Agriculture Canada

Research Branch / Direction générale de la recherche

Technical Bulletin 1989-6E

Aquatic vegetation on the Canadian prairies: physiology, ecology, and management

Canada

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Technical Bulletin 1989-6E
Lethbridge Research Station Contribution No. 14

Research Branch
Agriculture Canada
1989

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Produced by Research Program Service

Cat. No. A54-8/1989-6E
ISBN 0-662-16807-0

Cover illustration
The dots on the map represent Agriculture Canada research establishments.

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SUMMARY

This publication describes the aquatic ecosystem and discusses the interrelationships between the nonliving environment and the living biotic communities. Emphasis is on the understanding of the life cycles of aquatic plants and how their growth should be limited before it becomes excessive.

Aquatic vegetation management techniques are discussed and control procedures are given for specific aquatic vegetation problems in different aquatic environments. This information should assist farmers, irrigators, irrigation managers, water users and environmentalists in understanding and planning integrated aquatic vegetation management programs to preserve the Prairies' freshwater resources.

RÉSUMÉ

Cette publication décrit l'écosystème aquatique. Il y est également question des relations réciproques entre le milieu abiotique et les collectivités biotiques vivantes. On insiste surtout sur la compréhension des cycles biologiques des plantes aquatiques et sur les moyens de restreindre la croissance de ces plantes avant qu'elle ne devienne excessive.

De plus, on traite des techniques de gestion de la végétation aquatique et on propose certaines mesures de contrôle à adopter pour régler des problèmes précis à ce chapitre dans divers milieux aquatiques. Grâce à ces renseignements, les agriculteurs, les irrigateurs, les exploitants d'entreprises d'irrigation, les utilisateurs des ressources en eau et les environnementalistes seront en mesure de mieux comprendre et de planifier des programmes de gestion intégrée de la végétation aquatique en vue de préserver les ressources en eau douce des Prairies.

INTRODUCTION

The industrial and agricultural development along the East Slope of the Rocky Mountains has created enormous demands for freshwater supplies and these demands will increase in the years to come. Nearly one-half of Canada's total irrigated land is in Alberta's 13 irrigation districts. With new dams, improved on-stream storage, and more efficient delivery systems, Alberta could double its 578,000 ha of land presently under irrigation. However, aquatic vegetation can seriously impede the movement of water through irrigation conveyance systems, reducing the canal flow rates by as much as 91% of design carrying capacity. At present, over 12,000 km of canals and drains in Alberta are plugged with excessive aquatic weed growths. Some canals require as many as four aquatic herbicide treatments per year to permit the irrigation districts to meet peak water demands. Weed control costs in older main delivery canals can reach $2,500/km per season.

This manual will outline the theories and goals of vegetation management and the techniques available to control excessive aquatic vegetation in agriculturally associated freshwater ecosystems. Information on the composition of aquatic ecosystems is presented here to enable managers to keep their system healthy, i.e., to maintain excellent water quality while preventing excessive weed growth. A healthy freshwater ecosystem permits the development of a management program that will generate revenue from the system through aquaculture, the growth and harvesting of aquatic organisms that can be marketed as food or food byproducts.

WATER IN THE LANDSCAPE

Water has always added to the aesthetic value and recreational potential of land. The farm pond or dugout was originally built to supply water for livestock and to irrigate the family garden. Later it was found it could be used for domestic purposes excluding cooking and drinking. Recently, the farm pond has begun to supply potable water after filtration and water treatment. It also has a potential for boating, fishing and swimming as well as being an attractor of wildfowl and wild animals. When trees and shrubs were planted and a picnic table was added for family outdoor meals, the pond became a place for relaxation for the entire family as well as a source of water.

As leisure time increased, the public made greater demands for water-based recreation. Urban parks have been developed along the shores and banks of lakes and rivers. Abandoned gravel pits have been converted into parks with biking and walking paths and man-made ponds have been constructed to supply shallow ponds for leisure activities. Golf course designers construct ponds to act as water hazards to complement the sand traps and greens, which provide challenge as well as aesthetic beauty for golfers and club members.

Urban land developers construct small lakes, 10 to 15 ha in size, as focal points for new urban communities. The purpose of these man-made lakes is to collect surface runoff to provide irrigation water for the adjacent park areas and for the enjoyment and relaxation of the people of the community.

As urban development continues, city planners are faced with increased surface runoff problems from city streets and parking lots. This runoff overloads the sewage treatment facilities. Storm water can not be dumped directly into the river systems because it contains contaminates such as silt and organic material washed in from the streets. The water must be stored in storm-water retention or storage ponds to allow the silt and other material to settle and then it can be released slowly into natural drainage systems. While these ponds do not contain water of top quality, they can be used as focal points in city parks and green strips.

Even agricultural irrigation reservoirs, on-stream storage ponds, irrigation canals and drainage canals developed for the production of food are subjected to public pressure for further development into recreational areas. Canal banks and shorelines are excellent habitats for waterfowl and wildlife and large reservoirs offer recreational as well as commercial fishing possibilities.

The vast diversity of these aquatic environments is evident; a great variety of physical, chemical and biological characteristics exist in each system. However, they all have one thing in common: they are all highly eutrophic, meaning that they are nutrient-rich.

Eutrophic bodies of water are characterized by a shallow to intermediate depth, variable surface area, and oxygen levels that decrease sharply in the summer. They are subjected to nutrient enrichment from surface runoff and water temperature that rises rapidly in the summer, and they contain an abundance of dissolved nutrients and sediments that wash in from the surrounding land. These factors contribute to an overabundance of aquatic vegetation.

The seasonal growth and decay of this vegetation has a compounding effect on the aquatic ecosystem. The excessive growth of rooted aquatic macrophytes causes stagnation of the water column. This stagnant water generally has a higher temperature than that of flowing water. Increased water temperatures stimulate the growth of algae, both filamentous and planktonic, which in turn increases the organic content of the ecosystem. This creates a greater demand for dissolved oxygen. With the continued demand, the levels of dissolved oxygen drop and fish and related organisms are killed, which adds more organic matter and stagnation to the ecosystem. Bacteria begin to work on the decaying organic matter, odors are released into the water, the aquatic environment deteriorates further, and the aesthetic quality is destroyed.

For maximum fish growth and reproduction there must be at least 50% open water (research data from the United States suggest as high as 60% open, weed-free water for maximum sunfish and perch production). This allows for a normal size gradient from fry up to mature adult fish. The open water is the area for the adults while the fry seek refuge in aquatic vegetation in the shallower areas.

Trout require a minimum dissolved oxygen content of 3.0 ppm; serious die-off occurs at levels below 2.0 ppm. Widely fluctuating oxygen levels tend to shift the fish population from game fish to the coarse fish. As the water column warms in the summer, the ability of the water to retain oxygen decreases and the heavy phytoplankton blooms appear. When these blooms die, the biological oxygen demand increases and as the oxygen levels in the water decrease, even the coarse fish die off.

As the water body deteriorates, the nutrients and organic matter continue to increase and the aquatic vegetation becomes even more abundant. When the vegetation reaches the surface of the water, it forms mats which raise the surface water temperature. This increases water loss through increased evapotranspiration from the water's surface. Once this aquatic vegetation starts its prolific growth, it continues to increase in density, causing further deterioration in water quality and a subsequent large buildup of organic matter, which drops to the lake bed and contributes nutrients for further weed growth.

In a very short time, usually three to five years, a water body can lose its aesthetic value, the fishery can be destroyed, the water quality deteriorates, odors develop from the rotting vegetation, and where the water is used for irrigation the aquatic vegetation and debris begin to plug intake screens and pumps. Dense vegetative growth will also block turn-outs, thus preventing the movement of water from the water body.

The goal in aquatic vegetation management must be to prevent the buildup of excessive vegetation. Corrective steps after the buildup occurs are very expensive and, in the case of aquatic herbicides, the treatments must be applied year after year. To develop a successful aquatic vegetation management program we must first understand the aquatic ecosystem: what makes up the total ecosystem; where the water and nutrients come from; how the different components interact with each other, and, finally, how a semblance of balance can be maintained to keep the aquatic ecosystem healthy, viable, and functional.

AQUATIC ECOSYSTEMS

Aquatic ecosystems are dynamic systems which are in a state of slow but continual change both physically and biologically. Like most biological organisms, they undergo a constant aging process. Natural freshwater lakes can be viewed as small worlds composed of environmental factors and living organisms organized and bound together by interdependences of food and interrelationships of energy. These lakes may be influenced by surface runoff from the surrounding land and by the people who use and manage this land. Human activities may accelerate the natural aging process through increased and enriched surface runoff and the lake thus may become highly eutrophic over a shortened period of time. Young aquatic ecosystems begin nutrient-poor, with a low organic matter content that restricts the biological component of plants and fish. This is called an **oligotrophic** water body. As the water body matures, it receives more nutrients and silt from surface runoff, the organic content of the water increases and the aquatic vegetation becomes more abundant. This vegetation offers food and shelter to numerous aquatic organisms. This in turn begins to support a small game fish population. The body of water is now called **mesotrophic**.

When the water body reaches middle age it has received years of fertile runoff and is very nutrient-rich with a high organic matter content in the water column as well as the sediments. The aquatic vegetation is overabundant and there is very little open water. This overproduction of organic matter causes the oxygen levels to fluctuate widely and the fishery to shift to a few coarse fish. If organic matter production is allowed to continue, the water body will in time fill in with organic matter and become a marsh and then a swamp or muskeg. This is the natural aging process for a freshwater ecosystem.

Agriculturally associated freshwater ecosystems are usually aquatic systems that are made or at least modified by man. They may be small lakes, reservoirs, ponds, or dugouts that contain standing water; they are **lentic environments**. If the water is moving, such as in rivers, streams, creeks, irrigation delivery canals, farmer supply canals and drainage canals, the water system is referred to as a **lotic environment**. This distinction is important since we will see later that the type of aquatic vegetation and the preventive and corrective vegetation management techniques applied will depend on the type of aquatic environment involved.

These aquatic environments are only a small part of the total farm or irrigation district. They are composed of the physical environment, namely the water, the sediment of the pond bed, shorelines or banks, and the living organisms or biological community. The surrounding or adjacent land that supplies the surface runoff is the watershed and development on this watershed comprises the urban or rural land use pattern. The water may come from the local watershed or it may originate from an outside source such as irrigation water. It may stay on the site or pass through the site. The quality of the water is dependent on the quality of the input as well as the quality of the water that is discharged. The critical point to remember is that the better the water quality the fewer the aquatic vegetation problems, and hence less erosion and flooding, lower maintenance costs, fewer problems with irrigation equipment, fewer water taste and odor problems and greater aesthetic benefits to the landowner and the general public.

Large natural lakes with their large volume of water are essentially self-sustaining and require only radiant energy, the non-living or abiotic environment, and the communities of living or biotic organisms to function. These organisms act in the roles of producers, consumers, and decomposers to make the ecosystem function. Generally, the large system is very stable and essentially self-sustaining, being maintained more or less independently of the influence of other outside communities. The smaller agriculturally associated ecosystems, however, are much less stable and require outside help to maintain their equilibrum. Because change will manifest itself very rapidly, the system must be monitored closely. This should be viewed as a positive point since it means that we can manipulate the agricultural ecosystems to prevent excesses or correct deficiences. It only requires that the manager spend as much time on the aquatic ecosystem as on the rest of the agricultural holdings.

Environment (abiotic or non-living component)

The environment or non-living component of the aquatic ecosystem is composed of the sediments and soil of the banks and shores of the water body, and the water. The water is the most visible and important of the three. Of the many extraordinary properties of freshwater that contribute to its ability to maintain life in aquatic ecosystems, none is more important than the capacity of water to hold substances in solution and its ability to enter into numerous chemical reactions. Many of the naturally occurring elements of the earth's crust can be found in inland fresh water. Some of these substances occur in minute concentrations but in most cases they are only needed in minute quantities to support aquatic life.

Of all the chemical substances in fresh water, oxygen is one of the most significant both as a regulator of metabolic activity in the communities and the individual organisms and as an indicator of the health of the aquatic ecosystems. This oxygen exists as a dissolved gas in the water and may be derived from atmospheric oxygen or from the photosynthetic activity of green plants. The oxygen moves through the water column and may enter the sediments where it takes part in the oxidation of various compounds. The extent to which a compound may undergo oxidation-reduction processes is dependent on the concentration of other oxidizing-reducing systems and their products in the sediments and water column.

This oxidation-reduction potential or **redox potential** is important to the cycling of the nutrients such as phosphates from the sediments and their subsequent availability for the excessive growth of aquatic vegetation.

The other major dissolved gas in the aquatic ecosystem is carbon dioxide. This gas contributes three essential factors to the water. First, it acts as a buffer in the water to protect against rapid shifts in the acidity-alkalinity state. Through its reaction with water, carbon dioxide may form a weak acid, neutral salts, or a weak base in the water column. The maintenance of the near-neutral conditions in mineralized fresh water is due to the carbon dioxide-bicarbonate-carbonate complex. The second contribution is the role of carbon dioxide in regulating biological processes such as seed germination and plant growth as well as being involved in animal respiration and oxygen transport in blood. The third and most important contribution is that carbon dioxide is a source of carbon, one of the most versatile of all the elements in the aquatic ecosystem. Carbon dioxide and water supply the major components of carbon, oxygen, and hydrogen necessary for all living organisms.

The most conspicuous dissolved compounds found in varying concentrations in fresh water are the major anionic compounds such as carbonates, sulfates, phosphates, and nitrates and the minor anionic compounds of chlorides, sulfites, silicates, and nitrites. These compounds occur in combination with the major cationic elements of calcium, sodium, potassium, magnesium, and iron to form ionizable salts. Occurring at much lower concentrations are the minor or trace cationic elements of cobalt, zinc, copper, manganese, molybdenum, and boron. Generally, both the qualitative and quantitative composition of the fresh water are influenced by the geochemistry of the watershed surrounding the basin through which the surface runoff flows to reach the water body.

The inorganic composition of the water body is further modified by precipitation and concentration of salts due to evaporation. The total concentration of dissolved compounds or minerals is a useful parameter for describing the suitability of the water for irrigation, livestock or domestic use. This measure, total dissolved solids, is the dried residue of the water containing both inorganic and organic materials. The quality and quantity of the dissolved solids in large part determine the type and abundance of aquatic vegetation found in the ecosystem.

The sediments of aquatic ecosystems differ from terrestrial soils in a number of fundamental ways, thus providing a unique environment in which the aquatic plants take root and derive much of their nutrients. Sediments are typically anaerobic except for a few centimeters at the interface of the water column with the sediment bed. The inorganic compounds are primarily in the reduced state. At the interface with the water column the inorganic and organic compounds may undergo oxidation and diffuse up into the water column. Generally, there is a rich organic layer of particulate matter of decaying vegetation from 25-30 cm thick that floats over the sediment. Numerous adaptations are required by the submerged rooted aquatic macrophytes and their root systems to exist on this unique substrate and function under these physiological stresses. The aquatic plants exert a pronounced effect on the physical and chemical properties of the bottom sediments. Once submerged plants are established, their vegetative tops stimulate the settling of additional sediments by decreasing the water flow velocity and creating underwater currents.

Although extensive literature is available on the role of the rhizosphere of agronomically important terrestrial plants, little is known about aquatic plants. It is safe to suggest that the microfloral rhizosphere of aquatic plants probably plays a critical role in the nutrient uptake and subsequent vegetative growth of aquatic plants. More research into the interactions between the aquatic plant root systems, the sediments, the availability and uptake of nutrients, and the microfloral rhizosphere will give us a better understanding of the nutritional physiology of aquatic plants. This will lead to the development of innovative, ecologically safe vegetation management techniques to prevent excessive plant infestations and to even encourage beneficial aquatic vegetation.

Biological community (biotic or living component)

All agriculturally associated aquatic ecosystems are composed of biological communities of plants, animals, bacteria, and fungi. The maintenance of these communities is dependent to a great extent upon food relationships and energy flows that involve interactions between the non-living environment and the biological communities. In a small system these relationships are so closely connected that a change in one nutrient can cause a serious disruption in the entire ecosystem. The basic operation of the community's metabolism rests on the roles that the different organisms perform at various nutritional levels in maintaining the transfer of energy in the form of food through the various individuals of the aquatic ecosystem.

The aquatic vegetation makes up the group referred to as the **primary producers**. These organisms use nutrients from the water and sediments, dissolved carbon dioxide from the water, and solar energy to produce energy-containing organic substances through photosynthesis with the oxygen released back into the water. The organic substances are used by the plants to grow and reproduce. The consumers, mainly animals, are incapable of synthesis of matter from the sun's energy and hence depend directly on the producers. Within this group we recognize the herbivores, which feed on aquatic vegetation, and the carnivores, which feed upon herbivores or other carnivores. Both subgroups use the dissolved oxygen given off by the green plants to grow and develop while returning carbon dioxide and energy from respiration to the water column. The **decomposers** are composed of heterotrophic bacteria and fungi which in turn break down the organic substances from both the producers and consumers and return the inorganic and organic nutrients to the water column to be recycled by the producers.

The various links in the food chain represent different levels of food synthesis, feeding and being fed upon, and nutrient release by decay. The aquatic ecosystem is thus a pyramid with the dissolved nutrients at the base. The algae and aquatic macrophytes or producers occupy the next level. Located on and in the sediments of the water body are the bacteria and fungi of the decomposer group that break down the organic matter. The next level is composed of the grazing herbivores followed by the small carnivores such as trout fry. Last are the medium and large carnivores such as the perch, trout, and finally the pike of the consumer group.

While our major concern is the management of aquatic vegetation of the agriculturally associated aquatic ecosystem, it can readily be seen that the entire ecosystem is interrelated and what we do to one small segment may have a pronounced effect on the entire system.

AQUATIC PLANT CLASSIFICATION

The aquatic vegetation, or primary producers, is composed of two major groups of plants: the microphytes or algae and the macrophytes or vascular plants. Before any vegetation management program can be developed for our agriculturally associated aquatic ecosystems, the water bodies must be surveyed and the specific problem areas examined. After surveying, the nuisance aquatic vegetation must be properly identified.

Algae

Algae are plants of simple structure and organization and lack true leaves or flowers. They reproduce asexually by continuous vegetative growth and from specialized cells or minute spores. Generally free-floating, a few specialized species may become attached to submerged rocks, grow on damp soil, or even grow on the ice face of glaciers. Algae vary in size from microscopic forms to giant seaweeds that extend several hundred feet in the oceans. They are found in oceans, lakes, ponds, swamps, rivers, creeks, and canals where they can grow down to the depth of light penetration. Algae are considered primitive because the individual plant cell is capable of carrying out all the critical life processes without the assistance of specialized cells or tissues found in higher plants.

The algae found in our agricultural water systems are subdivided into three subgroups:

1. phytoplanktonic algae
2. filamentous algae
3. branching algae

The **phytoplanktonic** algae are microscopic, free-floating, only slightly mobile and exist at or near neutral buoyancy, usually existing in the upper 1 to 2 meters of the water column where they are subjected to the surface movements of water currents and wind. Phytoplankton production is influenced by sunlight, water temperature, dissolved inorganic and organic nutrient content of the surface water, the size, shape, slope and type of pond bed, and water currents. Phytoplankton are best known for the production of summer water blooms which cause colored water because of the rapid proliferation of algal colonies. In agricultural water systems the green water usually comes from species of Anacystis, Microcystis, and Anabaena; blue to blue-green water from Aphanizomenon; and reddish-brown water from Oscillatoria, Melosira, Fragilaria, and Navicula. Generally, phytoplankton do not interfere with irrigation systems but may cause serious problems in ponds and dugouts where toxic algae can kill hogs, sheep, and cattle. These plants decrease the aesthetic quality of the water, may cause objectionable odors and tastes, and in isolated incidences may cause summer fish kills because the collapse of the massive blooms causes serious oxygen deficiencies or releases toxins into the water column. During the collapse and death of individual phytoplankton blooms, bacterial populations may build up because of the breakdown of the algal cells and the release of organic matter into the water. This can cause additional nutrient enrichment, odors, and objectionable taste problems.

The **filamentous** algae are colonial types that consist of long, stringy, hair-like strands of cells. They may be attached to the pond bottom, draped over rooted macrophytes, or form floating mats or 'scums' on the surface of the water. The filaments may be bright green to yellow-green in color and appear as cotton-like masses on the surface of the water (Cladophora); be dark green in color and feel like coarse horse-hair (Pithophora); or appear as loose, slimy strands, bright green and rising from the pond bottom (Spirogyra). The filaments may form large mats that can clog screens, intakes, pumps, and sprinkler heads of irrigation systems. During hot, sunny weather the algae may trap air bubbles in the filaments and float up to the surface where it forms extensive mats that interfere with water-based recreation. These surface mats also increase the adsorption of radiant energy from the sun, causing the water temperature to rise. This in turn increases the evapotranspiration of water. During periods of drought this water loss can be critical to farmers and ranchers.

Branching algae are the most advanced algae possessing stems and branches. They grow attached to the pond bottom but lack true roots. They are usually found in hard water and have a gritty feeling when crushed because of the high calcium deposits in their vegetative parts. They are low-growing and generally cause very little trouble to the farmer or rancher. The low-growing, creeping habit makes it an excellent plant to stabilize and hold down the silt of pond or dugout bottoms. Branching algae are excellent cover for small aquatic organisms such as freshwater shrimp, which serve as food for fish. Chara and Nitella are the only representatives found in Canada and may be mistaken on first glance for coontail or water milfoil. The key difference is that the algae lack true roots and do not have true flower heads. When crushed, Chara will give off a strong musky, fish smell.

Aquatic macrophytes

The aquatic macrophytes or vascular hydrophytes are classified very simply according to their habit of vegetative growth:

1. submergent macrophytes
2. floating-leaved macrophytes
3. free-floating macrophytes
4. emergent macrophytes
5. marginal or ditchbank macrophytes

Submergent macrophytes grow completely submerged at water depths from 0.5 to 5 meters and are rooted in the hydrosoil. Although the plants are totally submerged, the flower heads may extend to the surface of the water and above for wind or insect pollination. The leaves may be thread-like, ribbon-like, broad or finely dissected. Four distinct types of leaf attachment occur in the submerged macrophytes. Whorled leaf arrangements have more than two leaves attached at the same point on the main stem (Ceratophyllum demersum, Myriophyllum spp., and Elodea canadensis). Opposite leaves are those with just two leaves attached at one point on the main stem but the leaves are attached opposite each other (Zannichellia pulustris and Najas flexilis). The alternate leaf attachment is where a single leaf is attached to each point along the main stem (Potomageton crispus, P. praelongus, P. richardsonii, P. gramineus, P. filiformis, P. pectinatus, P. vaginatus, P. zosterformis, P. pusullus, P. friesii, P. berchtoldii, P. foilose, and Ruppia occidentalis).

The **floating-leaved** macrophytes grow on submerged soils at water depths of 0.25 to 3.5 meters. In crowded habitats, the large leaves float to the waters surface on long flexible petioles. This subgroup is represented by the waterlilies (Nymphaeo and Nuphar spp.) as well as a few dimorphic pondweeds (Potomageton natans, P. gramineus and P. vaseyi).

Free-floating macrophytes are typically unattached plants that float freely on or just below the surface of the water. Some species may have extensive root systems extending down into the water column. In Canada, they range from the subsurface floaters with no roots (Utricularia spp. and Lemna trisulcata) to the surface floaters with very simple roots (Lemna and Spirodela spp.).

Emergent macrophytes are rooted in waterlogged soils, soils covered by up to 0.5 meters of water, or on exposed mud flats above the waterline but where the water table is within 0.25 meters of the soil surface. The plants are mainly perennials growing from creeping rhizomes or rootstocks. The mature leaves and stems as well as the flower parts are aerial. This subgroup is represented by Typha, Scirpus, Juncus, and Carex spp., Phragmites maximus, Zizamia aquatica, and Flumen festuccea.

The **marginal** or ditchbank **plants** are really terrestrial plants commonly found along waterways, ditchbanks, and in moist, seepage waste areas. These include many of the grasses (Gramineae spp.) such as manna grass, wild millet, cut-grass, blue joint grass, and reed canary (Glyceria spp., Echinochloa spp., Leersia oryzoides, Calamagrostis spp., and Phalaris arundinacea). Also in this subgroup are the woody herbaceous shrubs and trees of cottonwood, willows, wild rose, and water hemlock (Populus spp., Salix spp., Rosa acicularis and Cicuta spp.).

AQUATIC MACROPHYTE LIFE CYCLES

After identification of the aquatic weeds, the complete life cycle of each group of aquatic macrophytes must be determined, from the breaking of dormancy of the seed or tuber to the early development of the seedling to the initiation of flowering and the subsequent development of the seed, overwintering turion or winter bud. The rate of vegetative growth is important since chemical control measures are usually most effective and economical during a brief time of early plant growth or just after the initiation of flowering. Late in the season the mature plants are usually more resistant to the herbicide because of a heavy layer of marl (calcium carbonate) encasing the leaves, which prevents the absorption of the herbicide. Also, the total plant biomass may be so great that the dosage necessary to build up a toxic level of herbicide in the aquatic plant tissue makes the application of the herbicide uneconomical, environmentally impractical, and perhaps even unsafe. It is imperative that the mode of reproduction in the different aquatic plant species be fully understood.

The aquatic macrophytes in western Canada increase and become serious weed problems through prolific asexual or vegetative reproduction. After the first introduction, over 90% of the subsequent reproduction is by vegetative means. A cut or broken stem tip, 2.5-5.0 cm long and containing two whorls of leaves, can produce roots in 3-5 days, become attached to the substrate in 5-7 days, and will produce a water milfoil plant in 4 weeks. Canada waterweed and coontail can also reproduce by this fragmentation method and spread quickly throughout the aquatic ecosystem in two growing seasons.

Where overwintering buds, dormant apices, and specialized overwintering turions are formed at the ends of the vegetative shoots, the use of mechanical harvesters actually spreads the aquatic plant infestations and increases the density of the plant populations. The cutting of some rooted submerged aquatic plants by mechanical means tends to make the plants bushier and, as the plant matures, there are many more vegetative stem tips which give rise to overwintering structures. These drop to the mud of the pond or canal bottom and remain dormant until the following spring when they begin to grow as the water warms up. The tuber-producing pondweeds can also be stimulated to produce large numbers of axillary tubers and stoloniferous runners when subjected to cutting.

The pondweeds, particularly P. pectinatus, are known for their prolific production of tubers when given sufficient nutrients and space, with ideal physical and chemical conditions of the substrate. One tuber of P. pectinatus planted in a child's wading pool in April and given ample light, nutrients, warm water, and a rich organic mud for a substrate can produce up to 36,000 subterranean tubers, 6,000 seeds, and 1,000 axillary tubers in a single growing season.

Once established in a reservoir or canal, the plant begins a prolific vegetative reproduction by runners, dormant apices, tubers, turions or seeds and rapidly develops a dense stand which slows up the flow of water and causes a further deposition of silt and organic matter, which further stimulates aquatic plant growth.

Geotextiles and geomembranes (such as polyethylene, polyvinyl and butyl rubbers) used to line ponds and canals are often held in place and protected from the sun by a 5-25 cm layer of soil on top of the liner. The soil provides a good seedbed for shallow-rooted pondweeds such as P. pusillus to become established and to spread by runners and small vegetative dormant apices. A layer of soil, 2.5-5.0 cm thick, above the herbicide-treated canal bottom is enough to permit the shallow-rooted aquatic weeds to become established. However, the herbicide in treated soil below this deposition is still effective for the control of deep-rooted aquatic species.

It should be evident that control and management techniques must be matched to the problem plant species and their mode of vegetative growth and reproduction. From the general life cycles of the four different groups of aquatic plants one can determine the most susceptible times within the life cycle of the plant and select control procedures that are most effective to control the problem infestation with the least impact on water quality and the environment.

GOALS FOR MANAGEMENT PROCEDURES

Short-term management techniques

Until a long-term management program can be developed to manage the varied aquatic ecosystems, temporary or cosmetic corrective measures of integrated mechanical and chemical techniques will have to be used. Although critics may complain of the pollution and destruction of our environment through the use of aquatic herbicides, it is just as criminal to sit back and do nothing. Aquatic plants have a tremendous capacity to reproduce and to spread once introduced into an aquatic environment, and to eventually destroy the aquatic ecosystem through stagnation of the water, the subsequent deposition of mineral sediments, and the production of large amounts of organic matter from the decaying plant matter. This organic matter decomposition depletes the water column of oxygen and causes deficiencies, particularly during the winter months when the water is ice-covered. Odor and taste problems may develop as well as destruction of the fish population from lack of oxygen. Stagnation also causes reduced circulation of the water and subsequent stratification of the water column. The aquatic ecosystem is in a constant state of change. Today's technology helps maintain and in some cases improve the water quality of our freshwater ecosystems when they become stressed through overuse and abuse. Many management techniques can, in reality, restore the ecosystem to its normal sequence and rate of change.

Many different aquatic plant harvesting machines have been developed since the mid 1940s. Basically, the harvesters have been designed as 1) underwater cutters which cut the weeds and an inclined porous conveyor which collects the cut material and loads it into a holding compartment; 2) a transporter system to move the cut material from the cutter holding compartment to the shore; and 3) an unloading facility on shore to move the material from the transporter to trucks for delivery to a disposal site. Recent modifications have included equipment to dewater, shred and compact the bulky plant material to make transportation and disposal more economical. The big advantage of cutting and harvesting the aquatic plant material is the removal of the plant nutrients and organic matter from the water column and the aquatic environment.

The main disadvantages are the fact that the plants start regrowth immediately after cutting and develop a bushier habit of growth and stimulate greater development of asexual reproductive structures. Dense aquatic weed populations slow the forward cutting speed of the harvester, because of the resistance of the matted cut material on the pick-up conveyor belt. Speeds exceeding 1 km/hr cause a large displacement of water in front of the cutter/conveyor and the cut plant material tends to move around the pick-up system. Any plant material that escapes the pick-up system acts as a source of new aquatic plant infestations. The increased bulk of plant material, which is about 85%

water, increases the problems of transportation and disposal since the material must be drained of water and then dried down for final disposal. Mechanical cutting tends to be very capital- and labor-intensive and is a slow, tedious process. One must weigh the cost and slowness of the cutting operation along with the potential for developing bushier aquatic plants and spreading of aquatic plant infestations throughout the ecosystem against the advantage of removing the organic matter from the ecosystem, the removal of some of the nutrients bound up in the plant material, and the fact that no new foreign substances are added to the freshwater ecosystem. The environmentally acceptable mechanical cutting method may, in fact, cause the spread of the problem and do more harm than the spot treatment with a small amount of aquatic herbicide.

Aquatic herbicides are easy to apply and require a minimal amount of capital expense and labor. Since they are so easy to apply, a misconception may be that if there is nothing else to do, then go out in the boat and "treat the weeds". However, aquatic herbicides are just like medicine; you must prescribe the correct herbicide at the prescribed dosage for the specific problem aquatic plant at its most susceptible growth stage. Applied too late in the season or at too low a dosage, the herbicide may just chemically prune the target aquatic plants. If a herbicide is applied too often, the plant may develop a resistance to it or, worse still, the herbicide may select out resistant aquatic plant species that can take over the ecosystem. Treating an aquatic plant biomass that is too extensive will create serious problems when the plant material drops to the pond bottom and causes an organic matter buildup. A problem of real concern is the use of aquatic herbicides to treat only the visible result of a deeper, more basic problem, causing the excessive growth of specific plant species in the freshwater ecosystem. Once started, the aquatic herbicide program must be planned as a yearly maintenance procedure to selectively control excess vegetation, to minimize interference with water use, and to apply the herbicide at the correct time to attain maximium effectiveness.

In old, mature ecosystems the best program would be an integrated program using mechanical and chemical management techniques. Here the overabundance of aquatic vegetation is cut to remove it from the lake or pond. This removes some of the nutrients and a fair amount of the organic matter. Then herbicides could be applied at a reduced dosage to kill the remaining plants and to prevent regrowth and reinfestation due to fragmentation and clippings.

Long-term preventive management

Most bodies of freshwater will become infested with aquatic vegetation in time. Aquatic plants are necessary for the stabilization of the sediments, the oxygenation of the water column, and the shelter and protection of aquatic organisms. Seeds and tubers of aquatic macrophytes are important sources of food for waterfowl and wildlife. Aquatic ecosystems should be designed and managed to control excessive aquatic plant growth through the manipulation of the water body and the surrounding watershed. Aquatic plants do not grow well on rocky, gravelly or clay pond or canal beds. They prefer an organic-rich substrate with a steady supply of nitrogen and phosphorus. They grow very slowly at water temperatures below 15°C and cannot tolerate shading. With this knowledge, guidelines can be set for the design of ponds, reservoirs and irrigation conveyance systems to minimize potential aquatic weed problems.

The bottoms of ponds and canals should be excavated down to clay to prevent seepage and to provide a harsh environment for the introduction and development of aquatic seedlings. If the pond or canal site contains a high percentage of coarse-grained soils, then the bottom should be lined by 'blanketing' with a 30-cm layer of packed clay. If clay is not available at the site then the pond or canal should be lined with geotextiles. Slopes and canal banks should be lined with rocks and gravel to prevent erosion. If geomembranes or geotextiles are used for lining the pond or canal, then the covering material should be coarse and nutrient-poor. Once a harsh environment is established in the pond or canal it is imperative that the silt content of the introduced water be controlled through the use of silt traps and sediment catch basins. Little is accomplished if the rocky bed is allowed to silt in, because just 2.5-5.0 cm of sediment is enough for shallow-rooted aquatics to become established. This is particularly important during rehabilitation work because all the improvements are for nothing if part of the system can still release sediments and nutrients into the newly renovated pond or canal. Canals in southern Alberta can deposit enough sediment at bends in the canal in one season to permit the deposition of sediment-rich substrates for colonization by P. pusillus. After the pondweeds become established, the sediment deposition extends further upstream and increases in depth. Soon the deeper-rooted pondweeds such as P. pectinatus and P. richardsonii begin to appear in the center of the siltbar. Once established, the pondweeds extend into the harsher areas between the rocks and coarse gravel and continue to spread. Within five years the rehabilitated canal can be so infested that the delivery capacities are seriously reduced because of restricted flow. The weed bed can now serve as a source of plant inoculum for the rest of the canal system downstream.

The surrounding area must be landscaped and managed to prevent the introduction of nutrients from soil and organic matter carried into the pond by surface runoff and wind erosion. In the western Prairies the wind can be a problem and every effort should be made to establish windbreaks and shelter belts to prevent soil drifting into the ponds, dugouts, and canals and to retain snow for spring runoff. Shelter belts must be placed far enough away from the pond, reservoir, and canal bank to allow for a grass vegetative filter area to intercept sediment in the spring runoff. This will prevent the direct introduction of organic matter into the water. The area must be fenced to keep livestock away from the water's edge, thus preventing the destruction of the banks and the introduction of nutrients from manure. Particular attention should be paid to runoff gulleys and field drainage areas to prevent flash flooding and soil erosion.

Lastly, "dilution is never the solution"! Waste water must be treated to prevent the introduction of nutrients and organic matter into a water body. Through the use of biological vegetative filters, most of the sediment and oxygen-demanding organic matter can be removed before the runoff reaches the water body. Livestock runoff should never be allowed to drain directly into a water body without first passing through a vegetative filter.

The water user must remember that the better the water quality, the cheaper its cost and the fewer the problems that will arise. The poorer the water quality the more algae and hence the greater the problems with irrigation intakes, pumps, delivery systems and sprinkler nozzles. Poor water quality also means more expense in setting up and maintaining a farm and ranch domestic water treatment facility. Poor water quality also means greater aquatic plant problems which contribute to increased water loss through evapotranspiration and increased water temperature. With increased water temperatures there is increased algal and bacterial growth which creates odor and taste problems as well as potential toxic water problems.

AQUATIC VEGETATION MANAGEMENT TECHNIQUES

Non-chemical techniques

The mechanical methods of aquatic plant removal developed over the years all seem to neglect the fact that aquatic plants have the capacity to reproduce vegetatively from stem fragments, specialized stem apices, tubers, stoloniferous rhizomes, axcillary tubers and runners. Cutting, chaining, dredging or drag-lining, and pulling all tend to leave the root system, the crown at the substrate, and usually part of the vegetative plant intact. Regrowth begins immediately and with the healthy root system the plant grows even faster. In the case of cutting, the underwater plant becomes more bushy, increasing the potential for more turions and overwintering apices. Timing the cutting to remove the vegetative top growth before the tubers have developed and hence before there is a reserve food supply in the plant can be very effective in controlling some rooted submerged macrophytes. Combining the removal of the excessive vegetative top-growth or 'standing crop' of the aquatic plant population with timely injection of herbicides underwater, just above the new regrowth, will kill the plant back to the substrate and in some cases may even destroy the crown and root system.

Dredging or drag-lining is used extensively in the irrigation conveyance systems of southern Alberta but this has a tendency to spread the plant tubers. Mud and water that escape in the dredging operation spread a thin layer of nutrient-rich substrate and numerous tubers and rhizomes along the canal. These catch in crevices and give rise to new infestations.

Recently, new machines such as rotovators and hydro-jets mounted on barges have been designed and prototypes tested to dislodge the tubers, rhizomes, root systems and crowns from the muddy sediments. These research machines are in the experimental stage but may offer some long-term control once the design has been perfected. The important aspect of this engineering is that we are recognizing the significance of destroying the root systems. For control of aquatic weeds the plant must be dislodged from the substrate and then collected and removed from the water.

Habitat manipulation

Aquatic vegetation is only the visible symptom of a deeper underlying problem or cause. Aquatic plants can be harvested from now until the end of time but they will always grow back. They can never be eradicated because of their fantastic vegetative reproductive ability. A single plant can colonize a pond, reservoir or canal system in three to five years. Once established in a freshwater environment, the aquatic plants not only spread through that system vegetatively but form seeds that can then be spread to other systems by migrating duck and geese.

We must learn to manage the growth of aquatic vegetation and control the spread of aquatic weeds in our freshwater systems. By designing our freshwater ecosystems to limit the sunlight, manage the water temperatures to maintain cool water, restrict the inflow of necessary plant nutrient and prevent the accumulation of rich organic sediments necessary for the rooting of aquatic macrophytes, we can do much to slow up the establishment of overabundant aquatic weeds. A healthy aquatic environment actually requires some vegetation to support the aquatic invertebrate populations and a viable sport or commercial fishery.

Water level manipulation has long been one of the most often practised but least understood techniques. Certainly the lowering of the water level in the winter will achieve a degree of control through the freezing of the exposed crowns. Recent studies have shown that there is a minimum freezing period of 60 days and a minimum temperature of -10°C to kill tubers of P. pectinatus. It is probably safe to assume that each aquatic plant species has its own specific temperature requirements. Dormant apices and turions of a number of species appear to be much more resistant to low temperatures but less tolerant of desiccation. Preliminary studies suggest that the combination of freezing and desiccation proves much more effective for aquatic plant species with specialized overwintering vegetative structures that lie within the top 5.0-7.5 cm of the sediment surface.

A drawdown treatment in the summer for periods as short as 10 days appears to achieve good control through the desiccation of the aquatic plant tops, crowns and shallow root systems. This has been seen in irrigation canals and along pond banks during the last few drought years on the Prairies. Generally, the peak demand is for summer water but alternate storage sources could be designed to permit occasional summer drawdowns. Success is only achieved if the sediments are dried out. An elevated water table or saturated sediments prevent the aquatic plants from being killed.

Related to this is the increasing of the pond or dugout water level to flood out or drown aquatic plants at the beginning of the flowering stage of the life cycle. Studies have shown that pondweeds such as P. richardsonii, P. illinoisis, P. pectinatus and P. zosteriformis can be killed by raising the water level 5.0-8.0 cm above the plant tops after the plants begin to initiate flowering but before the flower buds open. This is attributed to the disruption of the final stages of the life cycle with the initiation of flowering and the approaching senescence stage. The increased water depth does not permit the plants to complete the flowering and seed development stages and the vegetative stage is completed. However, since tuber formation has already taken place, this technique will do nothing towards alleviating the following years' problems.

The introduction of cool water can slow the growth of rooted submerged aquatic macrophytes. Another technique is to circulate the water throughout the water body by moving colder water from deep in the pond or lake up to the surface by aeration. Stagnant water tends to be warmer because of summer heating and in shallow water bodies this stimulates vegetative macrophyte and algal growth. If colder water can be circulated through the entire pond and moved from deeper water to the shallower areas, the cooling effect will inhibit aquatic vegetative growth. Oxygenation through aeration is also beneficial with the cooler, more oxygenated water restricting the growth of some phytoplankton species.

Although research is lacking on the effect of oxygen levels in the water column on the growth of macrophytes, it is known that low oxygen levels stimulate algae production. Blue-green phytoplanktonic algae prefer warmer water temperatures (above 22°C) and oxygen levels below 2.0 ppm, whereas filamentous algae prefer oxygen levels above 5.0 ppm. Thus the use of aerators to mix, cool, and oxygenate the water all assist in the reduction of some nuisance aquatic vegetation. In western Canada the use of wind power has proven effective in running air compressors which supply air to air stones located on the bottom of dugouts, ponds and small irrigation reservoirs which aid in the cooling, circulation, and aeration of farm and ranch freshwater ecosystems. All these habitat improvement techniques make the aquatic ecosystem that much better for the growth and development of aquatic organisms including fish species.

Biological control

Aquaculture has been practised in many countries of the Old World and in Asia to supply food to the local inhabitants. The principles are based on maintaining a healthy and balanced aquatic ecosystem. The prime function of aquaculture in Israel is to grow sufficient fish to meet the demand for 20-25 kg per person per year. Through the careful selection of specific fish species it is possible to establish a **polyculture** which will utilize the entire water column from surface to substrate. It is even possible to select species that will feed in the mud of the pond bottom. The incorporation of other aquatic organism such as eels, shrimp and mussels permits the further purification of the water. Research in Israel and Germany has shown that aquatic vegetation and aquatic organisms can be used to purify water after domestic use.

In North America we grow enough food on the land so our freshwater resources have been used primarily for recreation, but the increased population growth has still put intense pressure on the aquatic ecosystems and the surrounding watersheds. This is seen in the nutrient enrichment of our waterways and the subsequent proliferation of aquatic vegetation and the deterioration of much of our surface water quality. In Canada aquaculture can be used to restore and maintain a healthy and balanced aquatic ecosystem and provide the added advantage of supplying fish protein. We cannot expect to maintain our freshwater resources in the pure primitive state while using our land intensely to support our present population. We must look at every available technology to improve and maintain our freshwater resources. In Canada there seems to be a real potential for biological control of aquatic vegetation.

Since the mid-1960s extensive research has been conducted around the world on the use of herbivorous organisms to harvest and control aquatic vegetation. Most of the research has been directed towards the determination of the efficiency of the white amur fish (Ctenopharyngodon idella) as a biological control agent for controlling noxious aquatic weed growth. Emphasis has been on the evaluation of the effects of space and plant nutrients resulting from the destruction of excessive weed growth in the aquatic ecosystem.

The Netherlands has about 150,000 ha of surface water, much of it in canals and drainage ditches. Filamentous algae create the major problems, but these waterways also contain extensive populations of higher plants. The Dutch started to investigate the potential for the use of the white amur or grass carp in 1966 with the importation of fish from Hungary and Taiwan. The impact studies in the Netherlands showed that the fish caused less ecological damage than herbicides and that dramatic changes in water quality did not occur. Czechoslovakia has been importing the white amur from Russia for the control of rooted aquatic macrophytes since the mid-1960s.

Austria has used the white amur since the early 1970s and has stocked most of its lakes and ponds with the fish. It has been in major Austrian river systems for the last 16 years without reproducing naturally. In West Germany the stocking of white amur has proven not only economical and cheaper than herbicides but environmental impact studies on the effect the grass carp has on native fish species have shown that the survival and growth of native species have not been adversely affected.

In North America the U.S. Army Engineers Waterways Experiment Station has been planning and conducting large-scale operations and management tests using grass carp to control aquatic plants such as hydrilla (Hydrilla verticillata) in the state of Florida. Their original research was concerned with the efficiency of the diploid fish as well as the long-term effect of the fish on the water quality. In 1980, the Bureau of Reclamation, Division of Research entered into a cooperative agreement with the U.S. Fish and Wildlife Service, The California Coachella Valley Water Users Organization, the Imperial Irrigation District of California and three State of California agencies to conduct research into the evaluation of the sterile triploid white amur for controlling aquatic weeds in the irrigation canals in southern California.

The favorable results from these studies prompted the Province of Alberta to establish a research committee on the potential use of biological organisms such as sterile grass carp to control aquatic vegetation in southern Alberta irrigation canals. The Committee is composed of representatives from the Alberta Fish and Wildlife Division, the Vegreville Environmental Research Centre, and the Pollution Control Branch of the Alberta Department of Environment; the Alberta Department of Agriculture, Irrigation Planning Division; Agriculture Canada, Lethbridge Research Station; and the Irrigation Projects Managers Association of southern Alberta. The research project is investigating certified imported stocks of grass carp fry under quarantine for potential diseases and parasites and studying their growth and development under laboratory conditions. The field studies will determine the seasonal water quality and vegetative biomass of selected southern Alberta irrigation canals before and after the introduction of sterile grass carp. Investigations will include the growth and survival of these fish under Alberta climatic conditions.

If these studies prove successful then further research into the potential for the use of other herbivorous organisms such as other fish, snails, and crayfish should be conducted. Studies on the harvesting and marketing of the grass carp as a source of fish protein for human food and as food supplements should be conducted.

Chemical (herbicide) control

Excessive aquatic weed infestations can be killed, controlled, or maintained at acceptable plant population densities through the use of aquatic herbicides and plant growth inhibitors. They offer an effective way to restore the flow rate of water through irrigation conveyance systems. Generally, the management of nuisance aquatic plant biomass is easiest and most economical through the use of aquatic herbicides. However, chemical management techniques are usually short-term, lack target plant specificity, may have undesirable side effects on other aquatic organisms, and be toxic to specific aquatic animals. The aquatic herbicide program is only a treatment and not a cure. Hence, once the herbicide program is started, it must be continued on a yearly basis.

Before any aquatic herbicides are applied to water the applicator must become familiar with the federal, provincial and local regulations. Only federally licensed herbicides may be used and the label restrictions must be followed. Standard safety precautions must be followed and particular care must be taken to avoid herbicide spillage where children and pets may come in contact with the herbicide. In public waters a provincial permit is required and the applicator must be licensed by the province.

The small 13.5-22.5 liter garden pressure-type sprayers available from most hardwares, garden supply stores, and farm supply centres are more than adequate for treating small ponds, dugouts, and irrigation conveyance systems. For ponds and lakes greater than 5-10 ha the use of larger commercial or farm field-type sprayers is recommended. In many cases the sprayer with its tank and pressure system can be loaded onto a flat-bottom boat or pontoon boat with a small outboard motor and be used for lakes up to 50 ha in size. It must be remembered that a large body of water cannot be treated at one time. Generally, no more than 10 to 20 per cent of the surface area should be treated at one time with successive treatments every third day. This is to prevent a massive oxygen depletion from the decaying aquatic vegetative biomass that is knocked down by the herbicide. Thus, large sprayers and large boats are of little value in aquatic herbicide spraying.

Granules can be spread by hand-operated, crank-type seed or fertilizer spreaders for spot treatment of areas around boat launching sites, docks, and swimming areas. Large commercial versions are available for tractor power takeoff or battery operation but again the goal should not be to see how much can be done in one day but to treat a small area very uniformly with no skips or excess material applied at any point. Helicopters have been used in the United States for liquids and granules but it is impossible to see any such application in Canada because of the diversity of our aquatic environments, the diversity of our irrigated crops, and the multiuse concept of our aquatic ecosystems.

Aquatic herbicide applications should start near the shore and move out into deeper water so that fish and other aquatic organisms are driven out of the treatment area. Particular attention must be paid to inflow areas since the herbicide must have sufficient contact time with the aquatic vegetation to permit absorption. Inlets and spillways must be closed and the treated water generally ponded for a minimum of three days before it is allowed to flow out of the area.

Where possible, the aquatic herbicide treatments should be made in the late spring or early summer when the aquatic plants are young and actively growing. In the case of emergent vegetation, applications must be made at the early inflorescence stage before the plants begin to flower. Treatments must be made on calm days to avoid the possibility of spray drift. It has been found that late evening applications allow the herbicide to mix through the water column and be absorbed more readily by the aquatic vegetation during darkness. This also applies to the application of herbicides to emergent, floating-leaved and ditchbank vegetation where the herbicide is absorbed by the plant tissue and translocated down the stem and into the rootstocks during darkness.

ALGAE

The most common algae problems are from filamentous algae in dugouts and irrigation reservoirs where they cause stagnation and plug intake screens, pumping systems and nozzle heads in irrigation delivery systems. Phytoplanktonic algae are usually associated with domestic water supply reservoirs and small farm and ranch systems. Here the key to success is the early application of herbicides before the algal population becomes dense since early application will have a better chance of getting the entire infestation and will enable the water manager to use less herbicide and hence be more economical. The water manager must check the pond or irrigation reservoir daily since an algal bloom may appear overnight. Algae exist in the water column all year round but under cool water temperatures they exist near the bottom of the water body. As the water temperature warms and the sunlight begins to penetrate beneath the surface of the water, the algae begin to grow. As the water temperature approaches the 22°C point, growth is greatly accelerated and the scums and dense floating mats begin to appear at the surface of the water. In the spring, daily checks should be made of the water bodies and daily microscopic examination of surface and subsurface water samples is an excellent practice for domestic reservoir water managers. Although every water body is different, water managers can generally become acquainted with their own systems. Through experience they will learn to anticipate when the critical first treatment in the spring is necessary and then read the seasonal signs for possible retreatment.

The herbicide used and the dosage required will depend on the type of algae involved, the degree of infestation, the water chemistry of the pond or reservoir, and the use to which the water is put. Appendix I lists the herbicides registered for algae control and the restrictions placed on each chemical. On the Prairies, the surface water is generally hard with a pH in the high 7 to mid 8 range and will require lower dosages applied in split treatments three to four times per season. For a split treatment, the recommended dosage is divided in thirds and applied as a surface spray every second day over a one-week period. This split treatment is also a good idea where trout are in the pond since trout are very sensitive to copper sulfate at levels above 1 ppm. Early treatment before a dense algae population occurs will ensure that when the algae are killed there is no serious oxygen depletion. The destruction of the algal population and the subsequent decay of the algal organic matter can cause a serious drop in the dissolved oxygen content of the water column. If this starts to occur it may be necessary to provide supplementary oxygen by aeration. Aeration cools, circulates, and oxygenates, making a healthier aquatic ecosystem.

SUBMERGENT MACROPHYTES

The submergent aquatic plants spend their entire life cycle beneath the surface of the water, except during flowering and pollination. The key to successful herbicide control of these plants is to apply the herbicide when the plants are actively growing and before the vegetative biomass becomes too great. This means applying the herbicide beneath the surface of the water just above the growing tip. With granules this is a simple matter but with liquid herbicides this requires the injection of the material underwater. A pressure-type application system and an extension system to permit delivery of the herbicide 1.0-1.5 meters underwater must be used. The herbicide should be diluted with 5-10 parts of clean water to permit uniform application of the material to the test area. Remember that beneath the surface of the water there is very little water movement so the application should be made in a criss-cross manner, north to south first and then east to west. It has been found at the Lethbridge Research Station that evening applications permit the herbicide to diffuse through the water column and to be more uniformly absorbed by the submergent aquatic plants. Evening applications also permit a reduction in the herbicide dosage by up to 25 per cent.

For large water bodies, spot treatment or channel cutting is a very effective way to reduce the aquatic nuisance population and at the same time not create serious oxygen depletions from massive weed kills. Remember, if it has taken many years to build up a serious aquatic weed infestation, it cannot be corrected with one massive herbicide treatment. Plan the control program to remove the aquatic infestation for 3-5 years and the management program for another 2-4 years.

FLOATING-LEAVED MACROPHYTES

Floating-leaved aquatic plants such as water lilies and water smartweeds are valued by fishermen and outdoor enthusiasts but may cause serious problems when they take over a pond or boating area. Herbicides must be applied to the actively growing leaves by surface spraying. It is best to add a wetting agent to the herbicide mixture to ensure uniform coverage and hence maximum absorption of the herbicide. Spray to the point of runoff. Evening spraying has proven effective since the herbicide is absorbed and translocated down the stems to the underwater tubers before the plants are exposed to sunlight again.

FREE-FLOATING MACROPHYTES

The free-floating aquatic plants such as the bladderworts, coontail, some buttercups and the duckweeds must be surface-sprayed but without the addition of wetting agents. The plants exist in the upper 12 cm of the water column and will absorb the herbicide from the water. Evening spraying has proven very effective on the Prairies. The lowest recommended dosage should be used since the plants appear very sensitive to all registered aquatic herbicides.

EMERGENT MACROPHYTES

Emergent aquatic plants grow in moist, water-saturated, swampy shoreline areas and extend out into the water to a depth of 30 cm from the shore. Most emergent plants are greatly valued by wildlife for food and shelter. They also stabilize the shoreline and banks to prevent water erosion. Before any control program is started, the long-term impact of vegetation removal must be examined. Foliar herbicide sprays should be applied in the early summer at the time of emergence of the flowers or inflorescences. At this time there is a narrow one-month period when the translocation of photosynthates in the plant is down from the leaves into the tubers and this is the most effective time for herbicide application to achieve total plant kill. Depending on the season, this is usually from the 15th of June to the 15th of July with effective control dropping off during August to almost no control in September. During this 'window' period it is necessary to have maximum absorption of the herbicide and so additional wetting agent must be added to the spray mixture. The spray must be applied to the point of runoff and every leaf must be thoroughly covered. Cattail control has been improved by evening applications so the herbicide is absorbed overnight and translocated in the carbohydrate stream down into the tubers. This is particularly true when using the herbicide Gramoxone.

MARGINAL OR DITCHBANK WEEDS

Many of the marginal and ditchbank plants are valuable plants for waterfowl and wildlife as shelter for nests and cover for the young. They also prevent bank erosion and act as vegetative biological filters to prevent the introduction of sediments and nutrients from surface runoff. At times it may be desirable to remove the vegetation from the bottom of the canal bed but leave the grass species on the upper inner banks and over the tops of the banks. Here the foliar application of a herbicide should be made in large volumes of water and sprayed to the point of runoff. The addition of a wetting agent will assist in ensuring uniform coverage and maximum herbicide absorption.

For the control of terrestrial weeds the manager should use the recommendation for the control of weed species used by farmers but must exercise care to avoid the contamination of irrigation water by overspray and spray drift.

The use of the wick applicator is excellent since the weeds are wiped with the herbicide-saturated wick and there is no chance of herbicides getting into the irrigation water. The wick applicator also permits the treatment of tall weeds while leaving the low-growing grasses untouched. This retains the grasses for ditchbank stabilization and surface runoff filtration.

WATER QUALITY IN RELATIONSHIP TO AQUATIC PLANT GROWTH

Water quality is just begining to be recognized as important not only to the development of aquatic vegetation but also to the effectiveness of aquatic herbicides. Much more research is necessary before the full role of the nutrients in the water column and the sediments is understood. Knowledge of the effect that seasonal variations in nutrient content have on the growth and development of algae and aquatic macrophytes is just beginning to enable us to establish guidelines for freshwater lakes, reservoirs, dugouts and irrigation conveyance systems. It is wise for all water users and water managers to start accumulating a database on their aquatic systems now. At least one sampling should be made every spring, midsummer, early fall and once through the ice in midwinter. These measurements will enable the manager to compare the water quality from year to year and should provide advanced warning of potential problems. Summer measurements will assist in the better utilization of aquatic herbicides under varying levels of pH, electrical conductivity, water hardness, soluble salts concentrations, and total solid and total dissolved solid concentrations. This information is also useful when designing and installing domestic water filtration and purification systems.

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APPENDIX I

The use of chemicals in aquatic ecosystems is subject to federal registration of the herbicide and then provincial regulations as to their use, mode of application, restrictions on using treated water and waiting periods before treated water can be used for irrigation, livestock watering or human consumption. Contact provincial authorities to obtain regulations and permits where necessary. The labels must be read carefully and followed. All necessary health regulations must be followed to protect the applicators and the general public.

ACROLEIN

Chemical name:	2-propenal
Type of plants controlled:	Submergent
Mode of action:	Contact herbicide causing disruption of cell enzyme systems.
Type of aquatic environment:	Irrigation ditches - moving water
Dosage rates:	Injected beneath the water at 0.6-11 L/cm (0.12-2.3 gal cfs) applied over 0.5-4.0 hours.
Time of application:	Apply when plants are young and water temperature is over 20°C.
Restrictions:	Treated water must not be used for drinking water or released into sources of drinking water.

AMITROLE

Chemical name:	1H-1,2,4-triazol-3-amine
Type of plants controlled:	Emergent
Mode of action:	Inhibits photosynthesis and regrowth from buds; slow absorption but good translocation throughout plant.
Type of aquatic environment:	Drainage ditches and marsh areas
Dosage rate:	Foliar spray to the point of runoff in 45 L of water with additional wetting agent at 2.25-11.2 kg/ha.
Time of application:	Early infloresence stage to appearance of mature flower head.
Restrictions:	Avoid contaminating drinking water supplies and spray drift onto other crops.

AQUASHADE

This is a water-soluble dye that suppresses algal growth by reducing the penetration of sunlight into the water column. Its use is only practical in fountains and small ornamental water gardens.

COPPER CHELATES

Chemical name:	8% copper as copper ethylenediamine or copper triethanolamine complexes
Type of plants controlled:	Filamentous and planktonic algae
Mode of action:	Acts as general cell toxicant. Copper chelate is absorbed from the water column.
Type of aquatic environment:	Farm ponds and dugouts - standing water
Dosage rates:	0.25-1.0 ppm applied to the water column as a surface spray. Split treatments applying 1/3 of the dosage every second day may prove more effective and safer when fish are in the pond.
Time of application:	Apply at FIRST sign of algae. Early application permits lower dosages to be used.
Restrictions:	Not for use in public or potable water systems.

DALAPON

Chemical name:	2,2-dichloropropanoic acid
Type of plants controlled:	Emergent
Mode of action:	Absorbed by roots and foliage and translocated throughout the plant. Accumulates in young tissue and buds.
Type of aquatic environment:	Drainage ditches and marsh areas
Dosage rates:	Foliar application at 11.2-22.4 kg/ha in 450 L water with additional wetting agent sprayed to point of runoff.
Time of application:	Early inflorescence to mature flower head.
Restrictions:	Do not spray in high winds; avoid spray drift. Formulations mildly corrosive so wash equipment throughly.

DICAMBA

Chemical name:	3,6-dichloro-2-methoxybenzoic acid
Type of plants controlled:	Emergent (cattails)
Mode of action:	Selective herbicide absorbed and translocated from both the leaves and roots with translocation to the apical meristems. Growth-hormone type of activity causes defoliation, swelling of stems, destruction of conductive tissue, death of growing points and necrosis of the plant.
Type of aquatic environment:	Marshes, swailles, swampy areas
Dosage rate:	Cattails require 4-6 kg/ha dicamba plus 6 kg/ha of dalapon.

Time of application:	Apply at early growth stages up to the early inflorescence stage, wetting foliage to point of runoff.
Restrictions:	Avoid direct application to water bodies and do not use treated water for irrigation for 14 days or for livestock for 7 days.

DICHLOBENIL

Chemical name:	2,6-dichlorobenzonitrile
Type of plants controlled:	Submergent, floating-leaved and emergent
Mode of action:	Nonselective herbicide absorbed mainly by the roots but with some absorption by submerged stems and leaves. Disrupts plant cell division in the growing tips causing death.
Type of aquatic environment:	Ponds and ornamental water gardens
Dosage rate:	Applied to dewatered pond beds at 5.5-17 kg/ha or as granulars spread over the surface of the water which sink through the water column.
Time of application:	Apply to dewatered pond, reservoirs and shorelines in early spring before aquatic plant growth begins. May be applied as a granular formulation spread over the water's surface from a boat.
Restrictions:	Treated water should not be used for irrigation, livestock watering, or human consumption. A 90-day waiting period is required prior to the use of fish from treated waters. Herbicide is non-selective and may kill shoreline vegetation.

DIQUAT

Chemical name:	6,7-dihydrodipyrido[1,2-α:2',1'-c] pyrazinediium ion
Type of plants controlled:	Submergent, free-floating, floating-leaved, emergent, and filamentous algae
Mode of action:	Contact type, non-selective, rapidly absorbed by foliage but very little transloction. Forms a free radical in the plant that is readily reoxidized releasing very active free radicals such as peroxides within the plant cells.
Type of aquatic environment:	Drainage and irrigation canal, farm ponds and dugouts, reservoirs and lakes

Dosage rates:	2.25-4.50 kg/ha in 45 L of water injected underwater for submergent vegetation or surface-sprayed for free-floating, floating-leaved or filamentous algae. Evening applications assist in mixing throughout the water column giving uniform coverage and better absorption by the plant material before herbicidal activity begins in daylight.
Time of application:	Must be applied after the green plant material begins to show in the water but before the plants begin to flower and become encrusted with marl. Water temperature should be 20°C.
Restrictions:	Do not use treated water for irrigation for 5 days or until chemical analysis shows less than 0.01 mg/L Diquat ion. Do not apply to muddy water or to plants heavily encrusted with marl or mud. Do not apply in high winds and avoid spray drift to food forage or desirable vegetation. Applicators should exercise extreme caution in handling Diquat.

DIURON

Chemical name:	_N_'-(3,4-dichlorophenyl)-_N_,_N_-dimethylurea
Type of plants controlled:	Ditchbank grasses and broadleaf deep-rooted weeds
Mode of action:	Herbicide is readily absorbed through the root system and translocated upward into the plant. Disrupts the Hill reaction in the plant cells.
Type of aquatic environment:	For general weed control in drainage and irrigation ditches where the ditch beds are intermittently filled and drained.
Dosage rate:	For total annual weed control apply at 4.48-12 kg/ha and for grasses and deep-rooted perennials at 12-35 kg/ha. Higher rates will give 3-5 years control. Apply in 450-900 L water to ensure uniform coverage of area to be treated.
Time of application:	Apply to dry canal beds in the fall before freeze-up. Adsorption increases as clay content and organic matter content of soil increase. Leaching from treated soils in the spring flush is greatest from sandy soils.

Restrictions:	Be sure to flush the canal with irrigation water in the spring before using ANY water for irrigation.

ENDOTHALL

Chemical name:	7-oxabicyclo[2,2,1]heptane-2,3-dicarboxylic acid as dipotassium salt
Type of plants controlled:	Submergent vegetation
Mode of action:	Contact type herbicide that inhibits protein synthesis. Very limited translocation throughout the plant.
Type of aquatic environment:	Lakes, farm ponds and dugouts
Dosage rate:	72-119 L/ha as a liquid and 374-631 kg/ha. Herbicide must remain in contact with the target plants for 2 hours.
Time of application:	Apply to young, actively growing vegetation when water temperature is at least 18°C.
Restrictions:	Do not use treated water for irrigation for 7 days, do not use for livestock or domestic use for 7-14 days, do not swim in the water for 24 hours and do not eat fish from treated water for 3 days. Applicators should use due care and read all label instructions.

GLYPHOSATE

Chemical name:	N-(phosphonomethyl)glycine
Type of plants controlled:	Emergent aquatic vegetation and green ditchbank vegetation
Mode of action:	The herbicide apparently disrupts the biosynthesis of phenylalanine and other aromatic compounds in the growing plant.
Type of aquatic environment:	Dry drainage and irrigation canals and shorelines for cattails and general weeds and brush
Dosage rate:	Emergent vegetation at 7.0 L/ha hectare sprayed to the point of runoff. Ditchbank vegetation at 5.3-8.8 L/ha applied to green foliage.
Time of application:	When vegetation is actively growing and with emergent aquatic vegetation, best results are obtained in the early inflorescence state until the beginning of the mature seed head.

Restrictions: Avoid spray drift and direct application to surface of water. Do not use contaminated water for irrigation or livestock use. Do not apply within 0.8 km upstream of domestic water intake. Do not exceed the 8.8 L/ha rate. Effects on target plants may not appear for up to 4 weeks depending on the growth stage of the plants.

MCPA

Chemical name: (4-chloro-2-methylphenoxy)acetic acid

Type of plants controlled: Emergent aquatic vegetation and ditchbank weeds and brush

Mode of action: Selective broadleaf foliage herbicide acting as a growth regulator absorbed through the foliage and readily translocated throughout the plant. Generally accumulates and is active in the meristematic tissue.

Type of aquatic environment: Dry drainage and irrigation canals and along shorelines

Dosage rate: 0.6-1.12 kg/ha applied as a low volume spray in 9-100 L water with additional wetting agent.

Time of application: Apply to actively growing plants where the herbicide is in contact with the plant for 2-4 days. Herbicide is readily washed off by rain.

Restrictions: Avoid spray drift and contamination of adjacent water bodies.

PARAQUAT

Chemical name: 1,1'-dimethyl-4,4'-bipyridinium dichloride salt

Type of plants controlled: Submergent, free-floating, floating-leaved and emergent vegetation

Mode of action: Contact type of herbicide absorbed by the foliage; may be translocated via the xylem under certain growing conditions.

Type of aquatic environment: Emergent vegetation and as a 1:1 mixture with diquat for submerged vegetation

Dosage rate: General emergent control at 0.6-1.12 kg/ha with a compatible surfactant. For submerged vegetation injected underwater as a 1:1 mixture with diquat at 4.5-9.4 L/ha mixed 10:1 with clean water.

Time of application:	Apply in the late spring to early summer when the plants are actively growing. Treat before the biomass gets too great. For submerged vegetation inject underwater to the area just above the growing plants and criss-cross the plot to ensure uniform coverage. Evening application to emergent and submerged aquatic vegetation seems to improve herbicide uptake.
Restrictions:	For emergent vegetation avoid spray drift and contamination of standing water. Do not use treated water for irrigation for 5 days or until chemical analysis shows less than 0.01 mg/L. Do not apply to muddy water or to plants heavily encrusted with marl or mud. Do not apply in high winds and avoid spray drift.

SIMAZINE

Chemical name:	6-chloro-N,N'-diethyl-1,3,5-triazine-2,4-diamine
Type of plants controlled:	Used as a selective herbicide for the control of broadleaf and grassy weeds in perennial grasses used for ditchbanks and as non-selective control of all vegetation in the canal bottoms of intermittently filled and drained irrigation canals in community pastures.
Mode of action:	Herbicide is absorbed through the roots with little foliar absorption. Translocated to the apical meristematic tissue where it inhibits photosynthesis.
Type of aquatic environment:	Dry drainage and intermittently filled irrigation canals. Beach area above the high water level.
Dosage rate:	For selective control of broadleaf weeds in established grasses apply at 2.0-4.5 kg/ha in 80-100 L of water to ensure uniform coverage. For total vegetation control apply in the fall to dewatered canal bottoms at 15-22 kg/ha in 150-200 L water to ensure complete coverage. Do not treat above the usual operating water level of the canal.
Time of application:	Generally apply to bare soil as herbicide must be root-absorbed. For total vegetation control apply in the fall just before freeze-up. The winter moisture will wash the herbicide into the soil where it will be bound in the top 10 cm of soil.

Restrictions:	Simazine is strongly adsorbed on clay and muck soils with little leaching downward due to its low solubility in water. To be safe, the first irrigation water in the spring should be flushed out of the system and wasted. Carefully and correctly applied herbicide to the canal bottom will give 3-5 years control before retreatment is necessary. Subsequent treatments at 5-10 kg/ha generally restore weed control for another 5 years.

2,4-D

Chemical name:	2.4-D as dimethylamine salt (liquid)
Type of plants controlled:	Emergent aquatic plants and broadleaved weeds and brush
Mode of action:	Selective as a systemic growth regulator with hormone-like activity. Readily absorbed from the roots and foliage and translocated throughout the plant. Inhibits or stimulates cell division in meristematic tissue causing necrosis in young tissue and death in mature tissues.
Type of aquatic environment:	Dry drainage and irrigation ditches
Dosage rate:	Canal bank vegetation at 1-2 kg/ha; emergent vegetation at 2-4 kg (active equivalent)/ha.
Time of application:	Apply in early spring when vegetation is actively growing. Additional water and wetting agent applied to the point of runoff will assist in the uptake of the herbicide.
Restrictions:	Liquid formulations are for use on emergent and ditchbank weeds and brush. Do not spray during high winds and prevent spray drift to nontarget vegetation. Do not use contaminated water for irrigation, livestock watering or domestic use for 3 weeks OR until chemical assays contain less than 0.1 ppm (0.1 mg/L) of 2,4-D acid.

2,4-D

Chemical name:	2,4-D as butoxyethanol ester (Granular)
Type of plants controlled:	Submergent aquatic vegetation, especially the water milfoils
Mode of action:	Same as above
Type of aquatic environment:	Drainage ditches and farmponds and dugouts where water is not used for irrigation

Dosage rate:	9.5-38 kg/ha using the higher dosage for heavy infestations.
Time of application:	Apply granulars through the water column in early spring while the submerged vegetation is actively growing. Use criss-cross application methods to ensure uniform coverage. Plots should be separated by a buffer, untreated plots of equal size.
Restrictions:	Do not use treated water for irrigation, livestock watering or domestic use until chemical assays of treated water contain less than 0.1 ppm of 2,4-D acid. Contact local fish and game authorities for specific restrictions on fishing and swimming.

Figure 1. Typical prairie aquatic ecosystems. A. Shallow irrigation reservoir located along the foothills of southern Alberta. B. Main delivery canal out of Travers Reservoir near Taber, Alberta. C. Henderson Lake at Lethbridge, Alberta, which serves as an on-stream irrigation storage reservoir and recreational lake in the center of the city. D. Typical farm dugout used for livestock watering and irrigation as well as domestic water after filtration and purification.

Figure 2. Life cycle of the submergent rooted aquatic macrophyte, Potamogeton richardsonii. A. Vegetative shoot of pondweed. B. Leaf structure showing the clasping characteristic of the leaf blade around the stem. C. Flower bud initiation in the axil of leaves underwater. D. Flower head extended to the surface of the water for wind pollination. E. Details of the flower head showing formation of a single seed at the tip of the flower head. F. Young shoots of pondweed at the sediment surface before water is turned into the reservoir. G. Young pondweed rhizome taken from 15-20 cm beneath the sediment surface in the spring. H. Same rhizome 7 days later showing the young plant vegetative shoot and the horizontal rhizome continuing its growth and the appearance of young roots at the site of the next vegetative shoot.

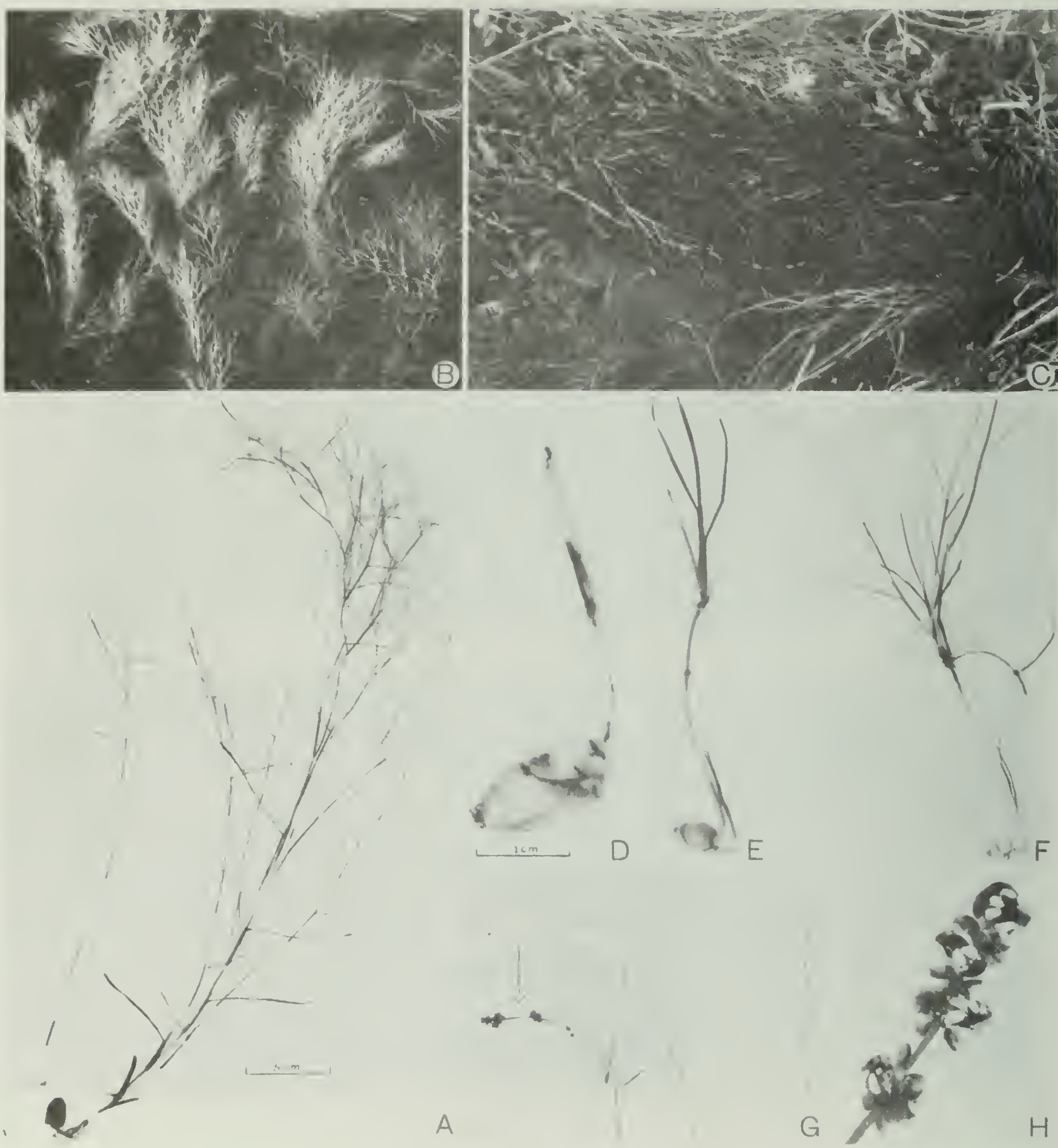

Figure 3. Life cycle of the submergent rooted aquatic macrophyte, Potamogeton pectinatus. A. Vegetative shoot of pondweed. B. Appearance of the plant in flowing water. C. Appearance of the plant in standing water growing with other rooted aquatic plant species. D. Overwintering tuber. E. Sprouting tuber showing root and shoot development. F. Vegetative shoot showing the runner and the start of a second plant from the parent tuber. G. Flower head showing the characteristic space or separation of the first and subsequent flower whorls. H. Details of the flower head showing flower structure.

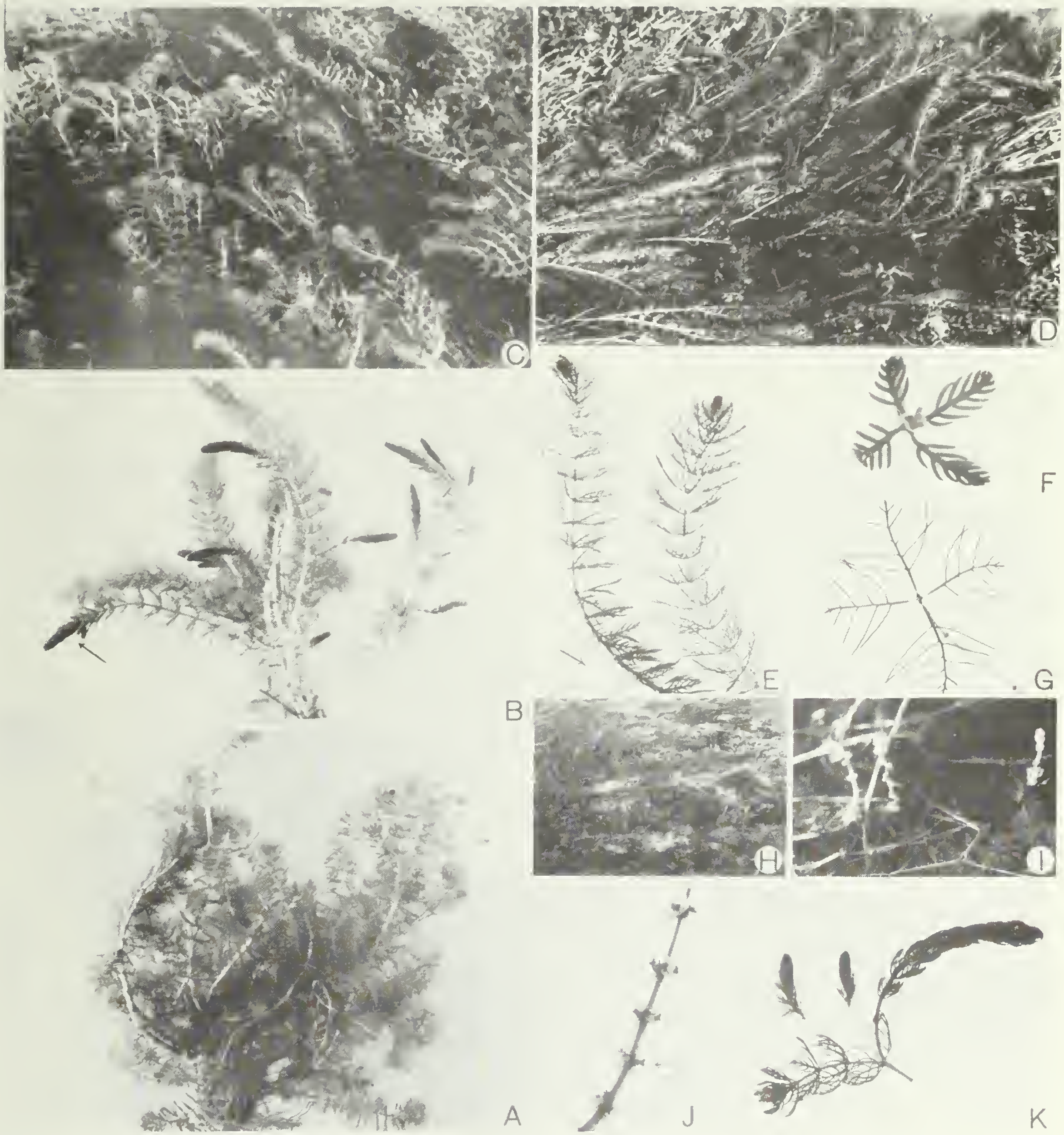

Figure 4. Life cycle of the submergent rooted aquatic macrophyte, Myriophyllum verticillatum. A. Vegetative shoot of water milfoil. B. Mature plant of water milfoil showing the production of overwintering buds or turions at the tip of each vegetative branch. C. Appearance of the plant in flowing water. D. Appearance of the plant in standing water with other rooted aquatic plant species. E. Stem fragments showing root development at the base of the shoot. F. Leaf structure of overwintering turion. G. Typical leaf structure of water milfoil plant. H. Flower head at the surface of the water. I. Flower head extending into the air for wind pollination. J. Details of flower head showing characteristic flower bracts used to identify Myriophyllum spp. K. Details of Myriophyllum spp. turions.

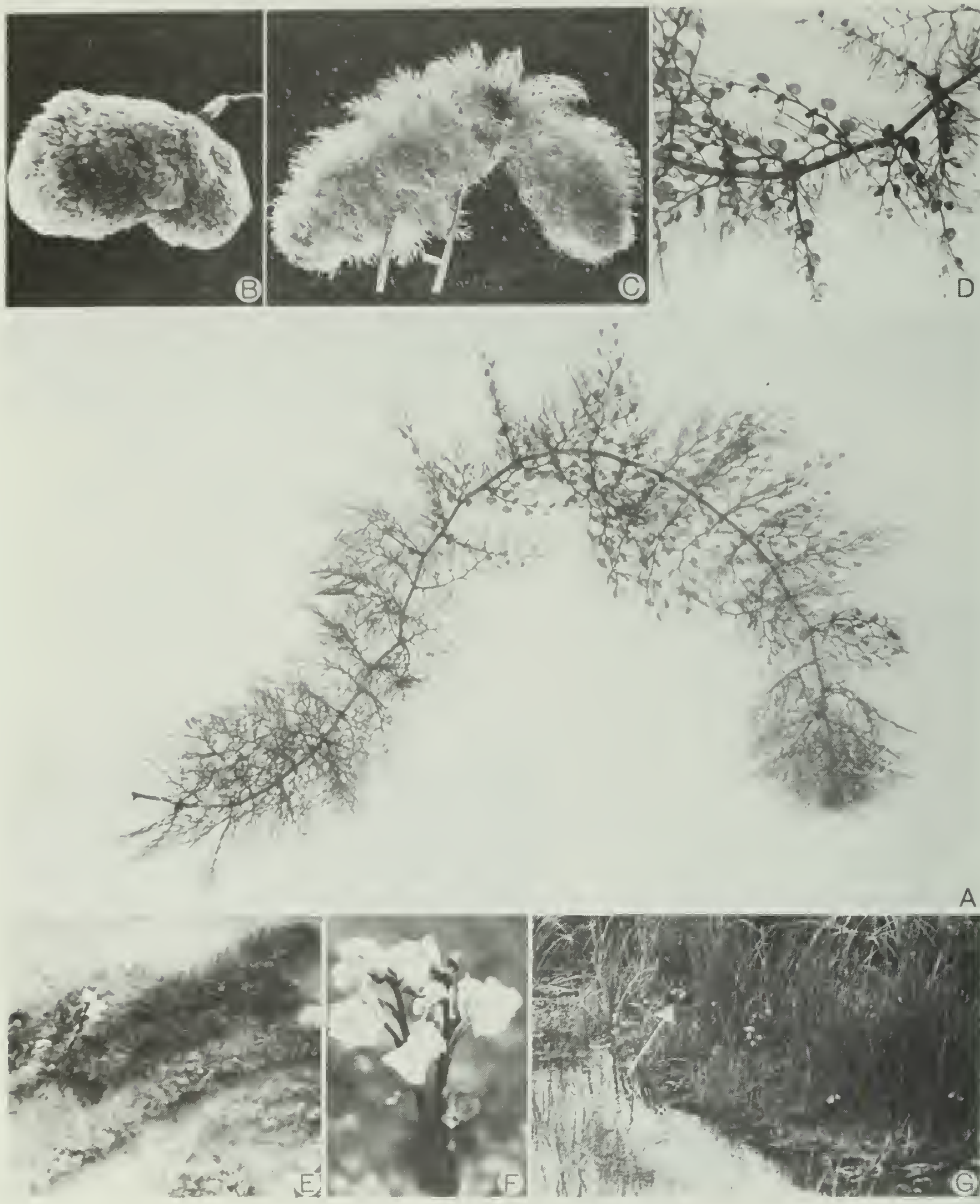

Figure 5. Life cycle of the free-floating aquatic macrophyte, Utricularia vulgarius. A. Vegetative shoot completely lacking roots but possessing small black bladders that assist in the trapping of aquatic organisms for food. B. Overwintering turion of the common bladderwort. C. The expansion of the turion in the spring when water temperature reaches 15°C. D. Details of leaf structure showing the small bladders. E. The free-floating bladderwort along the shore of a stock-watering pond showing the showy flower. F. Details of the flower head. G. Typical habitat of the common bladderwort showing the numerous flower heads.

Figure 6. Life cycle of the floating-leaved aquatic macrophyte, Nymphyia odorata. A. The typical plant growing under greenhouse or ornamental water garden conditions. B. Aerial view of water lilies growing in lakes in northern Alberta. C. Crown of water lily plant showing vegetative shoots. D. Tuber of water lily plant showing extended leaf petiole. E. Water lily plant planted in tub in an ornamental water garden. F. Detail of floating leaf of water lily plant. G. Water lily plant with fully open flower. H. Detail of the opened water lily flower.

Figure 7. Life cycle of the emergent aquatic macrophyte, Typha latifolia. A. Colony of cattails growing at the edge of a pond. B. Underground rhizome system showing two vegetative shoots and the root system. C. Young cattail shoots in 10-20 cm of water. D. Mature plant showing leaf formation and structure. E. Crown of a mature plant with root system. F. Early infloresence stage or 'window' when plants are most susceptible to chemical control showing male flowers above the female flowers. G. Young flower head with developing female portion and the male portion above after the pollen is shed. H. Mature cattail head just begining to shed the wind-disseminated seeds. I. Exploded cattail seed head with winged seeds ready to be wind-blown to potential marsh sites.