activities. In any plan, it is important to have a list of alternative methods that may be implemented if management goals are not being met. Constant monitoring is needed to determine if management is progressing towards desired goals or if an alternative strategy should be implemented to get management back on track. The outline of a typical plan may look like:

1. Define goals for a waterbody (financial input should be considered here)
2. Recognizing nuisance weed problems and if they occur, then
3. Scouting the site to determine the target plant ID and level/amount of infestation
4. Identifying potential management options and alternatives
5. Collection of pre-treatment data (%-cover, prevalence, and/or biomass) if desired
6. Implementation of control strategies
7. Continued monitoring and data collection
8. Shift to alternative control strategies if primary strategy ineffective
9. Continued monitoring and data collection.

Measures of success or failure – While not always necessary, there are a few simple measures of plant abundance that landowners and resource managers can record throughout the management process that will allow them to determine the level of success or failure attained by management activities. The most basic is percent-cover; this is a basic estimate of the amount of water surface covered by a target weed. Another useful metric is frequency of occurrence; this is recorded by setting up a grid of monitoring points in the waterbody and recording the presence or absence of the target vegetation pre- and post-management. To determine presence or absence of submersed vegetation, many resource managers will attach a weighted thatch or garden rake head to a rope and toss it in the water at each point and record the vegetation that is on the rake when it is pulled back to the surface. This allows managers to calculate the %-reduction of the plants geographic range in the waterbody; the more monitoring points the more accurate the calculation will be. A third metric is biomass (or weight), biomass can be recorded as 'fresh' or 'wet' weight by collecting all the target plant material in a known area (usually 1/10th to ½ of a square meter; a square foot PVC frame is also useful for this), letting the biomass drip dry and then weighing on a scale. This also needs to be done at multiple points throughout the waterbody pre- and post-management. A better measurement of biomass is dry weight but attaining this measurement can be time consuming and usually requires specialized drying ovens that may be unavailable to small pond owners and resource managers. The last metric (and in some cases, the most important) is propagule number; this can be difficult to assess as some resource managers may not know what the different propagules look like for a species or the propagules may be hard to detect (i.e., buried in sediments). For instance, many aquatic weeds can reproduce through multiple means like stem fragments, structures called turions, axillary buds, seeds, bulbils, and/or daughter plants. Understanding the difference in these structures and how they can affect the spread, colonization, or re-colonization of a previously managed site is always beneficial but may not be feasible for some resource managers. Contacting a vegetation control expert may be necessary to learn about propagule types for individual plant species. If possible, it is worth the time to learn about these structures and to record propagule numbers at survey sites during each monitoring event so that resource managers have a better understanding of how control strategies reduce propagule numbers (also called propagule banks) and therefore future nuisance potential from the target plant population.

Herbicide Labels and Mixing Calculations

One of the most common control techniques to reduce aquatic weed abundance and propagule banks, and usually the most effective option, is the use of herbicides that are labeled for use in aquatic environments. In the U.S., there are currently (as of 2019) 15 herbicides labeled for general use in aquatic environments (Table 1) versus hundreds that are used in terrestrial settings. Prior to selecting an herbicide, the landowner or herbicide applicator should always confirm the identity of the target plant as different herbicides have different levels of activity on different species.

Because one herbicide can be sold by various companies under many different trade names, researchers and vegetation control experts usually refer to herbicides by the active ingredient (i.e., glyphosate) that causes damage to plants rather than trade names used by different chemical companies (i.e., Rodeo, etc.). Additionally, not all trade names have the same amount of active ingredient; therefore, it is beneficial to reference the type of formulation in discussion so that end users have a point of reference when mixing herbicide solution; this is usually referenced as pounds active ingredient (a.i.) or pounds acid equivalent (a.e.) per gallon of product (Figure 1). For example, the herbicide imazapyr is sold in formulations with 2 lbs. (referred to as a 2 lb. formulation) and 4 lbs. (referred to as a 4 lb. formulation) a.e. per gallon of product; an herbicide applicator would need half the volume of the 4 lb. product when following the directions for mixing a tank of herbicide solution using 2 lb. instructions. Once an herbicide has been selected, the applicator should read the label carefully and follow all safety guidelines and instructions on the label; the label is the law (state and federal) so using an herbicide in an off-label manner is a violation of state and federal law. This document is meant to be an aid for resource managers dealing with aquatic weeds; not a replacement for herbicide labels. After the label has been read and all necessary safety equipment is in place, the applicator will need to select the appropriate herbicide rate and possibly adjuvant/surfactant rates. Herbicide that are legal for use in aquatic environments should have an ‘Aquatic Use’ section (or some variation thereof) to aid applicators targeting aquatic vegetation for control (Figure 2). This section of an herbicide label usually has a table with recommended use rates (Figure 3) for that specific chemical/product.

Herbicide rates can be calculated 3 ways: 2 calibrated and 1 non-calibrated. The first method is the calibrated weight of herbicide (lbs. a.i.) per unit area (i.e., acres) of treatment site; however, because the weight of herbicide is known for gallons of concentrated product (lbs. a.i. per gallon of product) this is usually presented as *volume-per-unit-area* (i.e., gallons per acre). The second method is a non-calibrated spot treatment rate where the concentration rate of active ingredient in solution is known but the unit area of treatment site is unknown. This method is usually presented as *%-solution* and is used on spotty patches of weeds or individual plants. The last method is the calibrated weight of herbicide per unit of volume of water in the waterbody or treatment site. Similar to the first method, the weight of herbicide is known in the concentrated product, so this method is usually reported as volume-per-unit-volume or more commonly *parts-per-million* or *billion*.

The first two methods are primarily for foliar applications and the third is for submersed herbicide applications; also called submersed injections. Spot rates should be used sparingly rather than as a substitute for calibrated methods due to the ability to easily over apply herbicide using the spot method; this can cause harm to the environment and be a waste of financial input and time. There are fourth, fifth, and sixth types of application techniques called granular, drip, and aerial applications (respectively) that will not be discussed in this document as they are not as common as the first 3 due to the need for specialized application equipment (granular, drip, and aerial) or specific aquatic environments (drip).

Volume-per-unit-area – For rates based on volume per acre basis, the appropriate amount of herbicide needs to be added to the solution and the total solution needs to be spread evenly over the specified amount of ground (water surface in the case of aquatic applications). The first step in this application method is calculation of the waterbody area (if total waterbody is covered) or infestation area (like pond margins); this measurement can made in free software packages like Google Earth Pro or using the area calculations for basic shapes like rectangles, circles, and triangles. This type of application is usually conducted by placing the herbicide spray equipment in a boat with a fixed nozzle (or boom with many nozzles) off the side or back of the boat that continuously sprays as the applicator navigates across the water body surface. This type of herbicide calculation requires the applicator to know the total spray tank volume, spray rate (gallons per minute), swath width of the nozzle or boom, and the speed needed to cover an acre at the predetermined swath width. Swath is measured by filling the tank half full of water and turning the sprayer on in an area where the swath can be measured on the ground (wet band on the ground or pond margin under the nozzles). Spray rate is measured by putting a container of known size under the nozzle or nozzles and measuring the amount of time needed to fill the container (ex: 5-gal bucket filled in 1 minute = 5 gal/min). If using a boom with multiple nozzles, each nozzles output should be measured separately as pressure may not be equal from nozzle to nozzle with can result in some nozzles releasing more herbicide solution than others (See Appendix A for step-by-step instructions and a worksheet).

Example 1: 25-gal ATV sprayer with a 15 ft swath and 2 gal/minute spray rate.

There are 43,560 sq-ft in an acre: 43,560 sq-ft / 15 ft swath = 2,904 linear ft of ground (Swath Length that is 15 ft wide) can be covered per tank of solution. If the sprayer is releasing 2 gal of solution per minute, the applicator has 12.5 minutes to cover 2,904 ft of ground (25 gal / 2 gal/min = 12.5 min). This means the applicator needs to travel at a velocity of 232.32 ft per minute (2,904 ft / 12.5 min = 232.32 ft/min) or 2.64 MPH (232.32 ft per min / 88 [ft/min]/MPH) to cover 1 acre of infested area with 1 spray tank of solution.

%-Solution – This method is similar to the first; however, the applicator will need to calculate the volume of herbicide needed as a percentage (as a decimal) of the total solution to be mixed prior to mixing. Once the volume is known, the same steps as in the previous example can be followed in order to apply the correct amount of herbicide to the target area. This method is very common for spot type applications where an applicator is aiming a nozzle (spray gun) by hand rather than having a fixed nozzle off the side or back of a boat (See Appendix B for step-by-step instructions and a worksheet).

Example 2: 2% solution needed in a 25-gal ATV sprayer.

There are 128 oz/gal: 25 gal/tank * 128 oz/gal = 3,200 oz/tank. 2% = 0.02, therefore, 3,200 * 0.02 = 64 oz/tank. To convert to gal simply divide 2% result (64 oz) by 128 oz/gal: 64 / 128 = 0.5 gal of herbicide needed.

Parts-per-million/billion – This method requires the applicator to know the volume of water to be treated prior to mixing herbicide solution. This method is commonly used when targeting submersed vegetation, floating vegetation, or algae. This type of application is conducted by placing spray equipment in a boat but instead of nozzles, the applicator typically uses drop hoses that hang off the side of the boat and inject the herbicide solution under the water surface. Some applicators may use a spray gun and travel across that waterbody while keeping the tip of the spray gun underwater. Once the herbicide is in the water it will disperse until a constant concentration (target ppm or ppb) is attained throughout the water body. The first step in this application method is calculation of the waterbody area and the average depth of the waterbody; these 2 measurements are needed to calculate the volume of water to be treated with herbicide. Applicators should navigate across the surface of the waterbody taking depth measurements with a sounding rod or depth finder (a minimum of 15-20 measurements should be taken for waterbodies; more is better). The average depth is calculated by summing the depths that were measured and dividing that sum by the total number of measurements taken. The volume of the waterbody is then calculated by multiplying the area (in acres) of the waterbody by the average depth (in feet). The volume of the pond is reported in acre-feet; an acre-foot is the volume of water needed to cover an acre with 1 foot of water. An acre-foot is equal to 43,560 cubic-feet of water or 325,851 gallons. To get parts per million (ppm), an applicator needs to divide the total gallons of water by 1 million (1 ppm) and then multiply by the total number of ppm needed. Most herbicide labels have already done this calculation and provide a table (Figure 3) that has the amount of herbicide needed to reach a target ppm in 1 ac-ft of water. Applicators should only need to calculate the volume of herbicide needed for their target rate by multiplying the target rate by the target ppm from the label and the product of this calculation by the ac-ft in the waterbody. 1 ppm equals 1,000 ppb so conversion between the two is simple if a ppb rate is needed instead (See Appendix C for step-by-step instructions and a worksheet).

Example 3: An applicator is preparing to conduct a submersed herbicide injection of 2.5 ppm on a 10-acre pond. The applicator took 20 depth readings across the pond totaling 120 ft. The herbicide label states that 0.71 gal of product is needed for a 1 ppm treatment for 1 ac-ft of water.

Waterbody Volume: 120 ft / 20 = 6 ft average depth. 10 ac * 6 ft = 60 ac-ft of water in the pond.

Herbicide needed: 0.71 gal is 1 ppm in 1 ac-ft of water. Therefore, 0.71 gal/ppm * 2.5 ppm/ac-ft * 60 ac-ft = 106.5 gal of herbicide needed to treat the entire pond at a rate of 2.5 ppm (2.5 * 1,000 = 2,500 ppb).

Adjuvants/surfactants – Most vegetation has a waxy layer on leaves called a cuticle that can slow or prevent herbicide uptake. Additionally, plant architecture (i.e., vertical vs. horizontal leaves) can lead to runoff of the solution which yields less herbicide uptake by target vegetation. As a result, many herbicide applicators include additives, broadly called adjuvants, to herbicide solutions that aid in herbicide uptake by target vegetation. Common adjuvants are penetrants, sticking agents, spreading agents, and wetting agents. Adjuvants increase herbicide uptake in many ways: the most common are by breaking down the cuticle (penetrants), helping the herbicide solution stick to leaves (sticking agents), by causing solution droplets to spread out and cover more of the leaf surfaces (spreading agents), or by increasing the amount of time it takes to dry out the solution on leaves (wetting agents). There are many different types of additives sold but those most commonly used in aquatic herbicide applications are non-ionic surfactants and crop/seed oils. Other ‘ionic” surfactants can attach to the gills of fish causing suffocation; applicators that use the wrong surfactant often see fish kills as a result. Surfactants are usually added as a percentage of total solution; the recommended percentage is found on the surfactant label. The surfactant amount is easily calculated by multiplying the total gallons of solution by 128 (number of ounces per gallon) then multiplying again by the percentage (as a decimal) needed (See Appendix B for step-by-step instructions and a worksheet).

Example 4: An applicator needs an herbicide solution containing 1% non-ionic surfactant in a 25-gallon ATV sprayer.

25 gal/tank * 128 oz/gal = 3,200 oz/tank * 0.01 = 32 oz/tank

After herbicide application, it may take weeks or months for symptomology to become evident. As mentioned earlier, reading the label prior to application will inform the applicator of the time to symptomology so that monitoring can be conducted at the correct time. Follow up monitoring is a crucial, yet often overlooked, step in any herbicide application. Monitoring allows the landowner or applicator to determine if management goals have been achieved and if not, allows them to adapt the management plan such that goals can be achieved. It is also important to remember that aquatic environments are very dynamic and undergo seasonal shifts throughout the year. These seasonal shifts affect water quality which in turn can affect the outcome of plant management activities (especially herbicide applications); for this reason, the timing of management activities should be considered prior to implementation of management practices.

Acknowledgements

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Tables and Figures

Table 1. Pesticides labeled for use in aquatic environments.

HERBICIDE	TRANSLOCATION	MODE OF ACTION	DEGRADATION
2,4-D	Systemic	Auxin mimic	Microbial/photolysis
Florpyrazuxifen-benzyl	Systemic	Auxin mimic	Microbial/photolysis
Triclopyr	Systemic	Auxin mimic	Microbial/photolysis
Bispyribac-sodium	Systemic	ALS inhibitor	Microbial
Imazamox	Systemic	ALS inhibitor	Microbial/photolysis
Imazapyr	Systemic	ALS inhibitor	Microbial/photolysis
Penoxsulam	Systemic	ALS inhibitor	Microbial/photolysis
Fluridone	Systemic	Pigment synthesis inhibitor	Microbial/photolysis
Topramezone	Systemic	4-HPPD inhibitor	Photolysis
Glyphosate	Systemic	EPSPS inhibitor	Adsorption/microbial
Endothall	Systemic/contact	S/P protein phosphatase inhibitor	Microbial
Carfentrazone-ethyl	Contact	PPO inhibitor	Hydrolysis/photolysis
Flumioxazin	Contact	PPO inhibitor	Hydrolysis/microbial/photolysis
Copper	Contact	Photosynthesis inhibitor	Chemically bound
Diquat	Contact	Photosynthesis inhibitor	Adsorption/photolysis
Peroxides	Contact	Oxidizes leaf surfaces	Hydrolysis
Dyes*	NA	Reflects/absorbs sunlight	Photolysis

*Dye use is a physical control technique that alters the environment around plants such that they cannot survive. Not all aquatic use dyes are registered for aquatic weed control; be sure to read the dye label prior to application to make sure the product selected has weed control verbage.

Figure 1. Image of the first page of an herbicide label showing the Trade name (red circle), Chemical name (blue circle), and the formulation amount of herbicide active ingredient per gallon of product (orange circle). Label found online at http://www.cdms.net/ldat/ld08K001.pdf.

BIOENERGY CROPS - GRASSES*

WEED CONTROL IN GIANT REEDGRASS (*Arundo donax*), SWITCHGRASS (*Panicum virgatum*), GIANT MISCANTHUS (*Miscanthus x giganteus*) AND OTHER NON-FOOD PERENNIAL GRASS BIOENERGY CROPS.

***Not for use in California to Bioenergy Crops – Grasses**

USE INSTRUCTIONS

This product may be applied for broadleaf weed control in giant reedgrass (*Arundo donax*), switchgrass (*Panicum virgatum*) giant Miscanthus (*Miscanthus x giganteus*) and other non-food perennial grass bioenergy crops.

For perennial grasses, apply no earlier than 4-leaf stage. Apply 1/2 to 2 pints per acre to seedling grasses with ground or air equipment. A rate of 1 to 4 pints per acre should be used when grasses are well established.

RESTRICTIONS AND LIMITATIONS

- Limited to 2 broadcast applications per year.
- Maximum of 4 pints (2.0 lb. ae) per acre per application.
- Minimum of 30 days between applications.
- Apply by air or ground equipment in sufficient gallonage to obtain adequate coverage. Minimum of 2 gallons of water per acre for aerial application and 10 or more for ground application is recommended.
- Do not spray immediately before irrigation and withhold above-ground irrigation for 3 days after application.
- Treated plantings not to be consumed by human or animal.

BIOENERGY CROPS - TREES

WEED CONTROL IN HYBRID POPLAR TREES, COTTONWOOD TREES AND WILLOW TREES GROWN AS BIOENERGY CROPS

USE INSTRUCTIONS

This product may be used in hybrid poplar trees, cottonwood trees and willow trees grown as bioenergy crops. Application during warm weather is preferred. Apply when weeds are actively growing, preferably before bud stage. Repeat treatment may be necessary for less susceptible weeds; re-apply as needed.

For hybrid poplar, cottonwood and willow make application prior to or after planting. For ground spray equipment, use 1/2 to 3 pints per acre. Apply 1 to 4 pints per acre using wick type applicators that treat weeds directly. Crop injury may result if the wick, wick solution or spray solution contact leaves or green bark of the crop trees.

NOTE: Extreme care should be exercised to avoid contact of the spray solution, spray, drift, or mist with tree foliage, green bark of trucks, stems or exposed roots of the poplar, cottonwood and will trees. Contact of the spray solution to these parts can result in serious damage. Even when using extreme care in application of this product, injury to crops from this herbicide may occur. <u>If you are not prepared to accept some degree of crop injury, do not use this product.</u>

TANK MIXTURES

This product may be tank mixed with Credit 41 Herbicide (EPA Reg. No. 71368-20) to provide broader spectrum of control.

RESTRICTIONS AND LIMITATIONS

- Limited to 1 broadcast applications per year.
- Maximum of 4 pints (2.0 lb. ae) per acre per application.
- Minimum of 30 days between applications.
- Use sufficient spray volume for thorough and uniform coverage, but a minimum of 10 gallons per acre for broadcast application.
- Do not apply this product by air for use of weed control in hybrid poplar tree, cottonwood trees and willow tress grown as bioenergy crops.
- Do not use this product in or near greenhouses, for use of weed control in hybrid poplar tree, cottonwood trees and willow tress grown as bioenergy crops.
- Do not spray immediately before irrigation and withhold above-ground irrigation for 3 days after application.
- Treated plantings not to be consumed by human or animal.

AQUATIC USES

Use Requirements for Aquatic Areas: When this product is applied to aquatic areas, follow PPE and reentry instructions in the "Non-Agricultural Use Requirements" section of this label.

CONTROL OF WEEDS AND BRUSH ON BANKS OF IRRIGATION CANALS AND DITCHES

Target Plants	Weedar 64 (pt/acre)	Specific Use Directions
Annual Weeds **Biennial and perennial broadleaf weeds and susceptible wood plants**	2 to 4 4	Apply using low pressure spray (10 to 40 psi) in a spray volume of 20 to 100 gallons per acre using power operated spray equipment. Apply when wind speed is low, 5 mph or less. Apply working upstream to avoid accidental concentration of spray into water. Cross-stream spraying to opposite banks is not permitted and avoid boom spraying over water surface. When spraying shoreline weeds, allow no more than 2 foot overspray onto water surface with an average of less than 1 foot of overspray to prevent significant water contamination. Apply when weeds are small and growing actively before the bud stage. Apply when biennial and perennial species are in the seedling to rosette stage and before stalks appear. For hard-to-control weeds, a repeat application after 30 days at the same rate may be needed. For woody species and patches of perennial weeds, mix 1 gallon of Weedar 64 in 150 gallons of total spray. Wet foliage by applying about 3 to 4 gallons of spray per 1000 sq ft (10.5 x 10.5 steps).

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Figure 2. Image of the "Aquatic Use" header on an herbicide label. Label found online at http://www.cdms.net/ldat/ld08K001.pdf.

supply or to individual private water users must be done in a manner to assure that the party is aware of the water use restrictions when this product is applied to potable water. The following is an example of a notification via posting, but other methods of notification which convey the above restrictions may be used and may be required in some cases under State or local law or as a condition of a permit.

Example: Posting notification should be located every 250 feet including the shoreline of the treated area and up to 250 feet of shoreline past the application site to include immediate public access points. Posting must include the day and time of application. Posting may be removed if analysis of a sample collected at the intake 3 or more days following application shows that the concentration in the water is less than 70 ppb (100 ppb for irrigation or sprays), or after 7 days following application, whichever occurs first.

Text of notification: Wait 7 days before diverting functioning surface water intakes from the treated aquatic site to use as drinking water, irrigation, or sprays, unless water at functioning drinking water intakes is tested at least 3 days after application and is demonstrated by assay to contain not more than 70 ppb 2,4-D (100 ppb for irrigation or sprays).

Application Date: ______ Time: _____ .

D. Following each application of this product, treated water must not be used for drinking water unless one of the following restrictions has been observed:
  i. A setback distance from functional water intake(s) of greater than or equal to 600 ft. was used for the application, or
  ii. A waiting period of 7 days from the time of application has elapsed, or,
  iii. An approved assay indicates that the 2,4-D concentration is 70 ppb (0.07 ppm) or less at the water intake. Sampling for drinking water analysis should occur no sooner than 3 days after 2,4-D application. Analysis of samples must be completed by a laboratory that is certified under the Safe Drinking Water Act to perform drinking water analysis using a currently approved version of analytical Method Number 515, 555, other methods for 2,4-D as may be listed in Title 40 CFR, Part 141.24, or Method Number 4015 (immunoassay of 2,4-D) from U.S. EPA Test Methods for Evaluating Solid Waste SW-846.

E. Note: Existing potable water intakes that are no longer in use, such as those replaced by a connection to a municipal water system or a potable water well, are not considered to be functioning potable water intakes.

F. Drinking water setback distances do not apply to terrestrial applications of 2,4-D adjacent to water bodies with potable water intakes.

3. Except as stated above, there are no restrictions on using water from treated areas for swimming, fishing, watering livestock or domestic purposes.

Coordination and approval of local and state authorities may be required, either by letter of agreement or issuance of special permits for aquatic applications.

SUBMERGED AQUATIC WEEDS: Including Eurasian Water Milfoil (*Myriophyllum spicatum*)

Treatment Site	**Maximum Application Rate†**	**Specific Use Directions**
Aquatic Weed Control In: **Ponds,** **Lakes,** **Reservoirs,** **Marshes,** **Bayous,** **Drainage Ditches,** **Canals,** **Rivers and Streams that are Quiescent or Slow Moving, Including (but not exclusive to) Programs of the Tennessee Valley Authority (TVA)**	2.84 gallons (10.8 lb of acid equivalent) per acre foot	**Application Timing:** For best results, apply in spring or early summer when aquatic weeds appear. Check for weed growth in areas heavily infested the previous year. A second application may be needed when weeds show signs of recovery, but no later than mid-August in most areas. **Subsurface Application:** Apply Weedar 64 undiluted directly to the water through a boat mounted distribution system. Shoreline areas should be treated by subsurface injection application by boat to avoid aerial drift. **Surface Application:** Use power operated boat mounted boom sprayer. If rate is less than 5 gallons per acre, dilute to a minimum spray volume of 5 gallons per surface acre. **Aerial Application:** Use drift control spray equipment or thickening agents mixed with sprays to reduce drift. Apply through standard boom systems in a minimum spray volume of 5 gallons per surface acre. For Microfoil (r) drift control spray systems, apply Weedar 64 in a total spray volume of 12 to 15 gallons per acre. Apply to attain a concentration of 2 to 4 ppm (see table below).

†Weedar 64 contains 3.8 lb of acid equivalent per gallon of product.

Table 1. Amount of 2,4-D to Apply for a Target Subsurface Concentration

Surface Area	**Average Depth**	**For typical conditions - 2 ppm (2,4-D a.e./acre)**	**For typical conditions - 2 ppm (Weedar 64 gal/acre)**	**For difficult conditions - 4 ppm* (2,4-D a.e./acre)**	**For difficult conditions - 4 ppm* (Weedar 64 gal/acre)**
1 acre	1 ft.	5.4	1.42	10.8	2.84
	2 ft.	10.8	2.84	21.6	5.68
	3 ft.	16.2	4.26	32.4	8.53
	4 ft.	21.6	5.68	43.2	11.37
	5 ft.	27.0	7.10	54.0	14.21

*Examples include spot treatment of pioneer colonies of Eurasian Water Milfoil and certain difficult to control aquatic species.

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Figure 3. Image showing a table of submersed herbicide (bottom of image) rates from an herbicide label. Label found online at http://www.cdms.net/ldat/ld08K001.pdf.

APPENDIX A

Instructions and Worksheet to calculate and mix Volume-per-unit-area herbicide rates

For rates based on volume-per-unit area basis, the appropriate amount of herbicide needs to be added to the solution and the total solution (Tank Volume) needs to be spread evenly over the specified amount of ground (Infested Area – water surface in the case of aquatic applications). Use Table A1 as a worksheet if needed.

Step 1. Infested Area – this can be measured using software packages or using basic measurements and area calculations for basic water body shapes: rectangle = length * width; circle = 3.1415 * radius * radius; triangle = 0.5 * length * width. All measurements should be in feet; area calculations will be in square-feet (sq-ft). Multiply acres by 43,560 to convert to sq-ft.

Step 2. Tank Volume – this value can be recorded by looking at the volume marks on the spray tank.

Step 3. Swath width – fill the sprayer partially full of water and spray for a few seconds on bare ground. Measure the length of the wet swath on the ground. Record this measurement the table below.

Step 4. Spray rate – this is measured by putting a container of known size under the nozzle or nozzles and measuring the amount of time needed to fill the container (ex: 5-gal bucket filled in 1 minute = 5 gal/min). If using a boom with multiple nozzles, each nozzles output should be measured separately as pressure may not be equal from nozzle to nozzle with can result in some nozzles releasing more herbicide solution than others.

Step 5. Swath Length – this is calculated by dividing the Infested Area (Step 1) by the Swath Width (Step 3).

Step 6. Application Time – this is calculated by dividing Tank Volume (Step 2) by Spray Rate (Step 4).

Step 7. Velocity – this is calculated by dividing Swath Length (Step 5) by Application Time (Step 6) and then dividing the solution by 88 to get final Velocity in MPH (Step 7). For reference, the average human walks at a speed of 2-3 MPH; this can be used as a guide for Velocity if an applicator doesn’t have access to a speedometer while making an herbicide application. NOTE: If calculated velocity is higher than 5 MPH, then divide the Infested Area into smaller sub-areas so that herbicide contact with target plants is optimal.

Table A1. Worksheet for herbicide tank mixing calculations prior to herbicide applications; record measurements and calculations in the VALUE column.

VABIABLE NAME	VARIABLE	CALCULATION	VALUE
Infested Area (Sq-ft)	A	Step 1	
Tank Volume (Gal)	B	Step 2	
Swath Width (Ft)	C	Step 3	
Spray Rate (Gal/min)	D	Step 4	
Swath Length (Ft)	E	Step 5: E = A/C	
Application Time (Min)	F	Step 6: F = B/D	
Velocity (MPH)	G	Step 7: G = (E/F)/88	

APPENDIX B

Instructions and Worksheet to calculate and mix %-Solution herbicide and Surfactant rates

This method is similar to Volume-per-unit-area herbicide mixing instructions (Appendix A); however, the applicator will need to calculate the volume of herbicide needed as a percentage (as a decimal) of the total solution to be mixed prior to mixing. Once the volume is known, the same steps as in the previous example can be followed in order to apply the correct amount of herbicide to the target area. This method is very common for spot type applications where an applicator is aiming a nozzle (spray gun) by hand rather than having a fixed nozzle off the side or back of a boat. Use the first method (Appendix A) rather than this if at all possible. This same methodology can be used to calculate adjuvant volumes needed. Use Table B1 as a worksheet if needed.

Step 1. Tank Volume (Gal) – this value can be recorded by looking at the volume marks on the spray tank.

Step 2. Tank Volume (Oz) – Multiplying the gallons per tank (Step 1) by 128 will give the tank volume in ounces.

Step 3. %-Herbicide (%) – this value can be recorded from the herbicide label.

Step 4. %-Herbicide (decimal) – divide the %-Herbicide (Step 3) by 100 to get the %-herbicide needed as a decimal. Ex. 2% herbicide solution needed divided by 100 equals 0.02 (2/100=0.02).

Step 5. Herbicide Volume (Oz) – this is calculated by multiplying the ounces per tank (Step 2) by the %-herbicide (decimal; Step 4).

Step 6. Herbicide Volume (Gal) – this can be calculated by dividing the Herbicide Volume (Oz; Step 5) by 128.

Table B1. Worksheet for herbicide tank mixing calculations prior to herbicide applications; record measurements and calculations in the VALUE column.

VABIABLE NAME	VARIABLE	CALCULATION	VALUE
Tank Volume (Gal)	A	Step 1	
Tank Volume (Oz)	B	Step 2: B = A * 128	
%-Herbicide (%)	C	Step 3	
%-Herbicide (decimal)	D	Step 4: D = C/100	
Herbicide Volume (Oz)	E	Step 5: E = B*D	
Herbicide Volume (Gal)	F	Step 6: F = E/128	

APPENDIX C

Instructions and Worksheet to calculate and mix Parts-Per-Million or Billion herbicide rates

This method requires the applicator to know the volume of water to be treated prior to mixing herbicide solution. This method is commonly used when targeting submersed vegetation, floating vegetation, or algae. This type of application is conducted by placing spray equipment in a boat but instead of nozzles, the applicator typically uses drop hoses that hang off the side of the boat and inject the herbicide solution under the water surface. Some applicators may use a spray gun and travel across that waterbody while keeping the tip of the spray gun underwater. Once the herbicide is in the water it will disperse until a constant concentration (target ppm or ppb) is attained throughout the water body. Use Tables C1 and C2 as worksheets if needed.

Step 1. Waterbody Surface Area (Acres) – this can be measured using software packages or using basic measurements and area calculations for basic water body shapes: rectangle = length * width; circle = 3.1415 * radius * radius; triangle = 0.5 * length * width. All measurements should be in feet; area calculations will be in square-feet (sq-ft). Divide the square feet area by 43,560 to convert to Acres.

Step 2. Average Depth (Ft) – Use table C1 below to record depths at 15-20 evenly spaced points across the waterbody. Sum the values of these depths and divide by the number of depth measurements recorded to calculate the average depth of the waterbody.

Step 3. Waterbody Volume (Ac-ft) – this value can be calculated by multiplying Surface Area (Step 1) and Average Depth (Step 2).

Step 4. Herbicide Volume (Gal per 1 ppm per ac-ft) – this value can be recorded from the herbicide label.

Step 5. Target ppm – this value can be recorded from the herbicide label.

Step 6. Herbicide Needed (Gal) – this value is calculated by multiplying the Waterbody Volume (Step 3), Herbicide Volume (Step 4), and Target ppm (Step 5) together.

Table C1. Worksheet for herbicide tank mixing calculations prior to herbicide applications; record measurements and calculations in the VALUE column.

VABIABLE NAME	VARIABLE	CALCULATION	VALUE
Infested Area (Ac)	A	Step 1	
Average Depth (Ft)	B	Step 2: From Table C2	
Waterbody Volume (Ac-ft)	C	Step 3: C = A*B	
Herbicide Volume (Gal per 1 ppm per ac-ft)	D	Step 4	
Target ppm	E	Step 5	
Herbicide Needed (Gal)	F	Step 6: F = C*D*E	

Table C2. Depth measurements across the waterbody; insert ‘B’ value in Table C1.

MEASUREMENT #	DEPTH
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
SUM OF DEPTHS	
AVERAGE DEPTH (Ft)	B = SUM OF DEPTHS / # OF MEASUREMENTS

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