RECLAMATION

Managing Water in the West

Canal Operation and Maintenance:

Vegetation

U.S. Department of the Interior
Bureau of Reclamation
Office of Policy
Technical Service Center
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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Acknowledgements

For this canal operation and maintenance manual, Reclamation staff, operating entities, and others provided their insights and experiences and their contributions and hard work are greatly appreciated. They include Chris Vick, Chris Duke, Kylie Fink, Chris Ellis, Deena Larsen, Tyler Chatfield, Denise Hosler, Jeremy Lorberau, Scott O'Meara, Jolene Trujillo, and Ryan Woodruff. A special thanks to National Pesticide Information Center (NPIC) for herbicide information. The assistance and diligent reviews of these and numerous others is gratefully acknowledged.

Disclaimer

Reclamation developed this manual to provide basic guidance to help canal operators promote safe and effective Operation and Maintenance for canal systems. This information complements—and does not replace—experience and sound judgment. This is general information useful for typical canal systems. As each canal system has unique designs and features, these general guidelines cannot substitute for facility or operating-specific guidance and specifications. Every operating entity is different, and this advice and strategies may not be suitable for all situations.

Portions of this manual make recommendations for actions to treat weeds, pests, and invasive species. These recommendations were made using the best information available at the time of preparation of this guidebook. No statement in this chapter is intended to contradict any law, regulation, statute, or herbicide product label. Herbicide labels are subject to change without notice. The herbicide user is responsible for obtaining, reading, and understanding the current herbicide product label before handling or using the herbicide product. Necessary approval and/or permits should be obtained in States where required for applying herbicides. In addition, certain Federal requirements apply as well that may not be listed on the herbicide product label. Refer to Reclamation's Manual Policy, Pest Management ENV-P02 for additional detail regarding issues related to the Clean Water Act and application herbicides.

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Acronyms and Abbreviations

ASTM	American Society for Testing and Materials
CSREES	Cooperative State Research, Extension, and Education Service
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
IPM	Integrated Pest Management
JHA	Job Hazard Analysis
MSDS	Material Safety Data Sheet
NAS	Nonindigenous Aquatic Species
NIOSH	National Institute for Occupational Safety and Health
NPIC	National Pesticide Information Center
NRCS	Natural Resources Conservation Service
O&M	Operation and Maintenance
OCSPP	Office of Chemical Safety and Pollution Prevention
OSHA	Occupational Safety and Health Administration
Reclamation	Bureau of Reclamation
TSC	Technical Service Center
USDA	United States Department of Agriculture
USF7WS	U.S. Fish and Wildlife Service

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1. Purpose and Scope of Guidance

This manual is designed to help operating entities better understand the impacts that vegetation can have on the Bureau of Reclamation's (Reclamation) conveyance systems, including canals. This volume describes how vegetation and root systems can lead to failure(s), types of vegetation commonly encountered, provides an outline for a preventive maintenance program, and how to repair damage caused by vegetation.

Reclamation staff are available to provide advice and technical support on Reclamation-owned canals. Contact Reclamation and consider additional engineering support before making modifications to the canal. If you determine work outlined in this manual requires more expertise than your staff can provide, please contact Reclamation for technical support at: www.usbr.gov/main/offices.html.

2. Why Be Concerned about Vegetation?

Mismanaging vegetation can lead to limited access and inspection capabilities, root damage, impact operational deliveries, create blockages, provide habitat for burrowing animals, and contribute to the likelihood of failures of Reclamation's assets, including canals. A number of canal failures occur each year and are often attributed to improper maintenance of vegetation. These failures can cause significant economic damages, loss of project benefits, injuries, and even loss of life.

2.1. Vegetation Limits Access and Inspection

Excessive vegetation can make inspections, regular maintenance, and emergency response measures more difficult. Overgrown vegetation can obscure canal embankment and prism slopes, making it difficult to perform visual inspections and detect issues such as seepage, boils, cracking, sinkholes, settlement, displacement, deflection, animal burrows, or other signs of problems. Figure 1 shows an area with overgrown vegetation and Figure 2 shows the same area after the vegetation has been removed, revealing issues. Early detection of developing issues is key to avoiding canal failures.

Figure 1. The vegetation in this canal prism is overgrown.

Figure 2. With the vegetation removed, miscellaneous pipes, fencing, and embankment distress emerges.

2.2. Damage from Root Systems

Canals provide a water source for trees, shrubs, and brush which often establish in and along the canal's prism and on the embankment slopes. Depending on the species, woody vegetation can develop an extensive root system that can cause costly damage or can contribute to a failure. Tree root systems can:

- Damage concrete by lifting or displacing the panels, which can cause cracking and separation at joints (Figure 3).

Figure 3. Extensive damage from trees on a concrete-lined canal.

- Form concentrated seepage paths through the embankment or foundation. Cottonwood trees can have root systems that extend laterally 50 to 100 feet. Dead or dying trees are of most concern. Decaying root systems separate from the surrounding soil over time—leaving a pathways for seepage (Figure 4). Cutting trees down or cutting root ends are not solutions, since trees commonly develop new live roots at or near the cut ends. Dead tree roots decompose, providing more seepage paths.

- Grow into and through wall joints, loosening and eroding wall-joint seals, thus damaging the water-proof characteristics.

- Expand cracks or joints in concrete walls, spillway floors, and canal linings.

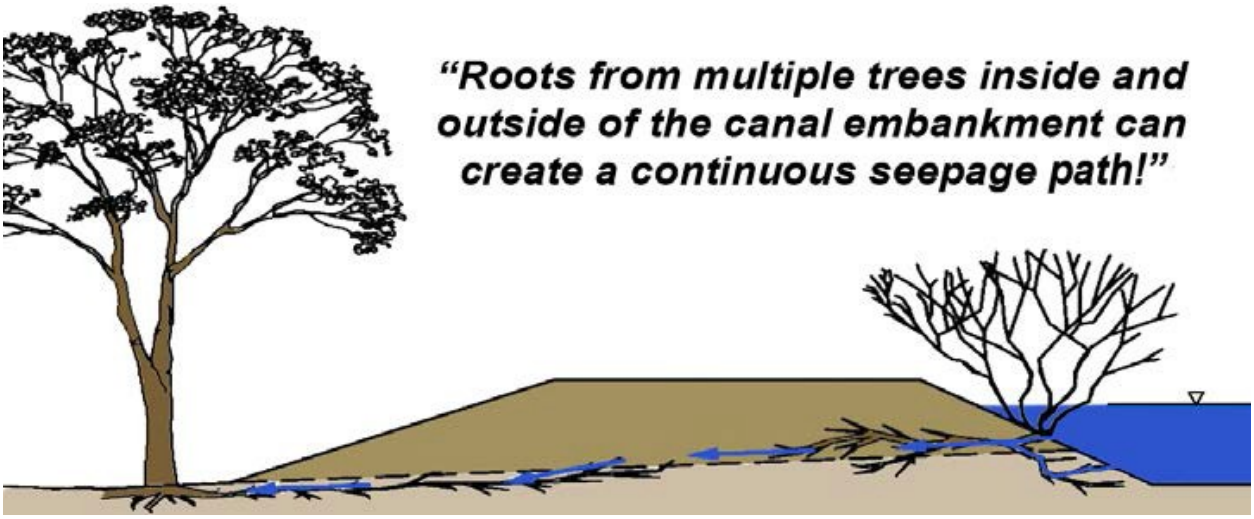

Figure 4. Potential seepage paths from roots.

2.3. Large Trees Can be Blown Over

Large, mature trees in close proximity to a canal may be blown over during a storm, blocking canal flows (Figure 5). If left undetected, the blockage may cause the water surface to rise and cause overtopping. Large trees on the canal's embankment that are blown over can cause significant damage as the root mass disturbs the surrounding soil. The disturbed area may lead to seepage and internal erosion or embankment instability.

Figure 5. Blown over tree blocking flows.

Figure 6. Vegetation consuming water along a canal.

2.4. Plants Affect Operations and Water Deliveries

Trees and other vegetation consume water, leaving less water available for deliveries (Figure 6).

Roots can block drains and pipes, restricting flows. Vegetation such as tumbleweeds can blow into the canal, and vegetation such as algae or other aquatic weeds can grow into the canal prism. Any weed that gets a foothold in a channel can accumulate sediments, creating a sandbar or other disruption to flow. Further, these sandbars can encourage more aquatic and emergent vegetation growth. These sandbars can also change flow characteristics in the canal, causing erosion of one side of the canal and forcing the canal to move.

Figure 7. Aquatic weeds impeding flow in a canal.

Figure 8. Weeds in a wasteway blocking emergency flows.

Blocking wasteways or spillway channels can also be a problem if emergency operations require releasing flows—as there won't be time to clear the channel before the emergency release starts (Figure 7).

Trees, brush, and aquatic weeds in the canal system's waterways and other open conveyance laterals can restrict flows and decrease the canal's ability to carry water or to make deliveries through turnouts (Figure 8).

The cleaner and smoother lined canal sides are, the more freeboard and capacity there is. Figure 9 shows the same canal depth for a rough and smooth-lined portion of a canal.

Figure 9. Clean canals have more capacity.

2.5. Overgrown Vegetation Invites Other Issues

Overgrown vegetation may create the impression that the canals are not being taken care of or visited regularly. Canals may then become a "dumping ground" for debris and trash—creating additional maintenance difficulties and potentially restricting capacity and emergency flows (Figure 10).

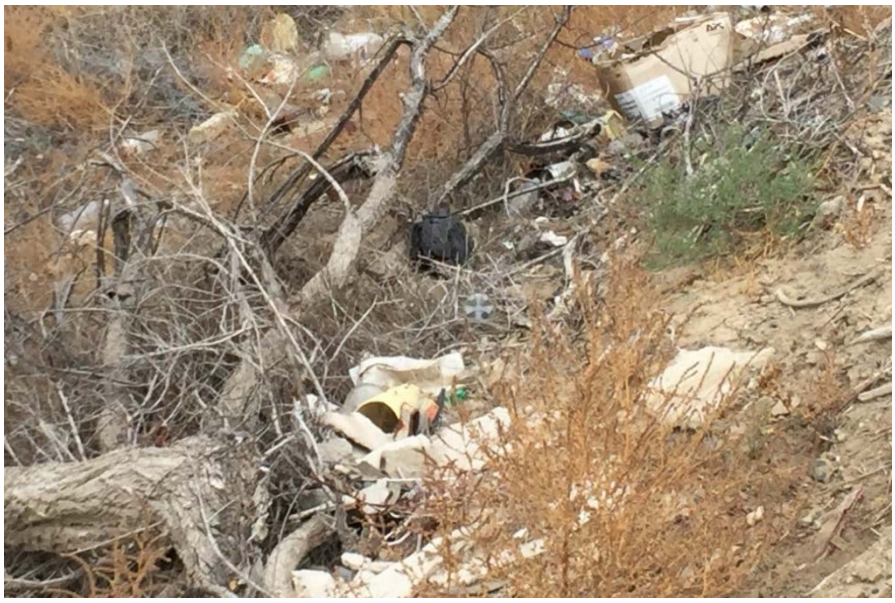

Figure 10. Trash in a canal with overgrown vegetation.

2.6. Vegetation Invites Wildlife

Brush and overgrown vegetation provides both food and cover for burrowing animals that can damage the canal system (Figure 11). Managing vegetation on canal embankments will make the area less inviting, thus reducing the likelihood of rodent activity and habitat in the embankments. Regularly mow or spray dense vegetation to reduce cover for animals. See Reclamation, 2017 (Animals).

Figure 11. Vegetation invites burrowing animals.

2.7. Invasive Plants Can Move in Quickly

Invasive plants are non-native plants that can cause economic or environmental damage. These weeds can plug a canal quickly. Invasive plants grow fast, so take action as quickly as possible. For example, hydrilla can grow an inch a day. Water hyacinth can form dense mats and double in size in less than two weeks under favorable conditions (Figure 12). Watch for any unusual plants species taking over the canal system (Figure 13).

Figure 12. Floating on water hyacinth (Photo courtesy of FISHBIO, all rights reserved).

Aquatic weeds impede water flow in drainage ditches, irrigation canals, and culverts—causing water to back up. Weeds, as well as sediment and debris, can cause canals, particularly earth-lined canals, to gradually fill in. Infrastructure can also be blocked.

Figure 13. Canal choked with water lettuce (photo courtesy of Dr. Michael Masser, Texas A&M University, all rights reserved).

Several laws and executive orders provide authority to control native and invasive weeds.

- **Federal Noxious Weed Act of 1974** (Public Law 93-629 as amended, see Public Law 101-624 for Section 15). The United States Department of Agriculture (USDA) has the authority to declare plants "noxious weeds," and limit the interstate spread of such plants without a permit. USDA can quarantine areas, if necessary to contain or limit the spread of noxious weeds.

- **Carlson-Foley Act of 1968** (Public Law 90-583, 82 Stat. 1146) provides the authorization for reimbursement of expenses to State or local agencies for weed control on Federal lands.

- **Executive Order 13112, 1999,** directs Federal agencies to use their full authority to "prevent and control invasive species to promote restoration of native species in their native ecosystems."

The USDA has a Noxious Weeds information website. Go to plants.usda.gov/java/noxComposite. You can zoom in on the map to see if this weed occurs in your county.

Reclamation has an Invasive Species Team, and you can work with your Area Office's invasive species coordinator.

Use the Nonindigenous Aquatic Species (NAS) Alert System for timely alerts at nas.er.usgs.gov/AlertSystem/Register.aspx.

3. Develop Your Integrated Vegetation Management Plan

3.1. Why Plan?

As part of an Integrated Pest Management (IPM) Plan, an Integrated Vegetation Management Program will establish a systematic approach for identifying, managing, and repairing vegetation issues. An Integrated Vegetation Management Plan helps determine:

- If vegetation management is needed
- When to start management actions
- What control treatments or combination will be most cost effective
- How often to treat
- The effectiveness of the treatment.

Integrated Vegetation Management Plans can:

- Identify the most effective methods to control weeds and pests
- Reduce operation and maintenance (O&M) costs
- Reduce herbicides in irrigation water
- Reduce the likelihood of a canal failure
- Avoid the spread of invasive species

Reclamation Manual Policy states:

> *"The goal of IPM is to manage pests and the environment so as to balance cost, benefits, public health, and environmental quality. IPM is a process for determining if pest management is needed; when management should be initiated; at what frequency treatments should be applied; what physical, cultural, biological, or chemical strategies should be employed; and the effect of the treatment." (www.usbr.gov/recman/env/env-p02.pdf)*

Reclamation Manual Directives and Standards states:

> *Programs for the control of undesirable plants on Department of Interior lands, waters, and facilities will incorporate integrated pest management concepts and practices. They shall include a systematic and environmentally compatible program developed by a team of individuals with appropriately diverse technical backgrounds (biology, endangered species, soil and water, herbicides, agronomy, information management, etc.) and adequate understanding of weed biology." (www.usbr.gov/recman/env/env01-01.pdf).*

To develop this plan, you need to understand the water systems that are being treated and the environment in which they operate, the species impacting these systems, and the control methods available. An Integrated Vegetation Management Plan should be comprehensive—determine how each action will interact with the entire canal system (embankments, road, canal prism, water flow, etc.).

3.2. How to Plan?

Your Integrated Vegetation Management Plan should be incorporated with a regular O&M program to avoid one-time fixes, but ensure a long-term approach. The ultimate goals should be to manage vegetation to avoid the need for costly removals and repairs and minimize habitat for animals that threaten the integrity of the canal system.

Start with these goals in mind. Vegetation can be an ally in a canal system, so don't just remove harmful vegetation, but plan to replace it with something that benefits your canal system. Shallow-rooted vegetation can provide slope stability and prevent erosion or even failures. Landscape planting can make canals look great and encourage neighbors and others to care for the surrounding area.

To create and follow the plan:

Identify the vegetation. Determine what types of vegetation (e.g., aquatic, weed, shrub, tree) are affecting your canal system and where they are (e.g., canal prism, canal embankment, O&M road/crest).

Determine how the vegetation is impacting operations and canal safety. What problems could this vegetation pose? Is it blocking inspection and O&M? Are there any slowdowns for operations or new seepage areas from root damage?

Identify the species and document the vegetation extent. Collect information on the species to better plan vegetation removal/management around growth habits (riparian woody species vs. aquatic herbaceous). Are there only a few pioneer plants? Or have they taken over and impacted miles of canal? What areas have a higher vegetation concentration? What is the extent of the root damage?

Determine management goals. What are long-term solutions and management plans (e.g., periodic O&M or eradication)?

Prioritize actions. First, eliminate vegetation that is causing a canal safety issue. Prioritize addressing vegetation issues at locations where the risks of a failure are the highest. For example, consider prioritizing treating areas in urban settings over those in rural settings or address areas where the canal is unlined before areas where it is lined. How is the vegetation impacting inspection and detection of a developing issue? How close is the tree to the

canal? How large is the tree? What is the extent of the root system? Does the vegetation have the potential to cause a blockage? Work with Reclamation's regular Review of Operation and Maintenance (RO&M) inspections to develop a priority list.

Research control options for the species. When is the best time to control? What methods does the vegetation respond to? Treatment methods depend on determining whether the vegetation is annual (one-year life cycle) or perennial (many-year life cycle) and how it spreads (seed, stem fragments, or roots). Also consider soil type, horizons, compaction, species, and slope to fully assess the ability of trees or deep rooted vegetation to promote or hinder slope stability.

Evaluate the site. Do the slopes allow for mowing equipment? How will tree and brush removal impact the adjacent residents? Is there access to the toe of the embankment slope for vegetation removal? Is there access to both canal banks?

Determine if permits are needed and other legal requirements. Work with State and local experts to determine if there any laws preventing a particular treatment method or permits needed for actions. Work with local biologists to identify endangered plant and animal species known to be in the area. In regions with endangered or threatened species, and/or their critical habitat, vegetation removal of any kind may require clearance through the U.S. Fish and Wildlife Service (USFWS) or the National Oceanic and Atmospheric Administration-National Marine Fisheries Service under the Endangered Species Act (ESA).

Coordinate with others. Who else may be affected (e.g., downstream water users, neighboring sites?) Who may have insights and be able to help (e.g., Reclamation, State and local agencies, universities, or other entities battling the same weeds)?

Consider timing for actions. Consider timing actions to prevent environmental damage and to ensure effective actions. For example, avoid operations at certain times of the year to protect species (e.g., avoiding mowing during bird nesting season to avoid impacts).

Implement the selected control options. Follow control plan guidelines and continue to evaluate the site.

Monitor the effectiveness of the control methods on controlling the plant. Periodic inspections and regular photographs from maintenance personnel will quantify changes over time, and can demonstrate whether treatments are effective.

Adjust control plans as site conditions change. After removing vegetation, inspect and monitor to determine any needed rehabilitation (Figure 14).

Figure 14. Photos showing canal prism before and after vegetation removal. Note the disturbance to the canal embankment.

Reclamation's Area Offices can help with Integrated Pest Management Plan practitioners to help assess the situation and develop a plan. They can also provide the most recent version of Reclamation's Integrated Pest Manual.

4. Prevent Problems

The costs of an Integrated Vegetation Management Program are comparatively less than the potential costs for flood damage, loss of project benefits, and litigation should a canal break occur that could have been avoided.

Figure 15. The earlier you remove the vegetation, the less it will cost.

The earlier a problem is addressed, the less expensive it will be to fix (Figure 15). Prevention is the first-line of defense and can be the most cost-effective approach to controlling vegetation. Once a species becomes widespread; controlling it may bust budgets and demand all of available resources. Preventing trees and weeds

from gaining a roothold into a canal system in the first place will save time and money. While invasive weeds in canals primarily come from upstream or nearby populations, reducing or eliminating their spread can help prevent invasive species problems.

Plants spread by seeds and plant fragments, which can enter the canal system via wind, birds, fish introduction, boat trailers, fishermen, etc. Seeds can lie dormant for years. Plant fragments, even less than an inch long, that do not completely dry out during transfer can survive and produce new plants. To avoid spreading more plants and seeds:

- Mark weed locations by staking with yellow-topped laths.
- Record weed locations. Give approximate size of infestation and location in reference to a structure or landmark.
- Always work into an infested area—don't go in from an infested area out to a non-infested area.
- Limit moving spoil piles to lessen the disturbance and spread of weeds.
- Take care to clean all equipment (trucks, tractors, boats, graders, etc.) at the site to remove aquatic weeds and terrestrial seeds.
- Use certified weed-free products (such as straw, mulch, mats, and gravel).
- Determine the proper timing for operations such as mowing to avoid spreading seeds.
- Remove weed debris from trashracks, gates, and check structures promptly and carefully.

For detailed instructions for inspecting and cleaning equipment, see Reclamation, 2012. Inspection and Cleaning Manual for Equipment and Vehicles to Prevent the Spread of Invasive Species. Technical Memorandum No. 86-68220-07-05. www.usbr.gov/mussels/prevention/docs/EquipmentInspectionandCleaningManual2010.pdf

5. Act: Vegetation Removal and Mitigation

5.1. Woody Vegetation and Root Systems

Approaches for removing woody vegetation vary and, in some cases, can do more harm than good (e.g., cutting down a tree and leaving the stump and root system). Over time, decaying root systems can lead to concentrated seepage (Figure 16). Other practices such as simply removing trees and brush with heavy equipment without proper repairs afterwards can disturb the surrounding soils and lead to shortened seepage paths. See Reclamation's Canal Operation and Maintenance: Embankment (Reclamation 2017 [Embankment]) for more information on seepage and erosion processes. This section discusses guidelines for planning, removal, repair and other mitigation measures to address woody vegetation and root systems.

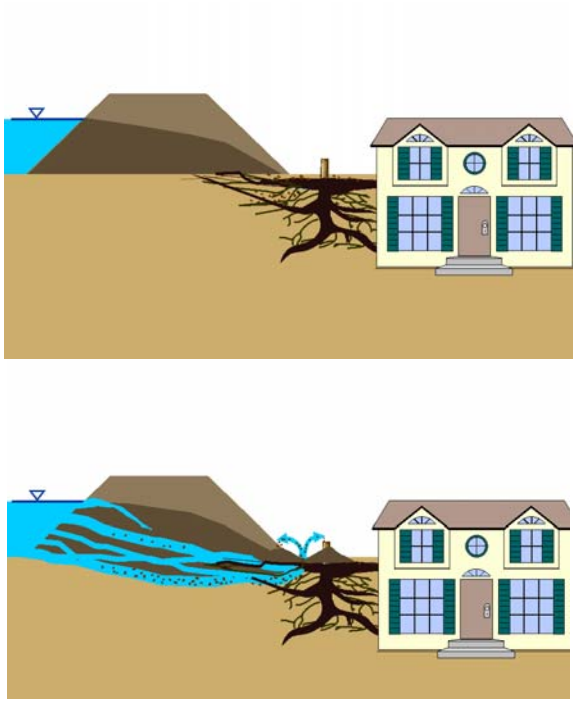

Figure 16. Decaying roots lead to seepage paths.

5.2. Develop a Plan

To reduce the likelihood of failure from woody vegetation:

- Make short and long-term plans to remove all woody vegetation in the canal's prism and within 20 feet of the canal embankment that either limits inspection and detection capabilities or might allow concentrated seepage along the root system.

- Prior to removal, monitor the area around existing woody vegetation closely for signs of seepage, embankment damage, or signs that a tree might be blown over.

- Plan tree and/or brush removal during a canal outage. Excavation and removal of the root mass can result in a canal failure if water is present in the canal.

- Determine if any part of the tree or root system is on private property. Work with the land owners to explain why the trees and brush must be removed. Work with local Reclamation's Area Office staff to facilitate these discussions.

- Determine if any environmental permitting or assessments are required. Coordinate with Reclamation's Area Office environmental staff, easement specialists, and engineers.

- Determine whether there are alternatives to removing the woody vegetation such as the addition of a robust canal lining or an embankment cutoff wall.

5.2.1. Determine the Extent of the Damage

Prior to removing woody vegetation, an investigation should be conducted to determine the extent of root damage. The investigation should begin with a surface inspection to determine the lateral extent of the root system (Figure 17). Look for tap roots entering the canal prism or support roots along the ground surface. Record the lateral distance the roots extent from the trunk (Figure 18).

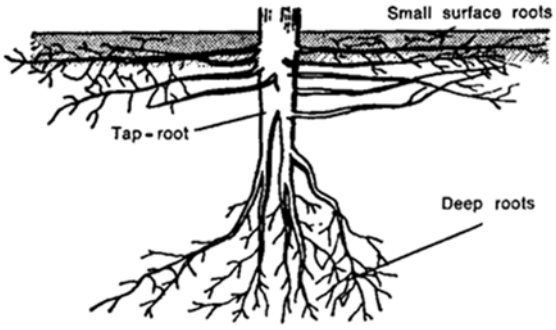

Figure 17. Types of roots.

A test pit program should be used to determine the extent of the root network. Starting at the trunk of the tree, carefully excavate along the root system until you have reached its limit. A number of tree root systems will need to be excavated to better understand their extent, as each tree is different. Record the lateral extent to which roots larger than ½-inch-diameter extend. Use the collected information to help develop a plan for removing the root system, repairing the embankment, or if there are other measures that can be used to cut off the root system.

Figure 18. Tree tap roots extending for 80 feet to the canal.

Figure 19. Roots extending into the embankment.

5.2.2. Remove the Woody Vegetation and Root System

Trees and brush that pose a risk to the canal should be removed.

Cut down the woody vegetation. All woody vegetation within 20 feet of the canal embankment should be removed. Use hand saws or chain saws to cut down the woody vegetation—leaving the stump about two feet above the ground. The stump will indicate where a tree or bush has been removed that still requires root removal. The stump will also aid in the root removal process. Remove all branches and leafy material from the site to expose the ground surface and improve inspection capabilities. Products can be applied to the stump to slow decay of the root system, providing additional time to plan and schedule removal of the root system.

Remove the root system. Place chains or cables around the stump. Remove the stump and supporting root ball with heavy equipment. Tap roots which extend towards the canal should be removed. From the cavity left by the stump removal, extend the excavation towards the canal prism. Extend the root removal excavation until all roots larger than ½-inch-diameter have been removed. This removal will damage the surrounding soil and will require repair.

5.2.3. Embankment Repair

After removing the root systems, reconstruct the affected embankment and foundation areas. Prior to repair, examine the excavation face carefully. If the root system continues further laterally into the embankment, widen the excavation. Side slopes and terminal ends of the excavation should be 3:1 (horizontal:vertical) or flatter (Figure 20). Periodic benches should be formed in the excavation side slopes to avoid slip surfaces following fill placement. See Reclamation's Canal Operation and Maintenance: Embankment (Reclamation 2017 [Embankment]) for more information on embankment reconstruction.

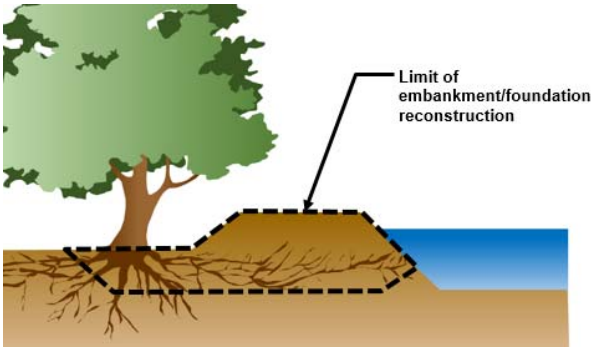

Figure 20. Example of embankment/foundation reconstruction limits.

Reclamation can help develop an embankment reconstruction plan.

See Reclamation's Canal Operation and Maintenance: Concrete (Reclamation 2017 [Concrete]) for more information on excavation and embankment repair.

Visit Occupational Safety and Health Administration's (OSHA) Safety and Health Topics web page on trenching and excavation at www.osha.gov/SLTC/trenchingexcavation/ index.html.

5.2.4. Cutoff Methods

Prior to making any substantial changes to Reclamation-owned assets, Reclamation's non-Federal partners must have Reclamation's approval.

As an alternative to removing the root systems, the root systems can be "cutoff" from the canal water by using a robust lining or cutoff wall system. Trees and brush may need to be cut down to improve inspection visibility, but the root systems can remain (Figure 21). The lining or cutoff wall system should extend at 25 least feet beyond the limits of the affected embankment along the canal alignment. Canal linings or cutoff wall systems do not eliminate the need for an Integrated Vegetation Management Plan and an IPM Program, but these systems can greatly reduce the risk of seepage and erosion along existing root networks. Acceptable lining systems include geomembranes with a concrete or shotcrete cover. The lining must be resistant to root growth under the lining system. Canal lining also minimizes the potential for new vegetation to develop in the canal's prism, and the reduction of seepage may limit growth of future woody vegetation on the embankment or toe area.

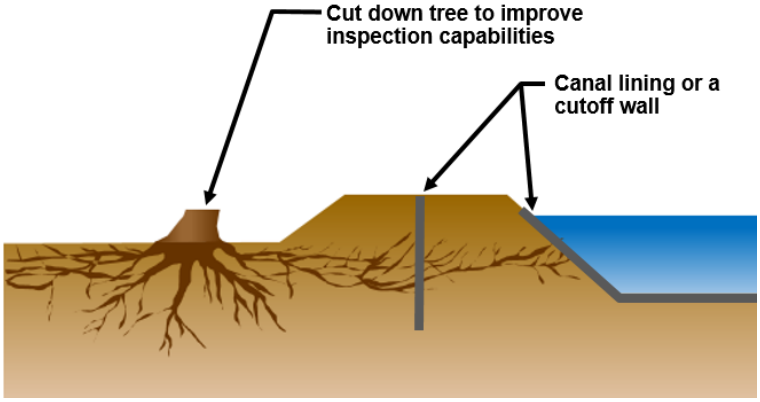

Figure 21. Acceptable methods to cutoff root systems.

Cutoff walls may also be used. Technologies include: steel sheet piling, synthetic sheet piling, and augured concrete secant walls. Driven sheet piles are more appropriate for loose fine grained soils. Dense granular soils containing cobbles may require trenching or auger construction methods. The cutoff wall material must be resistant to future root growth.

For detailed compaction instructions, see Reclamation's Earth Manual Part 1, 1990 and Design of Small Canal Structures, 1978 at www.usbr.gov/tsc/techreferences/mands/manuals.html.

The Soil Compaction Handbook from Multiquip provides a simple layout and graphics to understand basic compaction processes. www.multiquip.com/multiquip/pdfs/Soil_Compaction_Handbook_low_res_0212_DataId_59525_Version_1.pdf

5.3. Remove and Control Weeds

Keep O&M roads; canal embankments, toes, and prisms; wasteways; and drains free from overgrown vegetation and deep-rooted bushes and plants. Use these main methods of control together as part of your overall Integrated Vegetation Management Plan (Figure 22):

- **Mechanical:** Physically remove or cut above/below-ground vegetation (i.e., mowing) and/or removal
- **Cultural:** Modify environment to be less conducive to unwanted vegetation (e.g., covers, drawdowns, or light)
- **Physical:** Line canals in very troublesome areas
- **Chemical:** Use herbicides to stop or slow vegetation from growing or spreading
- **Biological:** Introduce natural biological enemies for invasive weeds

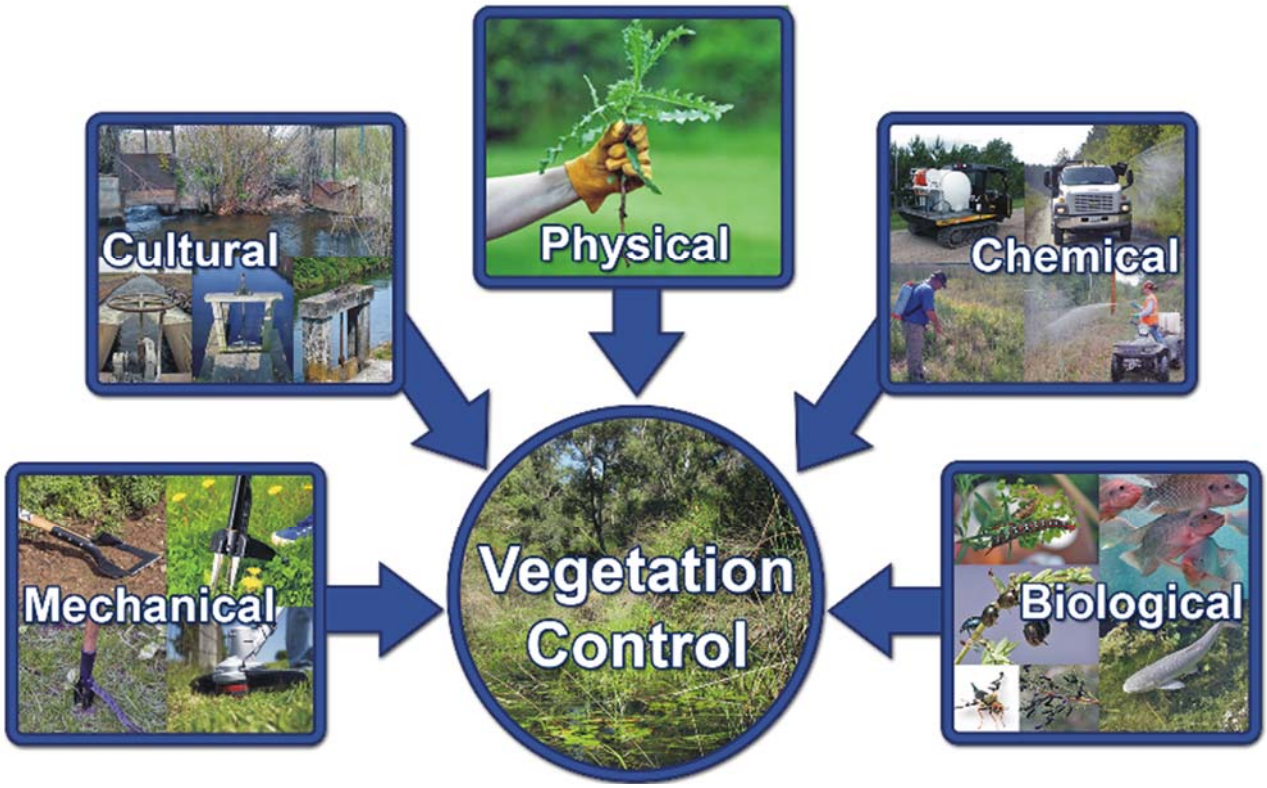

Figure 22. Major methods to control vegetation.

5.3.1. Mechanical

Vegetation can be controlled or reduced/suppressed with mowing, hand pulling, dredging, or chaining (Figure 23). As weeds grow back, these tasks are repeated as needed. Note that uprooting plants can lead to shoreline erosion and increased turbidity in a body of water.

While Federal and State permits and regulations for mechanical controls are not as stringent as those for chemical control, these should be researched and followed.

Removing vegetation can be an additional expense and should be planned for. The cut vegetation should be harvested and stored where it cannot reenter the water. The harvested material could be used as a fertilizer, livestock feed, or mulch in gardens or could be sent to a land fill.

Mechanical techniques can also leave large amounts of debris that must be removed safely to avoid plugging structures or spreading seeds or plant fragments.

Figure 23. Various equipment used for controlling vegetation.

5.3.1.1. Harvesting, Chaining, and Dredging

Dredging can be a time consuming and costly operation. A variety of specialized mechanical harvesters are currently available for terrestrial, wetland and aquatic applications.

Figure 24. Combination hydrocutter and harvester.

Shredders, such as tiger cutters, rotovators, and cookie cutters, are generally custom-made machines tailored to specific harvesting activities. Mowing, rototilling, and chaining activities generally use commercially available equipment, although custom built machines for steep slopes or difficult terrain may also be available (Figure 24).

Dredging operations are not as common but are still used. Dredging removes the impermeable clay lining and excess silt in the canal or ditch prism, which results in increased seepage. When appropriate, dredging is typically conducted in dry canals with specially adapted machines that scrape and remove vegetation and sediment from the bottom and sides of the canal. A Dredger is a machine equipped with a forked bucket which can be opened and closed on command. The machine could operate from the ground or from a boat in water.

Chaining uses a heavy chain linked between two vehicles on either side of a canal. The chain is dragged over the bottom of the canal to disrupt the seedbed and vegetation within the canal prism (Figure 25). Vegetation is then removed and loaded onto platforms. These loaders remove the product off-site to other locations, such as pastures or other areas for livestock, or to be chopped. Chaining is an older method that can be highly disruptive to the system, as it introduces large amounts of biomass into the canal, will typically leave roots to resprout, can cause water quality problems, and could even disturb the canal prism integrity.

Figure 25. Tandem disc cultivator on a drag chain in an irrigation ditch used to disrupt rooted weeds.

More information on mechanical harvesters was obtained from: United Marine International, Aquarius Systems, and Aquamarine Aquatic Plant Harvesters. These are only three of several companies; their listing does not imply an endorsement.

Figure 26. Aquatic weeds resprout from plant fragments.

Aquatic weeds will require special attention when performing mechanical control (i.e., chaining) to avoid leaving any plant fragments, although it is difficult to avoid completely in most cases (Figure 26). Also, most aquatic plants are perennials with underground portions that can resprout new shoots. Thus, below-ground growth must also be removed or disrupted. This is challenging, especially with larger plants like cattails. Hand-held devices for cutting or pulling plants in small areas are available from dealers that specialize in aquatic/fisheries supplies.

5.3.1.2. Mowing

Strive to keep grasses less than 6 inches high. Mow vegetation-free zones to a height of 3 to 6 inches at any time the grass reaches a height of 12 inches.

Periodic mowing is essential to:

- Maintain a healthy ground cover
- Control weeds
- Prevent the growth of brush and saplings
- Remove rodent habitat
- Make it easy to spot concerns such as rodent activity, slides, and cracking
- Prevent seed production and starve the underground parts of the plant

Mow the entire embankment, toe, and O&M road for access. Weed whips, power brushcutters, and mowers can be used.

To protect the integrity of the embankment:

- Mow during dry conditions. Avoid mowing with heavy equipment when the soil is wet to prevent rutting.

- Use only proper equipment designed specifically for the type of slope and vegetation.

- Follow the manufacturer's recommended safe operation procedures.

- Mow in alternating patterns.

- Avoid using tillage equipment next to the lining, as that can remove soil.

Timing the mowing to get the most "bang for your buck" depends on the species of vegetation, so consult with local experts. General tips are:

- Mow in spring after the new spring growth starts (cut very close to allow sunlight in for desirable grasses). The spring mowing should be a very close cutting of all vegetation to allow maximum sunlight to penetrate to desirable grass cover species.

- Mow in summer when the plant's energy stores (carbohydrate reserves) are low (when the active growth phase is over and the plants start to flower).

- Mow before weed seeds become mature enough to grow new weeds to help prevent weed establishment

- Mow in late fall immediately prior to the first killing frost or freeze (do not cut as close to provide maximum resistance to surface runoff erosion). This last mowing should be timed to allow the grass to grow to approximately 8 to 10 inches by the winter season.

- Time inspections to coincide with mowing.

5.3.2. Cultural

Changing the environment to make your canals a less inviting space for weeds is called “cultural control” and includes burning, drying, and covering up plants.

5.3.2.1. Burns

Burning may be used to control some vegetation in irrigation canals and wasteways, but is primarily used to clean up dead biomass. Burning works for some species, such as reeds and thistles, but not for others, such as toadflax. Burning can also disturb a site and make it more vulnerable to weeds such as cheatgrass and knapweed. Unless an area is reseeded with competitive grasses, cheatgrass density generally increases after fire. Some seeds survive in unburned litter, and fires can damage desirable plants. For a successful burn, it is usually best to shear the plants and then wait two to three weeks for the vegetation to dry enough to burn.

Prescribed burns can be dangerous to conduct, as fires in the dry grass can easily overrun personnel and equipment. Use extreme caution to ensure that the fire does not spread. Never leave the area in which a fire is burning until it is very clear that the fire is out and will not cause any damage.

Carefully plan the burn and make it part of your overall Integrated Vegetation Management Plan. Often mowing followed by burning or burning followed by herbicide application on regrowth will help the efficacy of each treatment. Follow this treatment with revegetation. To plan the burn:

- **Inventory weeds in the area.** How will these species respond to burns? When will they be most vulnerable to a burn?

- **Design fire to encompass the infested area.** Minimize fire lines and soil disturbance; use natural barriers.

- **Coordinate with local fire authorities for safety.** Permits may be required.

5.3.2.2. Drawdowns

Figure 27. Drawdowns can expose weeds.

When feasible, manipulating canal levels can also help manage aquatic weeds as most aquatic weeds respond quickly to changes in water levels. Draining water from canals and ditches and allowing them to dry out can be an effective method for controlling aquatic vegetation (Figure 27). Pondweed and other aquatic growths can be killed by exposure to the sun for periods of 3 to 8 days. If canals do not dry out quickly, this method may not work, as the canal cannot remain dry long enough to kill the weeds. Drawdowns may need to be used in conjunction with other methods such as chemical or mechanical controls.

Over the winter, drawdowns can expose aquatic weeds to freezing and thawing and thus kill the underground structures of many aquatic plants. This method has been successful for controlling Eurasian watermilfoil and waterlilies, although the degree of control depends on the severity of the winter. Flushing may be another method to control some species, particularly algae in open channels. However, some species can withstand periods without water or can handle changes in flow, and again it is important to identify the species you are dealing with and their tolerances.

5.3.2.3. Light

Plants need light to photosynthesize, especially submersed aquatic weeds. Blocking light with tarps may help control some vegetation.

5.3.3. Physical Barriers

Figure 28. Boom containing an infestation.

Physical structures can be added to existing canals or incorporated into the design of new canals. Physical structures may be worth the cost in particularly troublesome areas (where many trees sprout or where it may not be possible to remove trees and deep-rooted vegetation).

Booms can be temporary solutions to prevent or contain infestations, particularly for invasive species (Figure 28). Containment booms require a high degree of maintenance. An unmaintained boom can break and spread the infestation.

Bottom barriers are applied across sections of canals infested with noxious weeds and attached by pins or sandbags (Figure 29 and Figure 30). Common bottom barrier materials are geotextile ground cover cloth or erosion control materials. Anchoring black plastic sheeting on the bottom of the canal may prevent rooted plant growth. A number of commercial bottom barriers have been marketed over the years. Some, however, carry a premium price as they are advertised specifically for aquatic use. Similar or identical materials can be obtained from erosion control suppliers at a fraction of their cost.

Figure 29. Bottom barriers.

Designing more permanent solutions depends on the type of species, the area of the canal, and the purpose. Note that some of these, such as air gap systems and barrier systems may be expensive and impractical for long stretches of canals.

Figure 30. Installing bottom barriers.

- **Air gap systems.** These are gravel layers or areas with at least $^{3}/_{4}$ inch stone size or clean, graded, medium sized rubble that is not filled in with sand. They control tree root growth as the stone matrices dry quickly, create large air gaps, have poor water-holding ability, and are impermeable to systematic root penetration.

- **Barrier systems.** Various types of screens and barriers (such as copper screens, plastic panels, and geosynthetic linings) have been shown to be effective. Commercially available barrier systems are effective in controlling root elongation and growth. Many of these barrier systems are relatively expensive, but placing these over problem areas may be more cost effective. Root barriers may be used to provide an added measure of assurance, but they should not be a substitute for adequate distance between plantings and root-free zones. Some root barriers include herbicides to enhance effectiveness. In every case, these should be evaluated before use to prevent negative environmental impacts.

- **Trashracks.** Trashracks screen plant material along the waterway before entering the intake pipes.

- **Structural components**. Steel sheetpiles or slurry cutoff walls installed through the top of the embankment may alleviate the need to remove woody vegetation on some embankments.

- **Riprap**. Riprapping shorelines provides bank stability, and it can help with weed control for a few years.

- **Debris baffles and ribbon barriers.** These may be useful in preventing infestations of floating weeds from spreading.

5.3.4. Biological Control

Many of the weeds causing problems in the United States come from other parts of the world. Biological control strategies promote native species over these invasive species. Organisms used for biological control include insects, fish pathogens, nematodes, and parasitic and competing plants. Biocontrol must be used responsibly, due to ecological impacts.

Figure 31. Checking for insects for biological controls.

Successful implementation of biological control is more complex than other control methods because it requires long term planning, coordinated tactics and timing with other control measures. It can take at least 3 years or longer before the populations of the biocontrol insect can build to levels that will begin to affect the weeds (Figure 31). Final results may not be seen for 5 or 10 years, and even then targeted invasive populations will not be eradicated.

Reclamation and its affiliated operating entities have been using triploid grass carp to help control submersed aquatic weeds and algae for decades. These fish are generally herbivores, sterile, and are not used in open water systems—only in irrigation canals. Environmental regulations require the fish be sterile (triploid) and be physically contained within the canal system to avoid migration into natural rivers and streams. To qualify as a closed system, the canal system has been modified to include electric and physical fish barriers. Triploid grass carp are commercially available.

Pathogens like fungi, bacteria, nematodes, and viruses can be used for biological control (Figure 32). These pathogens need to target specific species, as pathogens with broad host range are unsuitable simply because they may attack the non-target beneficial plants.

Barley for algae control is widely used in England in canals. Fungi decompose the barley in water, which causes a chemical to be released that prevents the growth of some species of algae, but do not generally effect existing algal populations. Results of research have varied, and results can take several months. .

Insect biological controls have been approved and are available for:

- Hydrilla (Figure 32)
- Water hyacinth
- Purple loosestrife
- Leafy spurge
- Knapweeds
- Yellow starthistle
- Saltcedar
- Giant Salvinia
- Parrot Feather

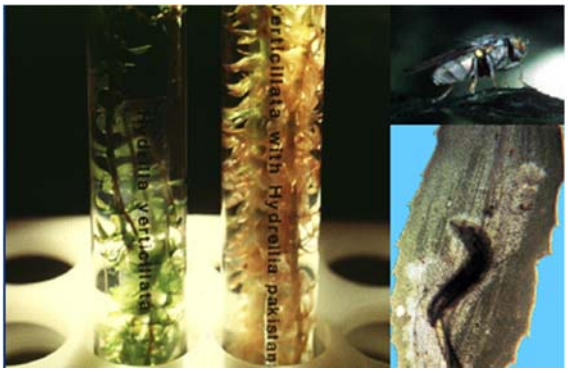

Figure 32. Biological control targeting hydrilla.

Please contact Reclamation's Area Offices to determine if using these types of biocontrol methods may help in your Integrated Vegetation Management Plan.

5.3.5. Chemical (Herbicides)

Herbicides can be used as an integral part of an overall vegetation control strategy in your Integrated Vegetation Management Plan, along with other mechanical, cultural, physical, and biological controls (Figure 33). Integrated Vegetation Management encourages judicious herbicide use and using more benign options. As herbicide use presents potential risks to health and the environment, choose these chemical controls only after carefully analyzing all other options for efficacy and cost-benefits. Consider environmental consequences. In many situations, nonchemical methods may be more effective, less costly, or less time consuming over the long term.

Figure 33. Applying herbicides.

5.3.5.1. Do Your Homework

- **Know the target weeds.** Correctly identifying target weeds and understanding their habitat requirements, life cycle, reproductive structures, and other characteristics are critical steps in any management program. Understanding how weeds grow and proliferate will greatly assist development of the most efficient actions for management.

- **Environmental conditions**. Climate, soil, and water quality conditions can impact the efficacy and non-target impacts of herbicides. Temperature is often the most important factor as it generally relates to the metabolic activity of all organisms in the environment, including herbicide uptake and degradation. Targeted and non-target effects also need to be assessed with consideration of site topography, neighboring land use, wind and water currents, and sensitive and/or desirable species proximity.

- **Get help from the experts.** Hundreds of different herbicides are available, with various target plants, modes of action, toxicity, environmental hazards, application methods, degradation time, and other characteristics. Herbicide applicators must familiarize themselves with all of these factors in order to choose the most appropriate herbicide and use it safely and effectively. While most of the pertinent information should be available on the herbicide label, expert advice is available from your local Reclamation IPM coordinator or natural resources manager, chemical company representative, Natural Resources Conservation Service (NRCS) agent, or other experts.

- **Know the herbicides.** Herbicides can be referred to by their trade or brand name, which differs between each formulated product (e.g., “Cascade®” or “Teton®”). Products may be sold under different names in different parts of the country. There are also common names for the active ingredients in herbicides, which can be found under various different trade names (e.g., “endothall”). Commercial products often have more than one ingredient and formulation, so it is important to research the product and trade name. Finally, the chemical name is the full name of the active ingredient chemical compound, and can be useful to distinguish different forms of an active ingredient that may have significantly different effects and use guidelines (e.g., the dipotassium salt versus the dimethylalkylamine salt of endothall).

  The EPA registration is a unique identifier (like a social security number) for products. So if a trade name has the same EPA registration number, then it is the same formula and same directions. If a trade number has a different number, then this indicates a different formula, which changes directions on the label.

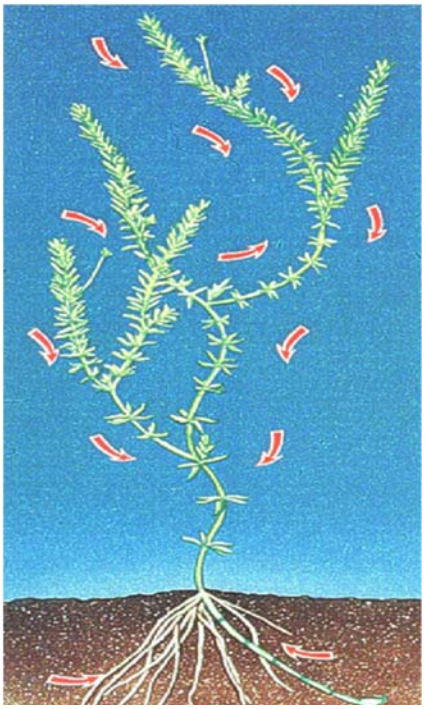

Figure 34. Systemic herbicides travel throughout the plant.

- **Know how herbicides work.** Systemic herbicides (Figure 34) are absorbed by the roots or foliage and translocated within the plant’s vascular system—affecting all tissues

rather than just the plant tissues exposed to the herbicide. Systemic herbicides tend to work more slowly than contact herbicides and require longer exposure times, but have the advantage of affecting the root system and below-ground reproductive structures (e.g., underground rhizomes or tubers), often resulting in greater long-term control . Contact herbicides kill only the plant tissues they come into direct contact with (contact herbicides).

Herbicides also differ in their selectivity (susceptibility variation between species), soil residual activity (pre vs. post-emergent activity), and mode of action (metabolic processes the herbicide affects). Herbicide activity can be either selective or non-selective. Selective herbicides are used to kill weeds without significant damage to desirable plants. Nonselective herbicides kill or injure all plants present if applied at an adequate rate. Although these aspects of herbicides are not generally described on the product label, they are important to be aware of in order to use herbicides safely and efficiently.

Pesticide Labeling Questions and Answers are at www.epa.gov/pesticide-labels/pesticide-labeling-questions-answers.

Herbicide registration information is at the National Pesticide Information Center (NPIC) npic.orst.edu/reg/register.html.

The National Institute for Occupational Safety and Health (NIOSH) and OSHA have compiled summary safety-related information and data for many hazardous chemicals, published in *Occupational Safety and Health Guidelines* bulletins. Each bulletin is devoted to a specific material or materials.

In addition, pesticide experts at land-grant colleges or your State's Cooperative Extension Service can provide valuable information on State and local pesticide laws and regulations, as well as serve as sources of current pesticide research and practical information.

5.3.5.2. Follow All Regulatory and Permitting Requirements

- **Always read and follow the label**. Pesticide labels and the Material Safety Data Sheet (MSDS) should kept in a convenient location for reference or in case of emergencies. The label is a legal document; application of herbicides outside of labeled directives or restrictions is a violation of law.
- **Use approved products only.** All herbicides must be registered with the EPA. Always use registered products that are labeled for use in your particular site and for control of the target species. If you are not familiar with herbicide use directions or if the label information is unclear, check with the EPA or other experts on site-specific information. Always consult with the appropriate agencies and stakeholders with interests in the application areas and review all available information before using herbicides within the range of any federally listed species. County-level bulletins may be issued for

specific herbicide materials and are available through the EPA, USFWS, USDA, county agricultural extension offices, and herbicide point-of-sale outlets. The county bulletins include habitat maps and possible herbicide use limits. If a product is classified as restricted, it will not be available for purchase or use unless by a certified pesticide applicator or under their direct supervision.

- **Understand permits and other requirements.** Research and follow all Federal, State, and local requirements. Plan herbicide operations accordingly. Treating or discharging herbicide treated water into United States' waters will require a permit—regardless of whether the waterways are wet, partially wet, or dry at the time of the discharge. Reclamation has general purpose permits in two States: Colorado and Washington (e.g., Columbia Basin Project and Colorado-Big Thompson Project). State permits reside on State sites. Necessary approval and/or permits should be obtained in States where required for application of herbicides to water. In addition, certain Federal requirements apply as well that may not be listed on the herbicide product label. Contact your local Reclamation IPM coordinator or natural resources manager.
- **Documentation**. All herbicide treatments should be documented in a standardized format and archived. Reclamation offices should have an up-to-date IPM plan on hand that describes the documentation requirements and protocol.

5.3.5.3. Apply Herbicides Effectively

- **Assess site conditions and treatment goals annually.** Application factors include dosage, placement, retention time, plant growth stage, physiological factors, and method of application. More than one treatment a season (e.g., copper sulfate on algae) may be required for adequate control. Treatments might also be needed in succeeding years.

- **Use only the amount of herbicide needed.** Overuse of herbicides may contribute to residuals that could prevent desirable vegetation establishment and affect non-targets. Overuse also increases costs unnecessarily and may reduce the efficacy of herbicides with similar modes of action in the future.

- **Rotate herbicide modes of action.** Repeated use of herbicides with similar modes of action can lead to the development of resistance in weeds, resulting in lower mortality rates from applications. To avoid this situation, rotate herbicide modes of action as much as possible. For aquatic applications, a relatively small suite of herbicides is available, and there are even fewer for irrigation water, which can make rotating modes of chemical control difficult. Integrating nonchemical and chemical control measures may be more effective for preventing herbicide resistance in aquatic management areas.

- **Anticipate where the herbicide will go.** Herbicides can drift on the wind, move with flowing water, and leach through soils. This is an essential difference between aquatic and terrestrial weed control and one of the reasons some aquatic herbicides are placed in a **Restricted Use** category by regulatory agencies. All herbicides should be used in a manner to reduce the risk of off-site movement as much as possible.

- **Coordinate and consult**. Follow the water and determine who may need to be notified about the herbicide use (e.g., downstream users, water customers), and coordinate with them. Consult with the appropriate agencies and review all available information prior to application herbicides within the range of a federally listed species.

- **Post appropriate notifications.** "If public notification is not implemented prior to aerial application of herbicides on Reclamation-managed lands, a clear and easily defensible justification for not implementing public notification must be documented." Reclamation Directives and Standards Env01-02.

Follow the law. These laws oversee what herbicides can be used and when to use them. Only a few herbicides are available to the general public. Most herbicides are considered too hazardous for general use, and are restricted to certified applicators. FIFRA established a system of examination and certification both at the private level and at the commercial level for applicators who wish to purchase and use restricted use herbicides. The distribution of restricted herbicides is also monitored.

- Federal Insecticide Fungicide and Rodenticide Act (FIFRA), as amended.

- Halogeton Glomeratus Control Act (66 Stat. 579)

- **Dispose of herbicide container and other wastes properly.** These are classified as hazardous waste, and usually a licensed hazardous waste contractor is required. Do not clean associated equipment near the canals.

5.3.5.4. Time Herbicide Use Effectively

Proper timing of herbicide application can be the difference between success and failure. Proper timing can be determined by experience, by reading and following labeling directions, by obtaining reliable information on the subject, and by consulting pest control specialists. Many factors influence application timing, such as:

- **Growth stage.** The type of plant and whether it is in the seedling, vegetative, flowering, or senescent stage. For example, treating annuals when they are seedlings can be effective, but perennials may need to be treated when they are flowering. Larger plants offer more surface area for the herbicide to penetrate, but may be able to tolerate larger concentrations of herbicides.

- **Plant characteristics.** The leaf's shape, the thickness of the wax on the leaf's surface, the density of hairs on the leaf all affect the ability of the chemicals to enter the leaf.

- **Environment.** Treat submerged or emergent aquatic weeds early in the year before plants get out of control.

    - Some herbicides can kill weeds that produce oxygen in the water. In addition, degradation of plant materials will also consume oxygen within the water column. As a result, dissolved oxygen levels can fall below levels that are needed to sustain fish populations. Therefore, work with biologists to determine proper timing if there are fish in your canals.

    - Interactions between the chemical and physical properties of soils and herbicides also need to be considered, including how the herbicide enters the soil (solubility, leaching, and diffusion) and how long it lasts (degradation mechanism). Soil types (e.g., sand, silt, clay) also influence herbicide movement in soil.

5.3.5.5. Use the Correct Herbicide for Your Weeds and Situation

To be effective, herbicides must:

1) Adequately contact plants
2) Be absorbed by plants
3) Move within the plants to the site of action without being deactivated
4) Reach toxic levels at the site of action.

NPIC and Reclamation developed Table 1 for herbicides for operating entities. NPIC has more information on herbicides. This table is meant as a discretionary guidance to some herbicides that might be appropriate to use in canal and waterway applications. Use this as a starting point for further research. This table is not intended to contradict any law, regulation, statute, or pesticide product label. Sample tradenames are provided for reference only. Reclamation does not endorse particular products. Restrictions provided are typical; always check label for specific requirements and restrictions prior to application.
You can get more information at NPIC's pesticide database at npic.orst.edu/NPRO.

Table 1. Sample Herbicides for Operating Entity Use

Active ingredient	Type of weeds controlled	Aquatic formulation trade names*	Contact or systemic	Selectivity	Notes	Irrigation restrictions**	Domestic and drinking water restrictions**
Elemental copper Copper sulfate Chelated copper	Algae; young submersed plants	Clearigate® Cutrine® Nautique® Captain®	Contact	Selective	Results may vary by plant species and density, flow rate, temperature, and distance of treatment. Toxic to fish and aquatic organisms. Water alkalinity can significantly affect control efficacy	None	No greater than 1.0 ppm metallic copper. Must receive additional and separate potable water treatment.
Sodium carbonate peroxyhydrate	Algae	GreenClean® PAK 27® Phycomycin®	Contact	Selective (algae)	Toxic to birds and insects.	None	None
Acrolein	Algae, plants up to 24 inches in height	Magnacide®	Contact	Non-Selective	Highly toxic, special application equipment required. Will impact everything it touches. Keep out of fish bearing water. 12-155 hour holding period for irrigation water.	None	Restricted, for irrigation use only.
Endothall	Emergent, floating, and submersed plants; algae	Aquathol® Hydrolthol® Cascade® Teton®	Contact	Selective	Amine salt more toxic to fish and aquatic organisms, and better algae control than the dipotassium salt. 6 to 72 hours treatment exposure necessary for good control.	7-25 day holding period both for crop irrigation and domestic use. Maximum of 5 ppm per 7 day interval, no greater than 30 ppm per growing season.	May require permits. Maximum contamination level of 0.1 ppm. 600 feet setback for potable water intakes.

Canal Operation and Maintenance: Vegetation

Active ingredient	Type of weeds controlled	Aquatic formulation trade names*	Contact or systemic	Selectivity	Notes	Irrigation restrictions**	Domestic and drinking water restrictions**
Fluridone	Floating, emergent, and submersed plants	Sonar® Avast!®	Systemic	Selective	Minimum 45 days treatment exposure necessary, 30 to 90 days to mortality. Control may vary by time of year, plant growth stage, and water movement. For use in limited-flow waterways, drawdown conditions.	No restrictions for dewatered applications. 7-30 day holding period for aquatic applications. *Solanaceae* (nightshade/potato) and newly seeded crops should not be irrigated with water above 5 ppb.	Do not apply at rates greater than 20 ppb within ¼ mile of intake.
Bispyribac-sodium	Floating, emergent, and submersed plants	Tradewind™	Systemic	Selective	Used in non-irrigation canals or limited-flow waterways. Slow acting, 60-90 days contact time required. Safe for fish-bearing waters. Do not apply to flowing water.	Restricted, non-irrigation canals only.	None
Penoxsulam	Floating, emergent, and submersed plants	Galleon®	Systemic	Selective	Pre and post-emergent activity. Can be used within water column, on bed sediment during drawdown, and on embankments and shorelines. Mortality may take 90 to 120 days. Can also be used for aquatic applications, but good control requires minimum of 2 weeks treatment exposure--not feasible for most canals.	Concentrations must be 1 ppb or less for food crops, 30 ppb or less for turf and rice	None
Glyphosate	Emergent and floating plants	Rodeo® Aquamaster® AquaPro®	Systemic	Non-selective	Foliar-applied only, no activity in soil or water column. Mortality can take up to 7 days; up to 30 days for woody species. Inactivated by tight soil adsorption – reduced control on dusty or hairy plant surfaces.	None	None

Canal Operation and Maintenance: Vegetation

Active ingredient	Type of weeds controlled	Aquatic formulation trade names*	Contact or systemic	Selectivity	Notes	Irrigation restrictions**	Domestic and drinking water restrictions**
Diquat	Floating, emergent, and submersed plants	Reward® WeedTrine®	Contact	Non-selective	Kills above-ground parts of plant within 24-36 hours. Binds tightly to spoil particles, ineffective in muddy water.	5 day holding period	1-5 day holding period.
Imazamox	Floating, submerged, and emergent plants	Clearcast®	Systemic	Selective	Pre and post-emergent activity. Used in limited-flow waterways, drawdown conditions, terrestrial and riparian areas. Mortality may take from 60 to 120 days.	Concentrations must be 50 ppb or less. Wait 24 hours when irrigating from waters treated within 100 feet of intake. Drawdown applications must be flushed until concentrations are less than 50 ppb before water can be used for irrigation. No restrictions for flowing waters when applied at 2 quarts per acre or less to waters with average depth of at least 4 feet.	Potable water restricted to less than` 500 ppb within ¼ mile of intake. Applications within ¼ mile of potable intakes restricted to less than 50 ppb.
Tricloypr	Emergent broadleaf, submersed, and floating; herbaceous and woody plants	Element 3A Renovate®	Systemic	Selective	Only for non-irrigation canals or seasonal irrigation waters/ditches with no continuous outflow. Good control of woody species with basal bark treatments.	120 day holding period or when concentrations are at 1 ppb or less.	Up to 1,300 foot setback from intakes for applications, depending on application rate.
2,4,-D	Broadleaf emergent and submersed plants	Navigate® Weedar 64®	Systemic	Selective	Used in limited-flow non-irrigation waterways, terrestrial and riparian areas. Reduced efficacy when water pH is over 8. Granulars sink to bottom for slow release, liquid can be sprayed on floating/emergent species.	Irrigation water restricted to 1 ppb.	7 day holding period, or when verified at less than 70 ppb. Application setback of 600 feet from intakes.

Canal Operation and Maintenance: Vegetation

Active ingredient	Type of weeds controlled	Aquatic formulation trade names*	Contact or systemic	Selectivity	Notes	Irrigation restrictions**	Domestic and drinking water restrictions**
Flumioxazin	Emergent, floating, and submersed plants	Clipper®	Contact	Selective	Pre and post-emergent activity. Works best on young or actively growing weeds and in waters with pH below 8.5. Do not apply to flowing water.	5 day holding period	None
Imazapyr	Floating and emergent plants	Habitat®	Systemic	Non-selective	No activity in water column, apply only to exposed vegetation. Some soil residual effects, can be used during drawdown conditions - wait 14 days before re-watering. Mortality may take two weeks or more.	120 day holding period or when residues are verified at less than 1 ppb. Wait 24 hours when irrigating from waters treated within 500 feet of intake.	Setback of ½ mile from intakes for application.
Carfentrazone-ethyl	Algae, floating, submersed, and emergent plants	Stingray®	Contact	Selective	Most effective on young and actively growing plants. Reduced efficacy in cold or muddy waters. Some soil residual effects, can be used during drawdown conditions - wait 7 days before re-watering.	14 day holding period or when concentrations are verified at less than 5 ppb.	Setback of ¼ mile from intakes for application. Holding period minimum of 24 hours or when concentrations are verified below 0.2 ppm.

This table is not intended to contradict any law, regulation, statute, or pesticide product label.
*Sample tradenames provided for reference only. Reclamation does not endorse particular products.
**Restrictions provided are typical; always check label for specific requirements and restrictions prior to application.

5.3.5.6. Keep Safe

Safety to both the general public and workers is a key element to Reclamation's chemical control activities. Reducing mishaps and employee exposure to herbicides is vital to maintaining effective weed control programs. Safety for handling herbicides comprises a wide range of actions, including:

- Preplanning
  - Obtain permits
  - Coordinate with all required entities (Federal, State, and local)
  - Read, understand, and follow current labels
- Protecting workers
  - Train employees in herbicide safety and applicable anticipation, recognition, evaluation, and control of herbicide hazards in accordance with applicable Federal, State, and local regulations
  - Use safe work practices
  - Use personal protective equipment
  - Conduct medical surveillance programs
  - Keep all poison in a closed container
  - Before smoking or eating, wash hands with detergent and water
  - Watch your step on uneven ground—watch out for snakes
  - Understand the Material Safety Data Sheet's (MSDS) specific information about the health effects associated with their products and observing the listed safety precautions.
  - Prepare Job Hazard Analysis (JHA) to anticipate, recognize, evaluate, and control potentially unsafe acts and conditions associated with each step of a job
- Post notices and coordinating with local agencies to protect the public
- Protect transport
  - Ensure the driver is trained to transport chemicals
  - Use appropriate markings

  - Coordinate with the appropriate Department of Transportation

- Proper storage to prevent spills and leaking containers
  - Limit stockpiles of chemicals
  - Conduct regular inspections
  - Post proper notices

- Spills and emergencies
  - Have contact information and ways to communicate on site
  - Prepare spill response and containment plans
  - Prepare emergency and evacuation plans
  - Maintain emergency kits to address spills, fires, or first aid
  - Maintain an emergency eyewash and shower

If good work practices are followed, even the most toxic herbicides may be used safely without creating a health hazard. Conversely, improper handling and application of low-toxicity herbicides may result in serious injury. These chemicals can enter humans through the skin, lungs, mouth, and eyes, and precautions must be taken against both acute and chronic exposures.

First contact your County Extension Office, found at npic.orst.edu/pest/countyext.htm.

Once you have a product in mind, talk with a Pesticide Specialist at the National Pesticide Information Center (NPIC) (npic.orst.edu/contactus.html). They can provide scientifically valid toxicological and environmental fate data (sponsored by the Environmental Protection Agency and Oregon State University).

Consult with your State and local environmental departments, and if needed, with:

- EPA's Office of Chemical Safety and Pollution Prevention (OCSPP)
- Your local USDA Service Center

6. Revegetation

Before removing weeds and trees, consider the aftermath—plan for revegetation and rehabilitation over the long term to stabilize the slopes to prevent erosion and sloughing and to help suppress weeds and habitat. Note that revegetation alone is not enough to control vegetation, as disturbed sites will continue to attract opportunistic weeds for several years after control measures, providing opportunities for reoccupation. However, maintaining intact plant communities with desired structure and ecological function can make takeovers from invasive species less likely. Restoration may not be necessary in every weed management scenario. Factors such as infestation size, density, distribution patterns, and the availability of surrounding desirable (remnant) vegetation need to be considered.

Figure 35. Grasses form thick, short mats that keep out invasive species and require little maintenance.

Revegetate the area with grass species appropriate for the region to maintain embankment stability (Figure 35). Grasses and shallow-rooted native vegetation are the most desirable surface covering. Use native grass or ground cover with maintenance mowing, and use kill zones where necessary around critical structures to control trees. Specific species recommendations for seeding or planting must be tailored to site-specific needs and environmental conditions. Attempts to simply use “generic” seed or plant mixtures without finding out or considering specific information on nature of disturbance, soils, climate, and other environmental parameters are doomed to fail in most instances. Revegetation strategies and techniques will vary with:

- **Purpose.** Controlling vegetation height may be needed to promote visibility and reduce habitat for burrowing animals. For erosion control and site stabilization, a uniform, regular cover may be needed.

- **Maintenance needs.** Low-maintenance plant materials are often the most appropriate choice. Perennials do not have to be replanted each year. Grasses may need to be mowed at least twice each season.

- **Weed species and infestation levels.** Seeds from annual weeds can lie dormant for many years, even decades. When a weedy plant spreads by creeping rhizomes, these connecting roots often penetrate many feet into the soil and will persist if only a shallow surface layer of soil is removed. Some weeds can alter the soil and other site environmental factors (for example, salt cedar can add salts to soils).

- **Soils.** Soil type, texture, structure, chemistry, salinity, and sodicity (alkali) will determine what plant species will thrive. Reclamation has national

and regional soil testing laboratories that can provide this information and perform a comprehensive array of soil analyses.

- **Soil habitat.** Microbes, worms, and insects aid in cycling soil nutrients, aerating the soil, and maintaining the soil structure.

To develop an effective revegetation strategy, answer:

- **Are remnants of native vegetation still present on the site?** Proper management of the land can stimulate what is left of the desirable plants, enhancing vigor and reproduction to compete with undesired plants.

- **Does the site require additional preparation before the planting can be undertaken?** Preparing the site can take many forms, including intensive tillage to remove seeds, burying weed seed, and improving soils. However, artificially modifying soil conditions and plant physical conditions needs careful assessment and site-specific evaluation for feasibility and cost effectiveness before proceeding.

- **Is seeding necessary?** In some areas, site stabilization needs or legal constraints may require seeding of a disturbed site within a certain period to prevent erosion.

- **Is the desired amount and type of seed available and affordable**? In some cases, enough sources of desirable seed may be present on the site to supply local harvest requirements.

The answers to these questions will help determine the feasibility, timing, cost, and probability of success of your project.

To evaluate the site and determine a revegetation plan and to select, get, propagate, and store plants, get help from:

- Local (county or State) NRCS offices and the Cooperative State Research, Extension, and Education Service (CSREES)

- County Extension Agents

- State Extension Specialists

Be sure to check with local land management, agricultural, and/or environmental regulatory agencies for restrictions.

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Appendix A. Integrated Pest Management Plan Outline

1. Purpose and Background
2. Description of Project Lands (list and describe project lands covered by the IPM plan)
3. Description of Management Areas (general description and concerns examples)
    - A. Lacustrine and Riverine Waters Including Canals
    - B. Palustrine Wetlands
    - C. Wildlife Habitat
    - D. Endangered Species Critical Habitat
    - E. Grasslands
    - F. Agricultural Land
    - G. Forest Land
    - H. Recreation Areas
    - I. Buildings and Facilities
4. Targeted Pests
    - A. Plants
        - (1) Noxious Weeds
        - (2) Aquatic Vegetation
        - (3) Woody Vegetation
        - (4) Other Nuisance Species
    - B. Animals
        - (1) Insects
        - (2) Rodents
        - (3) Mollusks
        - (4) Other Nuisance Species
5. General Objectives for Treatment
6. Documentation and Monitoring Guidelines
7. Threatened, Endangered, Species of Concern, and Environmental Comments (list and describe endangered species present, location, critical habitat, and protection plan)
8. Vegetation Management Strategy (use National Invasive Species Council definitions)
    - A. Prevention
    - B. Early Detection/Rapid Response
    - C. Control and Management
    - D. Restoration
9. Vegetation Management Techniques (description of methods)
    - A. Cultural/Mechanical Control
    - B. Biological Control
    - C. Chemical Control
    - D. Integrated Control