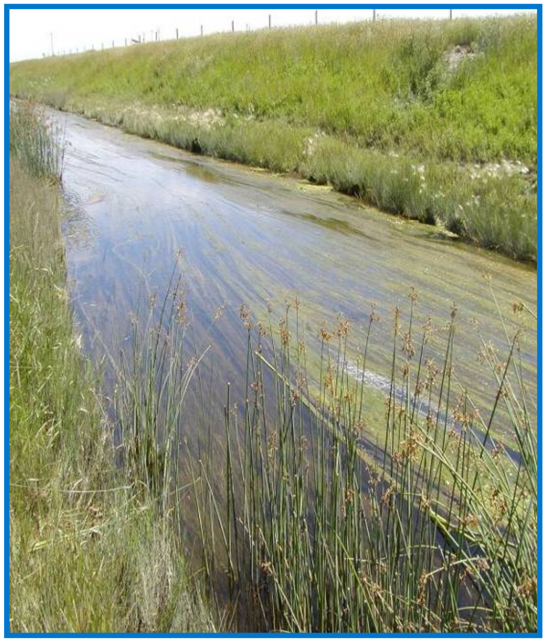
Alberta Agriculture and Food

Aquatic Weed and Algae Control in Irrigation Canals

Report



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1.0 Project Introduction

1.1 Background

Aquatic weeds and algae are an ongoing problem for irrigation districts in southern Alberta, as they adversely affect the operation and maintenance of canal and on-farm infrastructure. The need to allocate time and labour to address the problem and the loss in water conveyance and down-time presents a significant burden to both irrigation districts and water users. These problems are expected to increase if the irrigation season becomes hotter and longer as a result of climate change.

1.2 Project Objectives

This study identified and assessed current methods and strategies for:

- Prevention of aquatic weed and algae growth in canals
- Control of existing aquatic weed and algae problems in canals
- Effective screening of aquatic weed and algae for irrigation pumping systems.

1.3 Project Scope

The scope of this study involved:

- A literature review and assessment of aquatic weed and algae problems and their control strategies for streams, reservoirs and irrigation canals in Alberta, the United States, Australia and parts of Europe
- A series of at least five interviews with Alberta irrigation district managers and staff to determine the nature and effectiveness of current aquatic weed and algae prevention and control practices
- A prediction of aquatic weed and algae growth scenarios based on parameters such as flows, nutrient concentrations, drought years and reservoir storage
- An assessment of aquatic weed and algae prevention and screening technologies suitable for Alberta, including mechanical and chemical control systems and pump-screen equipment.

1.4 Project Limitations

The ability to comprehensively address the project objectives and scope is limited by the following factors:

- Availability of relevant literature
- Availability of irrigation district personnel
- Accuracy, precision and currency of climate predictions

- Accuracy, precision and currency of trends in aquatic weed and algae dispersal and establishment
- Variability in individual irrigation demands, water quality, species occurrence, prevalence and abundance
- Budget
- Time.

2.0 Information Collection

The information used in completing the project objectives and scope items was collected from a wide variety of sources. This section discusses the quantity and quality of this information.

2.1 General

Information collection consisted of a desk study and interviews with five Alberta irrigation districts. Additionally, visits were conducted and telephone calls made with various suppliers, government personnel and academics.

2.2 Literature Collection

A broad search method was used to obtain background information on the current state of aquatic weed and algae problems in Alberta and around the world, and their prevention, control and screening in irrigation systems. While articles directly related to the topic were targeted, the limited availability of directly relevant literature required that references addressing the issues in other parts of the world, in a limited scope, or addressed from other fields of study were also collected.

References from more than 400 books, articles, manuals, specifications, guidelines, reports and presentations were consulted. More than 250 of these were collected for sorting and potential inclusion in the report.

2.2.1 Text Books, Government Publications and Journal Articles

Most of the references consisted of text books, government publications and journal articles.

The following list includes the primary agencies for which relevant articles were found:

- Alberta Agriculture and Food
- Oregon Department of Agriculture
- Research Branch, Agriculture Canada
- University of Calgary
- USDA.

The primary journals for which relevant articles were found include:

- Agricultural Water Management
- Agriculture Ecosystems and Environment
- Aquatic Botany
- Biological Control
- Canadian Journal of Plant Science

- Canadian Journal of Soil Science
- Climatic Change
- Environmental Toxicology and Chemistry
- Freshwater Biology
- Hydrobiologia
- Journal of Aquatic Plant Management
- Journal of Environmental Quality
- Journal of Irrigation and Drainage Engineering
- Water Research
- Water Science & Technology.

The references were sorted as they were entered in an MS Excel spreadsheet. Sorting is discussed in Section 3.0 (Literature Sorting).

2.2.2 Web Sites

Most supplier information, government publications and several articles and were obtained from web sites. Common search engines such as Google and Yahoo were used to search related keywords.

2.2.3 Irrigation Districts

Several irrigation districts provided reports, maps and/or photos related to their experiences with prevention and control of aquatic weeds and algae, as well as to demonstrate the extent of the problem.

2.3 Interviews

Interviews were conducted with the following irrigation districts:

- Bow River Irrigation District (BRID – March 27)
- Eastern Irrigation District (EID – May 2)
- St. Mary River Irrigation District (SMRID – March 30)
- Taber Irrigation District (TID – March 30)
- Western Irrigation District (WID – March 28).

Interviews with most districts were scheduled relatively early in the process to help integrate the literature collection and review process. Lethbridge Northern Irrigation District was unavailable to participate in the process.

Members of the UMA project team met with the managers and operations personnel to discuss:

- History of aquatic weed and algae problems
- Recent changes in occurrence, prevalence and abundance
- The current situation
- Problem areas within the district
- Problem-free areas
- Potential causes of problems
- Prevention and control strategies and programs
- Future concerns
- Potential solutions.

The discussions with each irrigation district were then summarized in a Memo and are referred to throughout this report.

3.0 Literature Sorting

References considered as potentially relevant were entered in MS Excel with a four digit identification number corresponding to the researcher. Descriptors of the reference included source, region, locality, year of publication, category and relevance. Table 3.1 provides a range of attributes that were assigned to each descriptor.

Table 3.1: Sorting Table Descriptors and Attributes

Source	Region	Locality	Year	Category	Relevance
• Journal • Agency • Conference • Irrigation District • Supplier	• Alberta • Prairies • Canada • U.S. • Australia • Europe • Asia • Africa • S. America • World	• Province • State • Country • Prairies • North/South • West/East	• Date of publication	• All • Aquatic Biology • Chemicals • Climate/Future • Infrastructure and Operations • Water Quality	• 1 – high • 2 – moderate • 3 – general

The assignment of literature to categories resulted in the following quantities:

- All (comprehensive) – 11
- Aquatic Biology – 72
- Chemicals – 36
- Climate Change/Future – 29
- Infrastructure and Operations – 28
- Water Quality – 108.

Not all items fit easily in a single category as the discussion of any one category necessitates a relationship with topics in other categories. Sorting of references then required allocation based on the primary topic discussed in the article.

Further sorting of the data into subcategories within the spreadsheet was avoided as this was deemed inefficient due to multiple attributes, potential for arbitrary allocation, and did not assist in developing the report.

Approximately 110 references were attributed high relevance, 115 moderate and 70 for general or indirect relevance. The references that were entered in the spreadsheet were sorted for various descriptors using the sort function as required.

4.0 Literature Filtering

Literature filtering was integrated somewhat in the process of entering each item in the spreadsheet. Items that did not easily fit a category were reconsidered prior to entry. This also provided a check to assist a diverse group of researchers in keeping within the project scope.

A more formal filtering was completed during literature review, prior to starting the draft report to exclude articles that were no longer considered as a potential reference. Filtering also included re-assignment of relevance as articles were investigated in more detail.

5.0 Literature Review and Synthesis

The review of literature was integrated with the interview with the irrigation districts to assist with maintaining relevance. During the review process, benchmark studies that were highly relevant to the scope of work were identified. The benchmark studies for each discipline are identified here.

5.1 Aquatic Biology

- Plants of the Prairie Aquatic Ecosystems – Research Branch, Agriculture Canada (Lethbridge)
- An Identification Guide to Alberta Aquatic Plants – Pesticide Management Branch, AEP
- Aquatic Vegetation on the Canadian Prairies: Physiology, Ecology and Management – Research Branch, Agriculture Canada (Lethbridge)
- Environmental Influences on Aquatic Plants in Freshwater Ecosystems – Dalhousie University (Halifax)
- Atlas of Alberta Lakes – University of Alberta
- Factors Associated with Dominance of the Filamentous Green Alga *Cladaphora Glomerata* (Montana).

5.2 Water Quality

- Surface Water Quality Studies in the Lethbridge Northern and Bow River Irrigation Districts – Irrigation Branch, Alberta Agriculture
- Review of Irrigation District Water Quality (CAESA Water Quality Monitoring Committee – Cross)
- Minimizing Surface Water Eutrophication From Agriculture by Phosphorus Management
- A Prairie-Wide Perspective of Nonpoint Agricultural Effects on Water Quality (AAFC-PFRA)
- Controlled versus Conventional Drainage Effects on Water Quality.

5.3 Chemicals

- Aquatic Weed Management – Herbicides (Southern U.S.)
- Magnacide® H Herbicide – Application and Safety Manual
- Management of Aquatic Plants with Acrolein (NSW, Australia)
- Metabolic Fate of [14C] Acrolein under Aerobic and Anaerobic Aquatic Conditions (U.S.)

- Factors affecting the efficacy of acrolein in irrigation channels in southern Argentina
- Comprehensive Studies.

5.4 Infrastructure and Operations

- Impact of Weeds on Canal Performance (University of Calgary)
- Channel Systems Design for Southern Alberta
- A Simple Method to Predict Flow Distribution at Vertical Angled Screens in Open Channels (U of A / DFO)
- Comprehensive Studies.

5.5 Climate Change

- Climate Change, What is in the Future for Southern Alberta? Getting Started on Adaptation (D. Sauchyn – Prairie Adaptation Research Collaborative)
- Current and Future Water Issues in the Oldman River Basin of Alberta Canada (J. Byrne et. al., U of L)
- Climate Change Uncouples Trophic Interactions in an Aquatic Ecosystem (U of Washington, NW US)
- Trends in Winter Extreme Minimum Temperatures on the Canadian Prairies (Meteorological Service of Canada)
- Impacts of Present and Future Climate Change and Climate Variablility on Agriculture in the Temperate Regions: North America (USDA, etc.).

The literature review included the synthesis with information supplied by the irrigation districts to provide a single document. The process involved extracting information from individual references that was found to be useful in relating to and explaining the southern Alberta experience. The various methods of prevention and control were evaluated by major discipline (aquatic biology, water quality, chemicals, infrastructure and operations) and discussed during interdisciplinary meetings and communications. The findings were cross-referenced with interview results to assist in explanation and potential application.

6.0 Current Aquatic Weed and Algae Problems in Alberta Irrigation Districts

This section describes the current state of aquatic weed and algae problems in southern Alberta and current strategies regarding their prevention and control.

A brief working definition of aquatic weeds and algae is provided at this point.

Aquatic weeds are potentially problematic waterborne plants that can be seen with the unaided eye and are often referred to as macrophytes. These include **submergent** (underwater), **floating-leaved** and **emergent** (leaves above water) rooted plants as well as many free-floating plants and have a vascular system containing conductive tubes for transporting fluids.

Algae have no true leaves or flowers and can be microscopic free-floating (**phytoplanktonic algae**), colonized as mats (**filamentous algae**), or in the more advanced grouping as low-growing branches (**branching algae**). Algae are sometimes grouped by habitat such as surface floating (metaphyton), suspended in the water column (phytoplankton) and attached to submerged surfaces (periphyton) (Crumpton, 1989; Cole, 1994) Periphytic algae can be subdivided into those that grow within bottom sediments (epipelic), on plants (epiphytic) and on rocks (epilithic).

6.1 Aquatic Weeds and Algae Present

The presence of native and introduced aquatic plants in southern Alberta has been assessed comprehensively since 1966. The most recent survey was reported by the Lethbridge Research Station in the early 1990s (Allan and Braglin-Marsh, 1991). In this technical bulletin, a listing of 16 rooted, submerged, aquatic macrophytes occurring in southern Alberta irrigation canals was provided and assigned a range of canal flow regimes in which they are typically found. A second resource that provided a listing of aquatic weeds and algae in southern Alberta irrigation canals was a University of Calgary graduate thesis on the “Impact of Aquatic Weeds on the Performance of Irrigation Conveyance Systems” (Westhoff ,1985). This thesis included an extensive literature review of aquatic plants typical of irrigation canals as well as field observations. A further resource intended for regular use was produced by the Pesticide Management Branch of Alberta Environment and is entitled “An Identification Guide to Alberta Aquatic Plants (Burland, 1994).

Due to the concerns of expansion of invasive weeds throughout North America and the world, expressed in these articles and in other articles, it is likely that the literature for southern Alberta is out of date and new surveys are required, especially for irrigation systems.

The interviews with irrigation districts provided a current indication of the occurrence and prevalence of some species in some reservoirs and some reaches of individual canal systems; however, no regular weed identification programs or resources are in place and so exact identification cannot be verified.

With this in mind the numbers of each aquatic plant group based on the above resources are provided here, along with estimates of the number known to be in irrigation canals:

- 32 Submerged macrophytes (18 in canals)
- 17 Emergent macrophytes (9 in canals)

- 14 Floating macrophytes (3 in canals)
- 3 Phytoplanktonic algae (all in canals)
- 3 Filamentous algae (all in canals)
- 2 Branching algae (all in canals).

The following provides a brief description of the aquatic weeds and algae that are most likely to create problems in southern Alberta irrigation canals.

6.1.1 Submerged Aquatic Plants

Submerged weeds are rooted below the water surface, grow up to the water surface with a weak stem and spread their leaves for support. Seed heads and/or stem tips may extend above the water surface causing them to sometimes be misidentified as emergent. Traditionally, submerged weeds have caused more difficulties in irrigation canals than any other type of aquatic weed. With extensive growth they will reduce canal conveyance efficiency and clog trashracks and pump intakes (Westhoff, 1985).

Common submerged weeds in irrigation systems include:

Pondweed

- Fries' pondweed (*Potamogeton friesii*)
- Leafy pondweed (*Potamogeton foliosus*)
- Straight-leaf pondweed (*Potamogeton strictifolius*)
- small-leaf pondweed (*Potamogeton pusillus*)
- Richardson's pondweed (*Potamogeton richardsonii*)
- Sago pondweed (*Potamogeton pectinatus*)
- Flat-stemmed pondweed (*Potamogeton zosteriformis*)
- Giant or sheathed pondweed (*Potamogeton vaginatus*).

Waterweed

- Waterweed / Canada waterweed (*Elodea Canadensis*)

Water Buttercup

- Water crowfoot (*Ranunculus trichophyllus*).

Milfoil

- Variable leaf milfoil (*Myriophyllum heterophyllum*)
- Common or northern milfoil (*Myriophyllum exalbescens*)

- Green water milfoil (*Myriophyllum verticallatum*)

Water plantain

- Narrowleaf water plantain (*Alisma gramineum)*

Others

- Mare's tail (*Hippuris vulgaris L*)
- Holly-leaved water nymph *(Najas marina*)
- Waterstargrass *(Heteranthera dubia*)
- Watercress (*Radicula nasturtium-aquaticum*).

Eurasian watermilfoil (*Myriophyllum spicatum L*.) was identified as a significant threat to Alberta's waterways in the early 1980s. This species, which reproduces rapidly through fragmentation, was creating conveyance problems in the Okanagan River in British Columbia. Public awareness campaigns were widespread (Westhoff, 1985). Recent research indicates that in areas with herbivorous weevils (*Euhrychiopsis lecontei*) occurring naturally with native northern milfoil, including in the Okanagan, these excessive growths have declined (Creed, 1998; Creed, 2000). The research indicates that Alberta has the weevil present, but as of 2000 has not had an extensive invasion of Eurasian watermilfoil. Currently, Eurasian watermilfoil is rated as a restricted weed under the Weed Control Act (Bigelow et al., undated) and as such pose a serious threat and must be eradicated. Although usually found in small numbers in Alberta, restricted weeds spread rapidly and have superior competition. They are designated as restricted to prevent their establishment (Bigelow et al., undated).

A further significant threat is ***Hydrilla verticillata***. This particularly virulent submerged aquatic weed can displace native pondweeds and has spread rapidly throughout the United States and the monoecious population has potential to extend into Canada (Langeland, 1996). *Hydrilla* was confirmed in Washington State in 1995 (Parsons, 1995). Related to *Hydrilla*, ***Egeria densa*** (Brazilian Elodia or Anacharis common names) is also a widespread aquatic weed (Catling and Mitrow, 2001), but it is not known to be common in Canada.

Correct identification of Eurasian watermilfoil, *Hydrilla* and *Egeria densa* is difficult as; however, Catling and Mitrow (2001) have noted that *Egeria najas*, common in aquarium circles, is making identification even more problematic.

6.1.2 Emergent Aquatic Plants

Emergent weeds are also rooted below the water surface, but have stronger stems that support leaves or other parts extending above. The dominance of this group in shallower water leads to a choking of a typical trapezoidal channel from the sides. Additionally, the stronger stems tend to trap silt and debris and directly restrict flow (Westhoff, 1985).

Common emergent weeds in irrigation systems include:

Cattail

- Narrow-leaf cattail (*Typha augustifolia L*.)

- Broad-leaf cattail (*Typha latifolia L*.)

Bulrush

- Hardstem bulrush (*Scirpus acutus Muhl)*
- Softstem bulrush (*Scirpus validus Vahl.)*

Smartweed

- Water smartweed (*Polygonum amphibium var. stipulaceum)* (Coleman)
- Marsh smartweed (*Polygonum coccineum Muhl*.)

Reed

- Common reed (*Phragmites communis)*

Grass

- Canary reed grass (*Phalaris arundinacea L*)
- Slough Grass (*Bechmannia syzigachne*) (*Steud*.).

6.1.3 Floating Aquatic Plants

This group consists of aquatic weeds that are not rooted in the soil, but obtain nutrients from the water. These weeds can accumulate at trash racks, pump intakes and siphons (Westhoff, 1985) and can also clog on-farm pressure filters or sprinkler heads (W. Hacker, Pers. Commun.).

Common floating plants in irrigation systems include:

Duckweed

- Little or small duckweed *(Lemna minor L*.)
- Larger duckweed, water flaxseed (*Spirodela polyrhiza L.)*

Bladderwort

- *Utricularia vulgaris L.*

Water hyacinth (*Eichhornia crassipes*) is a significant nuisance in the tropics and subtropics, including the southern United States and is migrating north with moderating temperatures. Further north, this weed appears unable to establish itself due to frost and low temperatures (Julien, et al., 2000).

6.1.4 Phytoplanktonic Algae

The phytoplanktonic algae are microscopic free-floating algae that are suspended in the water column as single cells or as gelatinous chains or clumps. Blooms of phytoplanktonic algae following warm sunny days, result in the green, blue-green or reddish-brown coloration of the upper 1-2 metres of water (Allan, et al., 1989; Burland, 1994). Allan et al., (1989) indicated that although phytoplankton may cause serious problems in ponds and dugouts due to toxicity in livestock watering supplies, they generally do not interfere with irrigation systems. In natural systems and in reservoirs, planktonic algal blooms can cause summerkill of fish populations (Burland, 1994).

Common phytoplanktonic algae in irrigation systems include:

- Blue-green (*Microcystis spp.*) – green water
- Blue-green (*Anabaena spp.*) – green water
- Blue-green (*Aphanizomenon spp.*). – blue to blue-green water.

6.1.5 Filamentous Algae

Filamentous algae are characterized by long, stringy threads or filaments of narrow cells attached end to end. They can attach to the canal or reservoir bottom (epipelic-sediments / epilithic-rocks), or on other plants (epiphytic) during the early spring and when hot weather arrives, rise to the surface as a bubble-filled scum (Allan et al., 1989; Burland, 1994). The mats of filamentous algae can clog subsurface screens and intakes in the submerged state, but create the largest problems after they rise, become detached from the bottom and cause major blockages of downstream structures (R. Phillips, Pers. Commun.; J. Webber, Pers. Commun.).

Common filamentous algae in irrigation systems include:

- Cladophora (bright green to yellow green, appearing as cotton-like masses on the surface)
- Spirogyra (loose, slimy bright green strands rising from the bottom)
- Pithophora (dark green, feeling like coarse horse hair).

6.1.6 Branching Algae

Branching algae are also called macrophytic algae as they can grow sufficiently large that they can be easily viewed without a microscope (Burland, 1994). These are the most advanced of the algae as they have stems and branches. Branching algae are usually found in hard water and feel gritty when crushed due to the high calcium deposits. Branching algae are typically low growing and cause fewer problems than the other two types of algae (Allan et al., 1989).

Common branching algae in irrigation systems include:

- Chara spp (e.g. stonewort)
- Nitella spp.

6.2 Timing and Conditions for Problems

The irrigation districts reported that problems associated with aquatic weeds and algae begin in late May and end in late August. Significant growth starts as soon as it gets warm and sunny. The temperature threshold before problems occur is observed in the mid-teens Celsius. Once above this threshold, sunlight appeared to have a more significant effect than increased temperature on the weeds and algae of concern. This coincides with observations that problems are less severe in reaches of canal that are shaded (J. Webber, Pers. Commun.) and after successive days of cloud cover (R. Phillips, Pers. Commun.). TID speculated that blooms occurring during low flows following June rains may be a result of lower turbidity and deeper sunlight penetration (K. Bullock, Pers. Commun.).

The timing of late summer blooms may coincide with thermal inversion of some reservoirs causing mixing of the nutrient rich layer below a thermocline (E. Wilson, Pers. Commun.). As typical outlets discharge only from the upper few meters of the reservoir the subsequent release of this mixed water may induce blooms.

Further detail on the potential mechanisms is provided in Section 7 (Understanding the Problem of Aquatic Weeds and Algae in Irrigation Systems).

6.3 Location of Problems

The following locations were identified by the irrigation districts as either sources of or affected by aquatic weeds and algae problems:

- Recently rehabilitated or armoured canals
    - Filamentous algae – see Section 6.6 (Problems in Irrigation Canals)
- Shallow canals and reservoirs
    - Potentially due to increased light penetration
- Slow-flowing canals
    - Potentially due to lower turbidity and increased light penetration and/or warmer water
- Small / narrow canals and return drains
    - Backup due to submerged weeds or clogging due to filamentous algae mats
- Trash racks / screens / filters
    - Excessive build-up and clogging
- Sprinkler heads
    - Build-up and clogging (when no on-farm pressure filter).

Further detail on the potential mechanisms is provided in Section 7 (Understanding the Problem of Aquatic Weeds and Algae in Irrigation Systems).

6.4 Problems in Source Waters

The vast majority of water supplying irrigation districts in southern Alberta comes from snowmelt runoff originating in the headwaters of the St. Mary, Waterton, Belly, Oldman and Bow rivers (AAFRD, 2002). The remainder comes from direct precipitation and surface runoff from the remaining rural and urban lands within the South Saskatchewan River basin.

There is abundant macrophyte growth in most large rivers on the Canadian prairies, particularly downstream of nutrient sources (Chambers, et al., 1991). Unfortunately, there is little specific data on the occurrence, prevalence or abundance of aquatic weeds and algae available for river sources. Source water problems are then addressed in terms of surface water quality.

There has been a lot of focus on meeting various water quality guidelines for specific purposes. The Canadian water quality guidelines published by the Canadian Council of Ministers of the Environment (CCME) and the Alberta ambient surface water quality guidelines are often cited. Together these provide conservative maximum concentrations for various physical and chemical parameters for various uses. In order of decreasing maximum allowable concentrations are: irrigation, livestock watering, recreation, drinking water and aquatic life.

The quality of source water for irrigation purposes has historically been rated as good to excellent for the Bow River and Lethbridge Northern Irrigation Districts (Greenlee et al., 2000). The preliminary results from year one of a current two year study (2006 and 2007) show similar water quality results for other districts (Kalischuk, 2007). This is positive for the use of irrigation district water for crop production; however, the guidelines do not include thresholds for the emergence of aquatic weed and algae problems.

The concentration of nutrients in source waters is lower than that of return flows to the rivers (Kalischuk, 2007; Greenlee et al., 2000). On average, the concentration of nutrients in irrigation distribution systems lies somewhere in between the source and return flow concentrations; however, for the western districts, the water quality actually improves after it enters the primary reservoir systems (Kalischuk, 2007). This is described further in section 6.5.

The historic water quality of many of Alberta's rivers and lakes is available through Alberta Environment's Online Surface Water Quality Reports:
(http://www3.gov.ab.ca/env/water/reports/water_quality_reports.cfm)

6.5 Problems in Irrigation Reservoirs

An investigation was conducted and available information included in the Atlas of Alberta Lakes (University of Alberta, 1990). The atlas and website covers eight reservoirs that feed into irrigation district systems. Unfortunately, there is little specific data available on the occurrence, prevalence or abundance of aquatic weeds and algae for irrigation reservoirs.

A report by senior University of Calgary students looked closely at **Chestermere Lake**, the primary reservoir downstream of the Western Irrigation District diversion. This report provides a history of the legal, social and ecological issues and summarizes the results of various studies (University of Calgary, 2002). Essentially, high levels of phosphorus and other nutrients discharged primarily from storm water outfall from the City of Calgary were blamed for the dense growth of weeds on the bottom of the lake. The U of C report does not identify the specific weeds involved. Although there is disagreement on who should pay for the cost of weed removal, the Town of Chestermere currently operates a weed harvester, with limited success. There are several parties attempting to address the buildup of high nutrient sediments in the lake and the potential benefits/risks of dredging. There is also a project currently being developed to divert winter stormwater flowing into the Alberta Environment owned WID headworks canal to a constructed wetland for treatment, with final release to the Bow River (S. Holgate, Pers. Commun.). This project is funded by the City of Calgary as part of their legal settlement.

Interestingly, the U of C report indicates that the observed weed growth is significantly higher than that predicted by the measured phosphorus concentration based on measurements in other Alberta lakes, indicating that other factors are contributing to the dense growth (University of Calgary, 2002).The U of C report references a number of other studies that discuss the water quality and weed problems, the analysis of which is beyond the scope of this report.

Earlier studies indicate diatoms (*Bacillariophyta*) and green algae (*Chlorophyta*) were present in Chestermere Lake in early spring (University of Alberta, 1990). The dominant macrophyte genus is *Potomogetan*, growing profusely in the shallower northern half of the lake.

Lake McGregor, the first of the McGregor-Travers-Little Bow sequence at the upstream end of the Bow River Irrigation District (BRID) was shown to have a peak plankton biomass in July, dominated by a dinoflagellate (*Ceratum* sp.) (University of Alberta, 1990). **Travers Reservoir** had reports of dense growth of aquatic weeds (not identified) near the shore of Little Bow Provincial Park creating occasional problems (University of Alberta, 1990).

The **St. Mary Reservoir**, the first reservoir in the St. Mary River Irrigation District, was observed to have no significant macrophyte growth as a result of extreme annual drawdown (University of Alberta, 1990). **Lake Newell**, in the Eastern Irrigation District (EID) system, had similar low macrophyte density as a result of large annual fluctuations.

The **Crawling Valley Reservoir** in the EID was found to have dense populations of northern milfoil, Sago pondweed and Richardson's pondweed soon after construction (University of Alberta, 1990). This dense growth was suggested to be occurring as a result of nutrients continuing to be extracted from recently flooded soils. No follow-up studies were found that indicate the current status of this reservoir.

Alberta Environment's Online Surface Water Quality Reports mentioned in section 6.3 include data on chlorophyll-a and total phosphorus concentrations, along with a corresponding rating of the trophic state. Nine reservoirs corresponding to irrigation districts are included in the database. Table 6.1 summarizes these results for the May – September period.

Table 6.1: AENV Surface Water Quality for Select Reservoirs

Reservoir	District	Chlorophyll-a (ug/L)	Total Phosphorus (ug/L)	Trophic State (chlorophyll-a / TP)
Chestermere	WID	7	33	mesotrophic / mesotrophic
Crawling Valley	EID	15	40	eutrophic / eutrophic
Lake Newell	EID	6	20	mesotrophic / mesotrophic
Lake McGregor	BRID	8	25	eutrophic / mesotrophic
Travers	BRID	3	16	mesotrophic / mesotrophic
Little Bow	BRID	2	14	oligotrophic / mesotrophic
St. Mary	SMRID	2	20	oligotrophic / mesotrophic
Milk River Ridge	SMRID	3	13	mesotrophic / mesotrophic
Oldman	LNID	2	20	oligotrophic / mesotrophic

Oligotrophic – low productivity
Mesotrophic – moderate productivity
Eutrophic – high productivity

The trophic state gives an indication of the reservoir's productivity and is characteristic of the size, residence time (flow-through), slope, water depth, sediment depth, organic matter content, and resulting poor (oligotrophic) or rich (eutrophic) nutrient and phytoplankton content (Cole, 1994). Reservoirs can change in trophic state with external factors that affect the rate of inflow or outflow of nutrients. Increased development and subsequent increase in the concentration and volume of nutrients and runoff discharged to the reservoir will increase productivity, resulting in more weed and algae potential (Cole, 1994).

Where reservoirs have sufficient retention time, minimal surrounding development and are able to sustain a stable shore macrophyte population, they can mitigate nutrient concentrations. This is shown in the increasing water quality through the McGregor-Travers-Little Bow sequence. This is substantiated by water quality testing conducted by Madawaska Consulting (Cross, 1998; Cross, 2001; Cross, 2002). The total phosphorus, dissolved phosphorus and nitrate+nitrite concentrations dropped significantly between the headworks and the Little Bow Reservoir outlet. These concentrations came up partially, but remained lower than the source water until reaching the drain system. Preliminary results from year one of a two-year study (2006 and 2007) by Alberta Agriculture and Food show that water quality may improve downstream of a reservoir (Kalischuk, 2007). This was particularly evident in the westernmost districts where in 2006 there was a decrease in total nitrogen, total phosphorus and dissolved reactive phosphorus (orthophosphate) between the source water and the irrigation laterals, followed by a significant rise in the return flow drains.

The available research indicates that with the exception of new or rehabilitated reservoirs or those located in proximity to developed areas, primary reservoirs do not present significant aquatic weed and algae control problems.

Reservoirs within the irrigation districts however, are relatively small, shallow and warm compared to the primary reservoirs and can have direct problems. **Taber Lake Reservoir** within the Taber Irrigation District (TID) is shallow (3 m) and tends to experience the formation of dense clumps of synergistic aquatic vegetation best described as cattail islands (K. Bullock, Pers. Commun.). When these reach a large enough size, a strong Chinook wind will cause the vegetation to detach from the bottom and float northeast toward the Lateral M approach channel. Prior to installing interception posts and removal with a backhoe, these cattail islands would clog the outlet. **Scope Reservoir** within BRID experiences occasional blooms of blue-green algae, likely as a result of stagnant water from short-cutting of flow from the inlet to the nearby outlet (R. Phillips, Pers. Commun.).

The nutrient loading of reservoirs within irrigation districts may contribute to eutrophication and growth of aquatic weeds and algae. Potential sources include livestock and wildlife with direct access, municipal drain systems and surface and subsurface runoff from fertilized or heavily grazed fields.

6.6 Problems in Irrigation Canals

The irrigation districts have been aware of the presence of aquatic weeds and algae in irrigation canals since their inception. The CPR had custom-built excavating machines to clean silt and algae from ditches and used a dragline for cleaning larger canals in the Lethbridge Northern Irrigation District (LNID) (Gregorash, 1996).

Although much research has been undertaken studying terrestrial weeds in the prairies, there have been no systematic surveys of weeds and algae in irrigation canals. Problem weeds and algae identified by irrigation districts during the interviews included:

- Filamentous algae – bright lime green mats
- Milfoil / Water milfoil
- Richardson's pondweed
- Sago pondweed

- Waterweed
- Cattails
- Emergent grasses/sedges/rushes
- Russian thistle.

The most significant of these is filamentous algae. This problem became dramatically worse since the mid-1990s for some districts and as recently as 2001 for others. The life cycle was described similarly by each irrigation district. A mat of green algae, appearing like a layer of filter fabric, forms on the bottom of recently rehabilitated armoured canals in the spring. During the summer the mats detach and float downstream, continuing to grow. The mats then completely cover screens and pump intakes or will block narrow canal reaches.

Waterweed, Richardson's and Sago pondweed and other submerged aquatic weeds continue to create problems in backing up drain systems and restricting capacity of older canals with clay bottoms. These are more of a problem in long, high capacity canals, or near reservoirs and return drains where Magnacide® H (acrolein) treatments are either not cost effective or cannot be used due to the reach being immediately upstream of fish and recreational facilities.

Russian thistle is a terrestrial weed that is a problem prior to startup in spring as the dried tumbleweeds blown by the prevailing southwesterlies are deposited in intercepting canals. This is a particular problem where large grazing lands occur west of a canal. The tumbleweeds can completely fill some reaches of canal. These are removed from the canal and then burned on the outside bank or hauled away or else sometimes burned in place.

6.7 Problems in Pipeline Systems

The most significant effect of aquatic weeds and algae on pipeline systems is associated with the inlet system. The opening to the pipeline must have an access prevention system to prevent animals or people from accidentally entering. For irrigation districts that do not screen their water prior to delivery, this may be in the form of a coarse bar screen or trash rack. Some irrigation districts choose to provide some form of finer screening to eliminate the majority of debris and aquatic weeds and algae. In either case, the direct growth of weeds and algae in the vicinity or on the rack/screen creates problems; however, the greater issue is with the clogging of pipeline intakes with floating vegetation (Smith et al., 1991). The clogging can progress rapidly from restriction to blockage as a result of the continuity of flow equation. The velocity of the water passing the rack/screen increases linearly with the decrease in open area due to the blockage. The increased local velocity draws in more floating debris and increases the pressure of the blockage against the rack/screen (adhesion) exponentially. A restriction can quickly become a blockage, which can then cause flooding. The high adhesion makes removal of the blockage difficult and time-consuming. As mentioned previously, a floating mat of filamentous algae can completely cover a pipeline intake, resulting in immediate blockage. As almost all pipeline systems contain an isolation valve or gate, this too can become plugged so that it must be cleared to allow complete closure. Residual material on the valve or gate seat can result in incomplete sealing or bent discs.

There are few problems reported within pipeline systems related to aquatic weeds and algae. The smooth walls and relatively high velocities compared to canals result in easy passage of aquatic vegetation. Lack of sunlight and burial in ground that stays less than 15 degrees Celsius ensures conditions that are not conducive to growth. The only problem identified is with the potential accumulation of biomass in siphons during low flows (Westhoff, 1985).

6.8 Problems in On-Farm Systems

The most significant problem for on-farm systems with respect to aquatic weeds and algae is similar to that of the pipeline intake rack/screen and involves restrictions and blockages of pump intake screens, pump discharge filters (pressure filters) and pipe valving. High maintenance and/or high cost screen/filter systems may be required where weed and algae problems are extensive.

Pivot piping and sprinkler nozzles can also become clogged with vegetation, requiring regular maintenance to clear the lines. The improved spray patterns of modern impact plates and wobbler designs can deceive an irrigator into thinking the sprinkler system is clear when there may be a restriction (W. Hacker, Pers. Commun.). This results in inconsistent water application on the field and subsequent effects on yield.

A rare, but potentially serious problem is toxic poisoning of livestock where certain varieties of phytoplanktonic algal bloom occur (Burland, 1994; Allan et al., 1991).

6.9 Current Prevention and Control Strategies in Alberta Irrigation Districts

None of the irrigation districts interviewed have a comprehensive formal aquatic weed and algae prevention and control program. Individual strategies, some of which are well-planned and consistently implemented, are used on a priority basis.

6.9.1 Prevention Programs

- Rehabilitation of canals to pipeline
- Fencing of canals (primarily newly rehabilitated)
- No new drain inlets (some districts)
- Conditions on field dewatering following rain events (some districts)
- Mowing/burning of rooted vegetation.

The primary strategy that Alberta irrigation districts are using to prevent the growth of aquatic weeds and algae is by rehabilitating canals with buried pipeline systems. As discussed in section 6.7, once water passes the intake structure, pipelines do not have any issues with weed growth or clogging with the exception of the potential of blockage in some siphons.

Fencing of canals prevents access to the canal by livestock, thus eliminating disturbance of bed sediments and addition of high nutrient wastes.

Drain inlets are a concern as surface runoff from farmer fields can be high in nutrients and suspended solids (Cross, 1997). This is a particular problem in SMRID and TID as their canals intercept a large regional drainage area. Some cross drains are put in to bypass the canals where these are constructed in fill (above grade); however, this water eventually either arrives in a down slope canal or reservoir directly or indirectly by contributing to down slope runoff potential (Cross, 1997; Tamminga, Pers. Commun.). Subsurface drains are also a potential significant contributor of nitrate (and likely other nutrients) due to leaching from manure and/or inorganic fertilizer into shallow groundwater where application exceeded crop requirements (Rodvang et al., 1998). Tile drain systems intercept this groundwater and discharge to intercepting canals. The number of subsurface drain inlets and their discharge volume and water quality is not known.

Field dewatering after rain events simply exacerbates the problem of surface runoff through surface drain inlets. Some irrigation districts are not permitting producers to pump out their fields into district canals where the nutrient concentration exceeds certain levels. This policy is in line with the regulations of the Natural Resources Conservation Board (NRCB), with the potential of stiff fines. The monitoring and education provided by ditchriders appears to act as a deterrent to indiscriminate pollution of district water (Tamminga, Pers. Commun.).

Mowing or burning of rooted vegetation in the pre-season may delay the onset of problems in reaches of canals where this is a problem historically. This prevention strategy is not widely used.

6.9.2 Control Programs

- General preparedness for control in place
  - Equipment and personnel
  - Magnacide® H notifications
- Reactive response is common
  - Problems addressed as they are reported/observed
- One pro-active chemical program
  - SMRID Magnacide® H treatment plan.

The fact that the irrigation districts have personnel and equipment dedicated to control of aquatic weeds and algae indicates awareness of the problem and willingness to allocate resources to solutions. Control programs have evolved on a piecemeal basis as new equipment and methods have been developed and tested by innovative operations and maintenance crews. Direct research, inter-district communication or technology transfer programs have facilitated in this process, but have not resulted in wholesale change in management of this issue.

Some of the methods currently used by Alberta irrigation districts are listed here with descriptions and assessments provided in section 8:

Chemical

- Magnacide® H (acrolein) – flowing waters where fish/recreation is absent
- Glyphosate – emergent weeds during low flows eg. cattails, reed canary grass
- 2,4-D – ditchbank weeds during low flows

Physical / Mechanical

- Chaining – submerged weeds in large canals where Magnacide® H is not cost effective
- Hoe with screened bucket attachment – upstream of structures or downstream of chaining operation
- Hoe with sickle attachment - cattails

- Screening
    - Exclude large debris/masses/cattail islands – interception posts; trash racks
    - Contain small debris – cattails and other emergent vegetation
    - Pass debris downstream – vertical screen; automated side sweep
    - Remove debris – sweep-up-the-bank; travelling screen
    - On-Farm (suction) – twin screen; passive with/without backwash; rotating drum with backwash
    - On-Farm (discharge) – pressure filter
- Flow-through sprinkler nozzles

Biological

- Constructed wetlands (few)
- Bank and near-bank vegetation
- Shelterbelt/shade trees
- Competitive plants.

6.9.3 Failed Control Programs

- Chemical
    - Liming (WID; EID)
- Mechanical
    - Sweep-up-the-bank (BRID, TID)
- Biological
    - Grass carp (EID).

6.9.4 Potential Control Methods to be Tested

- Chemical
    - Polypro® chelated copper-based algaecide (BRID)
    - Reward® (diquat) non-selective aquatic herbicide – very slow-moving water
- Mechanical
    - Rotating cable harvester (SMRID).

7.0 Understanding the Problem of Aquatic Weeds and Algae in Irrigation Systems

This section describes the science and ecology behind the problem of aquatic weeds and algae and opportunities for prevention and control. An extensive discussion of the environmental factors affecting the occurrence, prevalence and abundance of aquatic weeds and algae is followed by a look at their effects on canal performance.

7.1 Environmental Factors Affecting Aquatic Weeds and Algae

There are a wide variety of environmental factors that affect the occurrence, prevalence and abundance of aquatic weeds and algae. These vary in their effect on individual aquatic plants and species populations and will influence their location, timing, relative abundance, density, growth form (height, spread), regeneration/reproduction and metabolism (Lacoul and Freedman, 2006). Lacoul and Freedman, (2006) completed a comprehensive article addressing the environmental influences on aquatic plants in freshwater ecosystems. This section summarizes the relevant factors from the Lacoul and Freedman article and elaborates on certain factors with discussion and supplementary references.

The primary local environmental factors affecting growth are discussed here and include:

- Climatic factors
  - Temperature
  - Ice Cover
  - Wind
  - Precipitation
- Hydrology
- Geomorphology (geological and physical)
  - Habitat Area
  - Light
  - Sediment
  - Nutrients and trophic status
  - Alkalinity and pH
  - Salinity

- Population dynamics
  - Competition
  - Herbivory
  - Diseases.

Large scale migration and translocation factors including invasive species and climate change will be addressed in section 10 that discusses prediction of future weed and algae problems.

7.1.1 Climatic Factors

7.1.1.1 Temperature

As observed by the irrigation districts, aquatic weeds and algae require a minimum threshold temperature to proliferate. Temperature affects the physiology of aquatic plants including seed germination, seasonal start time and rate of growth and timing of dormancy. As such, temperature is the single-most important factor in setting the stage for aquatic weed and algae growth.

The minimum water/soil temperature for growth of aquatic plants is 10^{o} C, while the maximum is 45^{o} C. Dormancy or death will occur at temperatures below 3^{o}C, depending on individual species tolerance. For rooted plants, the sediment temperature has a greater influence than water temperature.

Interannual (year to year) variations in temperature had a significant effect on depth and biomass production of submerged vegetation found in a Quebec boreal lake (Rooney and Kalff, 2000). Although the water temperature was not taken, the air temperatures during the critical early months were on either side of 10^{o}C for the warm and cool years. This effect may be more pronounced due to temperature fluctuations close to lower thresholds of tolerance for key species. Based on work by Rooney and Kalff, (2000), temperatures in the early spring may be an indicator of future growth potential within that season.

Species distribution and community structure are also affected by temperature. Temperature influences can affect species distribution and prevalence and may affect the ability to compete.

Higher temperatures can compress the growth cycle of aquatic weeds, resulting in faster regeneration after weed removal where reproductive potential remains (seeds, reproductive fragments).

7.1.1.2 Ice Cover

Lake (reservoir) ice provides shade and also scours shorelines after break-up. Longer ice-free seasons may have an effect on initiation of growth and colonization of new or invasive species.

7.1.1.3 Wind

Wind affects pollination and vegetative reproduction dispersal, nutrient cycling, uprooting and scouring in reservoirs. Wind and wave intensity has varying effects on different species. Moderate wind and wave action may encourage macrophyte growth by enhancing nutrient supply and reducing shade effects of floating aquatics. Severe wind may adversely affect the aquatic macrophytes in reservoirs and cause erosion of bottom sediments and nutrient suspension through strong mixing as a result of wave action. This water may then contribute to future blooms when discharged to canals.

7.1.1.4 Precipitation

The amount and timing of precipitation has an effect on aquatic plant growth. In the irrigation districts, the effect is primarily due to influx of nutrients from surface and subsurface drains (see Prevention Programs in Section 6.9.1). Precipitation amount and timing is also important in terms of the seasonal development of vegetative buffers.

7.1.2 Hydrology

Hydrology refers to how water abundance, water level, water velocity, channel discharge characteristics and their timing affect aquatic weed and algae growth. Hydrology in turn affects scour and sedimentation, water clarity, water chemistry and currents.

Disturbance or scour as well as drought affect the species composition, relative abundance and distribution of aquatic macrophytes as well as how these species establish and change (successional dynamics).

Flowing water will generally stimulate growth of macrophytes and is associated with increased availability of oxygen and enhanced nutrient and other chemical exchange (Barendregt and Bio, 2003). Studies in the Bow River on submerged macrophyte growth indicated that biomass decreased with increasing current velocity as a result of both direct effects on plant shoots and indirect effects on sediment nutrient concentrations (Chambers et al., 1991). At current velocities > 1 m/s, submerged macrophyte growth was rare. Further studies showed that both abundance and diversity were stimulated at low to moderate velocities and reducing growth at higher velocities (Madsen et al., 2001). The macrophyte stands themselves were found to reduce current velocity within and adjacent to the bed which then increased sedimentation and reduced turbidity. In this way, submerged weed establishment helped improve conditions for their further growth. Increased residence time as a result of slow flowing canals was also correlated to the formation of algal mats in concrete irrigation channels (Ferreira et al., 1999).

The most significant influence of flowing water on the establishment of aquatic macrophytes is transport of sediments and the nutrients these sediments contain (Barendregt and Bio, 2003). Modelling of sediment transport has been done on a river basin level (Barendregt and Bio, 2003)..

Drawdown can be effective in managing macrophyte growth (Cooke, 1980; Allan et al., 1989; Sytsma and Parker, 1999). The objective of drawdown is to desiccate (dry out) the aquatic plant tops, crowns and shallow root systems. The vulnerability of submersed aquatic plants to desiccation is primarily in the lack of a cuticle (Sytsma and Parker, 1999). Success, however, is only achieved if the sediments are completely dried out as saturated soil or a high water table will prevent the plant from being killed (Allan et al., 1989).

An understanding of the life cycle of the target species is critical in coordinating the timing of water level manipulation (Sytsma and Parker, 1999). The resistance of some weeds to drawdown will select for their prevalence following re-fill (Cooke, 1980). The species that are selected for when lake levels fluctuate tend to be desiccation-resistant (Van Geest, et al., 2005). Additionally, upon re-filling there is a significant release of ammonia (NH_4-N) as well as a tendency for algal blooms (McGowan et al., 2005; Cooke, 1980).

In McGowan’s study, investigating the effects of winter drought (drawdown) in southern Saskatchewan lakes, there was a 2.5 fold increase in macrophyte abundance and a shift from a community dominated by Coontail (*Ceratophyllum demersum)* to one composed of Sago Pondweed (*Potamogeton pectinatus)* in the following spring/summer. Allan et al. (1989) noted that a minimum freezing period of 60 days and a minimum temperature of –10^{o}C are required to kill tubers of Sago pondweed. The combination of freezing and desiccation has proved much more effective in reducing populations of aquatic plant species with specialized over-wintering vegetative structures that lie within the top 5.0-7.5 cm of sediment surface (Allan et al., 1989).

7.1.3 Geomorphology

Geomorphology refers to the geological and physical characteristics of the water body and has both direct and indirect effects on aquatic plant growth. Significant parameters include habitat area, light availability, substrate and canal characteristics.

7.1.3.1 Habitat Area

Species diversity is directly proportional to the area of suitable habitat. Although irrigation systems are composed of engineered structures, integration with the surrounding habitat is inevitable. Where habitat is limited, the number of competing species declines, leaving weedy species prevalent. Competition is discussed in section 7.1.4.1 (Competition).

Both the total area as well as the quality of the habitat is important, taking into account upland, shoreline, near shore and deep water characteristics. Consideration of vegetation density, shoreline length (straight versus meandering), shoreline slope, sediment types, wave exposure and others can contribute to the quality of the aquatic environment.

7.1.3.2 Light Availability

The influence of light on the distribution of aquatic plants has been well studied in the field (Chambers and Kalff, 1987; Lacoul and Freedman, 2006) and in the laboratory (Barko and Smart, 1981; Sand-Jensen and Madsen, 1991; Lacoul and Freedman, 2006).

Light is essential for photosynthesis and the absence of light such as occurs in pipelines and turbid or deep freshwaters, prevents the growth of submerged aquatic weeds and algae (Sytsma and Parker, 1999). The ability of submerged weeds to grow depends on the depth to which light is able to penetrate and the tolerance of a species to low light conditions. The transmission of light through the water column is affected by water colour, turbidity, and shading. Shading can be from cloud cover, from ditch bank vegetation and structures and from aquatic plants above. The growth form affects the ability to survive low light conditions. In comparing the effect of light and nutrients on the growth of pondweeds, Chamber and Kalff (1987) found that biomass was determined primarily by nutrients in the upright plant and by light availability in the bottom-dwelling plant.

Light levels affect species composition (Sand-Jensen and Madsen, 1991; Khedr and El-Demerdash, 1999; Sytsma and Parker, 1999). This is clearly seen in the prevalence of bottom-dwelling diatoms in shaded conditions while filamentous algae dominate in abundant light (Dodds, 1991; Mosisch et al., 2001). Additional studies also identify a strong correlation of the formation of mats of filamentous algae with light availability (Jones, 1984; Ferreira et al., 1999).

Adaptation to low light conditions is possible in some species and in experiments has resulted in stem elongation of Eurasian watermilfoil and higher concentrations of chlorophyll-a in a species of pondweed (P. perfoliatus) (Twilley and Barko, 1991). Growth efficiency was shown to have greater variability between species than within species (Sand-Jensen and Madsen, 1991), suggesting that low light levels will affect species composition more readily than individual species adaptation. This means that if species adapted to low light levels are present, with time they have the potential to displace less tolerant species even if that have some adaptive ability.

7.1.3.3 Substrate

Substrate refers to the bottom sediments of the reservoir or canal which act as an anchoring medium as well as the primary source of nutrients for rooted aquatic plants. The preference of substrate texture and composition is species-specific (Lacoul and Freedman, 2006) and will therefore influence the occurrence, prevalence and abundance of aquatic weeds and algae.

The ability of an aquatic plant to anchor is dependent on the bottom type. Bedrock, coarse cobble, fine clay and excessively soft and flocculent surfaces are not suitable for rooted macrophytes (Barko and Smart, 1986; Allan et al., 1989, Lacoul and Freedman, 2006). Filamentous algae prefer more solid surfaces such as rocks, concrete and submerged aquatic macrophytes (Dodds, 1991; Ferreira et al., 1999), while branching algae prefer silty pond bottoms (Allan et al. 1989).

For sediments, texture/density influences growth of rooted aquatic weeds indirectly by the ability to store nutrients. Generally, the finer the texture the higher the nutrient-holding ability. Sediment consisting of 75% sand by dry weight was found to correspond with poor macrophyte growth, likely due to lower nutrient content (Barko and Smart, 1986).

Organic matter composition within the substrate has an effect on macrophyte growth. Although addition of organic matter showed decreased macrophyte growth with increasing organic matter (Barko and Smart, 1983; Barko and Smart, 1986), high organic matter corresponds with high macrophyte growth in other studies (Squires and Lesack, 2003; Lacoul and Freedman, 2006). This is likely due to the temporary effect of nitrogen sequestration with high loading of organic matter and is well-known in managing agricultural soil amendments (University of Minnesota, 2002). The nitrifying bacteria nitrobacter and nitrosomonas are also present in aquatic environments where oxygen is available and will rapidly take up nitrogen as they take up the carbon released in the decay of organic matter (Fritz Industries, 2007). Once equilibrium is restored, the nitrogen once again becomes available (University of Minnesota, 2002).

7.1.3.4 Nutrients

Rooted aquatic weeds obtain almost all of their nutrients from the substrate, while free-floating plants as well as the three groups of algae (floating, filamentous and branching) obtain most of their nutrients from the water. Therefore, the composition of canal and reservoir sediments will more directly influence rooted aquatic plants, while nutrients dissolved in irrigation water will more directly influence non-rooted aquatic plants. Water nutrients will indirectly affect sediment nutrient content through the decomposition of non-rooted vegetation.

Nitrogen and phosphorus are the nutrients of primary concern and are considered limiting to growth in water bodies with relatively low fertility and this is generally also the case in more productive situations (Lacoul and Freedman, 2006). In the latter case, the productivity of aquatic plants is generally nitrogen limited when the N:P ratio is <14 and phosphorus limited when $N:P>16$. Carr (1998) found differences when comparing the relatively high influence of phosphorus in the laboratory versus that in the South Saskatchewan River, indicating that there are other environmental factors that have an important role in regulating macrophyte growth in rivers. This complexity in natural ecosystems was observed by Barendregt and Bio (2003), highlighting the ability of macrophyte species to alter sediment chemistry through the oxygen in their roots. Another study in the Mackenzie Delta showed that macrophyte biomass increased with increasing nitrogen (Squires and Lesack, 2003). Waterweed (*Elodea canadensis*) was found to require high levels of nitrogen to maintain carbon metabolism (Madsen and Baattrup-Pedersen, 1995).

Algae did not show a similar discrepancy in limiting nutrients. Where temperature and light are not limiting, algae are clearly limited by nitrogen, more specifically ammonia (NH_4-N) (Dodds, 1991; Mosisch et al., 2001).

7.1.3.5 Alkalinity and pH

Lacoul and Freedman (2006) identified four major groups of aquatic plants according to their preference for conditions associated with alkalinity, pH and associated factors. These are:

- Softwater habitats (< 0.2 mequiv./L HCO_3^-; pH 6.0-7.5 (circumneutral) / pH <5.5 (acidic))
- Hardwater habitats (> 0.4 mequiv./L HCO_3^-; pH >7)
- Brownwater habitats (humic with high dissolved organic carbon, poor visibility, pH <5.5)
- Saline habitats (high sodium, chloride and extremely high alkalinity and pH).

Southern Alberta rivers, lakes and irrigation systems are all in the hardwater group. This group is characterized by high species richness with the following aquatic plants found in southern Alberta reaching their greatest abundance (Lacoul and Freedman, 2006). Plants mentioned in section 6.1 are in **bold**:

- **Coontail (*Ceratophyllum demersum*)**
- **Canada waterweed (*Elodea canadensis*)**
- **Eurasian watermilfoil (*Myriophyllum spicatum*)**
- **Curly-leaf pondweed (*Potamogeton crispus*)**
- **Fine-leaf pondweed (*Potamogeton filiformis*)**
- **Fries' pondweed (*Potamogeton friesii*)**
- **Sago pondweed (*Potamogeton pectinatus*)**
- **Giant pondweed (*Potamogeton vaginatus*)**
- Widgeon grass (*Ruppia martima*)
- **Common bladderwort (*Utricularia vulgaris*)**
- Horned pondweed (*Nanichellia palustris*)
- ***Hydrilla verticillata*.**

Although treatment for pH and alkalinity is not feasible in southern Alberta, knowing whether or not these are limiting for a target weed species may be useful in management.

7.1.3.6 Salinity

As with pH and alkalinity, there are species of aquatic plants and algae that are more or less tolerant of saline environments. Small duckweed (*Lemna minor*) is very salt tolerant (up to 167 mg/L) (Lacoul and Freedman, 2006), and will dominate in the more saline environments. Hydrilla (*Hydrilla verticillata*), Eurasian watermilfoil (*Myriophyllum spicatum*) and Sago pondweed (*Potamogeton pectinatus*) are much less tolerant. Partridge and Wilson (1987) published a comprehensive list of the salt tolerance of aquatic plants (Lacoul and Freedman, 2006).

7.1.3.7 Canal Characteristics

The size, shape, slope, construction materials and construction method of the canal can affect the growth of aquatic weeds and algae.

Blooms of filamentous algae in concrete canals are highly correlated to canal width, attributed to the resulting increased light availability (Ferreira et al., 1999). Additionally new trapezoidal channels have more light available to the bed and banks compared to a more rectangular shape characteristic of older canals (Ferreira et al. 1999).

Varying canal slope at a fixed bed width indirectly affects the establishment of rooted macrophytes by increasing velocity. Velocity is discussed in Section 7.1.2 on Hydrology.

Substrate is discussed in Section 7.1.3.3 (Substrate), and should be considered in canal design and construction. Sytsma and Parker (1999) indicate that canal lining type has an effect on aquatic plant growth. Rock size has been correlated to the growth of the filamentous algae *Cladophora glomerata* (Dodds, 1991) and attributed primarily to the reduced bed disturbance. This is consistent with observations of each of the irrigation district interviews with respect to the prevalence of filamentous algae in recently rehabilitated armoured canals described in Section 6.6 (Problems in Irrigation Canals), and the dominance in concrete-lined canals (Ferreira et al., 1999). The canals being replaced were earthen-lined canals that exhibited susceptibility to sediment deposition and scour. This not only results in sediment mobility, but will also contribute to turbidity and hence light penetration. Observations of variations in filamentous algal growth within the same reach of the recently rehabilitated Carseland-Bow River Headworks suggest that the method of placement of gravel armour may have an effect on growth potential (S. Munroe and D.J. Miller, Pers. Commun.). A further consideration in comparing substrate is the suitability for microbial habitat. The population of nitrosomonas and nitrobacter in the sediments of the mature earthen-lined canals may be competing with filamentous algae for dissolved nitrogen in the water. Rehabilitation with membrane-lined and armoured canal removes the microbial habitat for the first few years while the rock content dramatically reduces it in the long term unless it becomes silt-laden.

The other canal liner type being marketed in southern Alberta is the bituminous coal membrane. This liner is more common in Europe, a major manufacturer being Coletanche. No studies were found on the effectiveness of bituminous coal membrane liners in inhibiting aquatic weed and algae growth; however, Sytsma and Parker (1999) suggest a new bituminous geotextile material may provide a relatively inexpensive long-term solution to aquatic weed growth in canals. Eastern Irrigation District (EID) observed that they have no problems with aquatic plants in a reach of canal that cuts through an open coal seam. The chemical Xylene, found naturally in coal, is also used as a herbicide in the United States (section 8.1.1), and may be the active compound that inhibits growth. Westhoff (1985) mentions that an asphalt-lined canal in the Western Irrigation District is prone to colonization of a Volvox algae; however, it is unclear whether or not the difference in chemical and surface characteristics are contributing factors.

7.1.4 Biological Interactions

As introduced in section 7.1.3.1, irrigation systems are part of the larger ecosystem and as such are subject to biological interactions.

Grime (2001) established a three-category classification of life-history strategies of plants (Lacoul and Freedman, 2006):

- Ruderals – post-disturbance plants with rapid and prolific establishment
  - Examples: Mare's tail (*Hippuris vulgaris*); Smartweed (*Polygonium punctatum*)
- Stress-Tolerants – occur in low nutrient, acidic/alkaline or saline habitats with little disturbance and are long-lived and reproduce slowly
  - Examples: Northern watermilfoil (*Myriophyllum exalbescens Fern*.)
- Competitors – occur in fertile, infrequently disturbed habitats and have high productivity
  - Examples: Canada waterweed (*Elodea canadensis*); Hydrilla (*Hydrilla verticillata*); Eurasian watermilfoil (*Myriophyllum spicatum*); Curly-leaf pondweed (*Potamogetan crispus*); Broadleaf cattail (*Typha latifolia*).

The ruderals are colonizers and can be problematic weeds in regularly disturbed areas such as reservoirs or canals with frequent changes in water level or discharge. The competitors are the most problematic weedy species and can take over in areas with a continuous supply of nutrients where stress conditions (high/low pH, saline, etc.) are not limiting.

The two primary biological interactions affecting the establishment of aquatic weeds and algae are competition and herbivory.

7.1.4.1 Competition

Competition involves both the interference between individuals of the same species (intraspecific) as well as interference between different species (interspecific) in obtaining limited resources. The basic idea is that aquatic plants and algae will continue to establish and grow at their full productivity until one or more resources (light, nutrients, space, etc.), becomes limiting (Allan et al., 1989; Lacoul and Freedman, 2006). Once this happens, they compete for what is left and the more competitive will increase in abundance relative to those that are less-capable.

Competition has a relatively low importance (<5%) in the structure of natural wetland communities in equilibrium conditions (Lacoul and Freedman, 2006). In this case, hydrology accounts for about 50% of the structure, while other environmental factors are involved in the remainder. Interspecific competition does not typically eliminate the less capable species, but rather relegates them to marginal habitat such as deeper water. This tends to increase species diversity and limit the dominance of a particular species.

The presence of highly competitive or invasive alien species will upset this balance and increase the relative importance of competition. This may diminish or exclude native species from habitats (Lacoul and Freedman, 2006). The mechanism for the success of alien invasive species lies in the relative freedom from their native controlling diseases and herbivores.

Competition for light may have an influence on the relative abundance of the filamentous algae *Cladophora glomerata* compared to epiphyte diatoms (Dodds, 1991).

7.1.4.2 Herbivory

Herbivory refers to grazing of aquatic plants by fish, waterfowl and others and affects the overall productivity of a waterbody as well as relative abundance of individual plant species. Herbivory can act as a natural form of harvesting (Allan et al., 1989) and, as discussed in 8.2.5, harvesting can remove nutrients from the system.

Ducks, geese and swans are voracious consumers of aquatic plants, especially in shallow, productive ponds. In Delta Marsh in Manitoba, waterfowl were found to consume as much as 40% of the standing crop of Sago pondweed (*Potamogeton pectinatus*) (Lacoul and Freedman, 2006).

Other natural predators of aquatic plants are required to help keep growth in check. As discussed in section 6.1.1, herbivorous weevils that help keep native Canada watermilfoil (*Myriophyllum exalbescens Fern*.) populations stable are also consuming Eurasian watermilfoil (*Myriophyllum spicatum*) in many areas of the United States.

7.1.5 Anthropogenic (Human) Influence

The influence of people is most dramatically shown in the translocation of alien invasive species into Alberta waters through dumping of aquarium species, bilge and bait water. About 6-10% of those species establish themselves and become abundant enough to be considered seriously invasive (Lacoul and Freedman, 2006).

In irrigation systems, the two primary human influences are disturbance and nutrient pollution. Disturbance occurs as part of regular and seasonal operations, including drawdown and filling, flushing, burning of debris, maintenance and rehabilitation. These activities stir up sediments and nutrients, remove beneficial microbes, disturb habitat of herbivorous organisms and prevent the establishment of competing less problematic aquatic plants and algae. Nutrient pollution occurs due to point and non-point sources of livestock manure, artificial fertilizers and natural deposits as discussed in section 6.9.1.

7.2 Effects of Vegetation on Canal Performance

Aquatic weeds can affect the backwater depth in canals. The actual change in water depth depends on various characteristics of the weeds themselves and also the canal settings. Westhoff and Manz published studies that investigated the sensitivity of seven weed and infrastructure variables on canal performance (Westhoff, 1985; Manz and Westhoff, 1986a; Manz and Westhoff, 1986b). The findings for a rectangular channel conclude:

1. Density
    a. Increasing Manning's n with increasing density
    b. Increasing water level with increasing density
    c. 300 plants per square metre (max density) results in 135% increase in depth
2. Length
    a. Increasing Manning's n & water depth with increasing length < 0.3 m

   b. Decreasing Manning's n & water depth with increasing length > 0.3 m

3. Modulus of Elasticity (rigidity)
   a. Increasing Manning's n & water depth with increasing E
   b. Manning's n is 43% greater during day than at night in weedy canal due to photosynthesis

4. Diameter
   a. Increasing Manning's n with increasing diameter
   b. Maximum Manning's n reached at 5.0 mm stem diameter
   c. 5.0 mm stem diameter results in 80% increase in depth

5. Weir Height (weir at downstream end of 1000 m test reach)
   a. Upstream Manning's n is unaffected due to length of canal
   b. The midpoint affected Manning's n only when weir was set > 0.3 m
   c. The end of the reach near the weir increased Manning's n
      i. Immediately, but gradual
      ii. Rapidly between 0.3 – 0.4 m weir height
      iii. Gradual > 0.4 m weir height

6. Discharge
   a. Increasing Manning's n with increasing discharge

7. Trailing Coefficient [leaf drag]
   a. Increasing trailing coefficient has no effect below a critical value (length specific)
   b. Increasing trailing coefficient increases deflected height above critical value.

Further experiments by Westhoff and Manz compared the effect on Manning's n and backwater elevation of a clean canal with canals having only bank vegetation and having total vegetation (Westhoff, 1985; Manz and Westhoff, 1986a; Manz and Westhoff, 1986b). These tests were on a small trapezoidal channel (0.5 m bottom width and 3:1 side slopes) upstream of a weir. Manning's n increased 100% for ditch bank vegetation and 170% for a totally vegetated cross-section. The increases in water depth were 30% and 50%, respectively.

8.0 Assessment of Available Prevention and Control Strategies

This section provides a comprehensive listing, description and assessment of strategies for the prevention and control of aquatic weeds and algae in irrigation systems. The areas of chemical, physical/mechanical, biological and operational control are addressed.

8.1 Chemical Control

8.1.1 General

Chemical control of nuisance plants has been documented through ancient history with written accounts of chemicals used for the control of insects and plant diseases as early as 1000 B.C.(Timmons, 2005). The discovery of the phytotoxic properties of the phenoxyacetic acids occurring c.a. 1943 marked the beginning of the renaissance of chemical herbicides, and the number of herbicides available increased to approximately 25 by 1950. Advances in organic chemistry occurring in the 1950s and 1960s resulted in tremendous advances in herbicides, and the number of herbicides registered or being tested for use had increased to approximately 120 by 1969 (Timmons, 2005).

In addition to an increased variety of herbicides being used and tested after 1950, was a significant increase in the volume of herbicides being used (Timmons, 2005). Between 1963 and 1968, the use of herbicides in Alberta, Saskatchewan, and Manitoba increased by more than eleven fold (Timmons, 2005). The most current usage statistics available for the Province of Alberta (Alberta Environment, 2001) indicates that total agricultural herbicide sales were 6.86 x10^6 kg of active ingredient in 1998.

Advances in organic chemistry have resulted in the development of selective herbicides, which have lower toxicity to non-target organisms, and are less persistent in the environment. This expansion has resulted in a wide variety of products available to the agricultural sector. At present, there are 210 products registered for use in Alberta. The large number of herbicides available to the agricultural sector does not, however, extend to water managers. The intrinsic connectivity of water bodies dictates that selection and registration of herbicides for use in surface waters be carefully controlled.

Worldwide there are a number of herbicides registered for aquatic use. These include but are not limited to:

- Diquat dibromide
- Endothall
- Glyphosate
- 2, 4-D
- Fluridone
- Triclopyr
- Imazapyr

- Acrolein
- Xylene
- Copper and Chelated Copper Compounds.

All of these are registered for aquatic use in the United States, with various conditions assigned to each herbicide. Currently there is a single product, Magnacide®-H, an acrolein based aquatic herbicide, registered for aquatic use in flowing waters in Alberta (Agriteam Canada Consulting, 1996). Acrolein provides effective control of submersed plants and algae, but does not control emergent plants. Irrigation districts in Alberta have been using glyphosate and 2,4-D for control of emergent species during periods of drawdown.

Chemical control of aquatic macrophytes and algae has been shown to be a cost effective treatment with a high degree of efficacy (Allan et al., 1989). The efficacy of different herbicides and selection of products for use will be largely driven by the plant species to be controlled. Different herbicides have different modes of action and sensitivities to different genera of plants. In addition, some species within genera may exhibit different sensitivity to herbicides. Therefore, to have a successful chemical control program it is critical that nuisance plants be identified correctly.

One of the significant drawbacks to chemical control is the sudden death and decomposition of organic matter. The sudden increase in organic matter and subsequent decomposition often results in anoxic conditions due to oxygen drawdown associated with aerobic decomposition. This creates a toxic condition for fish and other aquatic organisms, which can result in fish kills. This is a critical concern in slow moving quiescent water bodies. In these cases it is critical to treat only small portions of the water body at a time in order to reduce the potential for large scale anoxic conditions. An additional drawback to in situ death of organic material is the release of nutrients from plant decomposition into already fertile waters. This nutrient input encourages the colonization of the waterway once the effects of herbicide treatments have dissipated. As well, dependence on chemical controls may be more costly in the long run than other modes of control and in some instances can exacerbate the problem of excess plant growth (Saskatchewan Environment, 2006). Use of non selective herbicides can eliminate native vegetation, reducing the competitive interaction with invasive nuisance plants.

Efficacy of different herbicides to aquatic plants is presented in Table 8.1. A brief description of those which are more popular or relevant to Alberta follows.

Table 8.1: Efficacy of Different Herbicides to a Variety of Aquatic plant Species (Langeland et al., 2006).

	Endothall		Diquat	2,4-D		Copper	Fluridone	Glyphosate	Imazapyr	Triclopyr
	Aquathol	Hydrothol		Granular	Liquid					
FLOATING										
Duckweed	*	*	G	*	F	*	E	*	*	*
Watermeal	*	*	*	*	*	*	F	*	*	*
Water fern	*	*	E	*	*	*	G	*	*	*
Mosquito fern	*	*	E	*	*	*	G	*	*	*
Water hyacinth	*	*	E	*	E	F	*	G	E	G
Water lettuce	*	*	E	*	*	F	*	F	E	*
Frog's bit	*	*	E	*	*	*	*	*	E	F
Alligatorweed	*	*	*	*	F	*	F	G	E	G
SUBMERSED										
Bladderwort	F	F	G	F	*	*	G	*	*	*
Brazilianelodea	*	*	E	*	*	F	G	*	*	*
Coontail	E	E	E	G	*	*	E	*	*	G
Hydrilla	E	E	E	*	*	F	E	*	*	*
Parrotsfeather	E	E	G	F	*	*	F	*	*	G
Pondweed	E	E	G	*	*	*	F[1]	*	*	*
Slender naiad	E	E	E	*	*	*	E	*	*	*
Southern naiad	G	G	E	*	*	*	G	*	*	*
Proliferating spikerush	*	*	*	*	*	*	F	*	*	*
Variable leaf milfoil	G	G	G	E	*	*	G	*	*	G
EMERSED										
American lotus	*	*	*	G	*	*	G	G	G	E
Cattail	*	*	G	*	*	*	F	E	E	*
Fragrantwaterlily	*	*	*	E	*	*	G	E	E	G
Soft rush	*	*	*	F	F	*	*	G	E	*
Spadderdock	*	*	*	E	F	*	G	E	E	F
Water pennywort	*	*	F	G	G	*	*	E	E	G
Torpedograss[2]	*	*	*	*	*	*	G	E	E	*
ALGAE										
Macrophytic	*	F	F	*	*	F	*	*	*	*
Filamentous	*	G	G	*	*	G	*	*	*	*
Planktonic	*	*	*	*	*	G	*	*		*

* = Not recommended; F = Fair; G = Good; E = Excellent

[1] Certain species such as Potamogeton *illinoensis* are relatively tolerant to fluridone while others such as *P. nodosus* are sensitive.

[2] Re-growth occurs from underground plant parts and repeat applications are necessary.

8.1.2 Acrolein

Acrolein, the active ingredient in Magnacide-H, is a highly effective contact herbicide used for the control of submersed weeds and algae in Canada, the United States, Australia, Argentina, and Egypt (Bowmer and Smith, 1984; Lancar and Krake, 2002). Acrolein is a highly reactive, volatile chemical which requires specialized equipment and training to use safely and effectively. Acrolein is a contact biocide that acts by interrupting vital enzyme reactions on contact with plant tissues. Tissues that are exposed to a toxic dose begin to disintegrate, and are destroyed within a period of days. This disintegration of tissues is an advantage compared to other herbicide treatments, as it limits the mass of dead vegetation available to be trapped within water management structures.

Acrolein is an effective method for control of submerged weeds, floating plants and algae, and has been shown to provide control of a variety of species (Lancar and Krake, 2002; Baker Petrolite Corporation, 2005). Refer to Table 8.2 for a listing of susceptible aquatic weeds and algae. Emergent plant species such as cattails are not affected (Baker Petrolite Corporation, 2005). Submerged species who also have floating leaves, such as *Potamogeton crispus* and *Potamogeton illinoiensis* are more difficult to control using Acrolein; however, these species have shown to be susceptible if treated while immature.

Table 8.2: Species shown to be susceptible to Magnacide-H.

Algae	
Anabaena flos-aquae	(blue-green algae)
Chara sp.	(stoneworts)
Cladophora sp.	(green algae)
Cladophora glomerata	(green algae)
Hydrodictyon reticulatum	
Navicilla pelliculosa	(freshwater diatom)
Selenastrum capricornutum	(green algae)
Skeletonema costatum	(marine diatom)
Spirogyra sp.	(green algae)
Submersed Aquatic Plants	
Callitriche sp.	(water starwort)
Ceratophyllum demersum	(coontail)
Elodea canadensis	(waterweed)
Heteranthera dubia	(waterstargrass)
Lemna gibba	(duckweed)
Potamogeton crispus	(curlyleaf pondweed)
Potamogeton foliosus	(leafy pondweed)
Potamogeton illinoiensis	(pondweed)
Potamogeton nodosus	(American pondweed)
Potamogeton obtusifolius	(pondweed)
Potamogeton pectinatus	(sago pondweed)
Potamogeton richardsonni	(richardson pondweed)
Najas sp.	(naiad)
Zannichellia palustris	(horned pondweed)

The advantages of acrolein are that it is effective when applied by injection during a relatively short time frame, and that it dissipates quickly from water leaving no phytotoxic residues (Bowmer and Sainty, 1977;

Bowmer and Higgins, 1976). The dissipation of acrolein is controlled by a variety of processes, including but not limited to degradation, volatilization, adsorption, and dilution (Nordone et al., 1996). Nordone et al. (1996) observed that the dissipation half-life of acrolein was 10.2 hours in a Washington State weedy canal. This experiment was conducted at a nominal water temperature of 12 °C, a water temperature lower than recommended for effective use of the herbicide. Other studies have observed shorter half-lives when acrolein is injected into warmer natural waters, with a rate constant of 0.163 per hour, and a calculated half-life of 4.25 hours (Bowmer and Sainty, 1977).

An important goal in managing aquatic nuisance plants is to limit the potential for propagation after control methods are implemented. Acrolein has been shown to have an indirect effect on the reproductive potential of some aquatic plants by reducing photosynthetic potential, thus reducing the carbohydrate to reach underground structures (Bentivegna et al., 2004). It has been observed that the season after acrolein application there will be a reduction in new plants derived from seed germination and shoot growth from remaining tubers and rhizomes. After three years of repeated treatment, rhizome fresh weight was decreased by 92%, and seed numbers were decreased by 79% (Bentivegna et al., 2004). Once equilibrium conditions were reached, operating conditions could be maintained with fewer treatments at lower concentrations, thus reducing the operating costs of the control program; however, interruption of chemical control will result in weed infestation similar to original situation (Bentivegna et al., 2004).

Timing of acrolein application is an important factor to its efficacy, and varies based on environment and the plant species being controlled. Acrolein has been shown to be most effective when applied early in the growing season before weeds become too dense. Studies in irrigation canals found that 100% of weeds were killed in an irrigation canal with uniform velocity, while this number was decreased to 60% when 30% of the water cross section was still (Lancar and Krake, 2002). A study of the factors affecting acrolein efficacy identified acrolein dosage, plant height, and water flow velocity as the principal components, accounting for 80% of the reduction in submerged plant biomass (Bentivegna and Fernandez, 2005). Early application has also shown to provide control using the least amount of product (Bentivegna et al., 2004).

Temperature is also a critical factor to the efficacy of acrolein application. Studies have shown that control at temperatures of 15 °C and above require 50% less product than if applied at water temperatures below 15 °C (Lancar and Krake, 2002).

While there are some distinct advantages to the use of acrolein as an aquatic herbicide, there are some drawbacks. Acrolein has been shown to be lethal to fish, and other organisms (PMRA, 2005). As a result, it is imperative to manage water resources such that treated water is not permitted to return to the natural aquatic environment.

8.1.3 Copper Sulfate and Chelated Copper

Copper sulfate as an algaecide has been used extensively on a global scale since 1904 (Lancar and Krake, 2002) and is one of the cheapest algaecides available, a factor which undoubtedly contributes to its extensive use. Copper sulfate provides effective control against sensitive algal species (Extoxnet, 2007), and has been used as an algaecide in lakes and reservoirs (McKnight et al., 1983). Copper sulfate is classified as a general use pesticide by the US Environmental Protection Agency, and is classified as toxicity class 1 – highly toxic (Extoxnet, 2007).

The use of copper sulfate is largely limited by geochemical parameters of the water treated (Lancar and Krake, 2002; McKnight et al., 1983) with pH and alkalinity being the major drivers. In waters with below neutral pH, the toxic free copper ion is the major species; however, in waters neutral or above copper complexes, and precipitates such as malachite are predicted to be the major species (McKnight et al., 1983). Highly alkaline waters, $CaCO_3$ >100 mg/L, copper is precipitated in insoluble forms, becoming inactive. This provides some explanation for the need for higher doses in waters with high pH and alkalinity.

Turbidity, and the concentration of suspended particulate material, particularly reactive materials such as clay, will significantly affect the geochemistry of copper sulfate and the relative concentration of biologically available copper ions. In turbid waters, particularly those with neutral or alkaline pH, copper can be readily adsorbed to particles in the water column rendering them unavailable for the control of aquatic plants. The result is an increased dosage requirement in order to occupy binding sites and overcome loss of toxicity due to adsorption (McKnight et al., 1983).

As previously mentioned, copper sulfate is a toxicity class 1 chemical, and is highly toxic to fish and aquatic invertebrates (Extoxnet, 2007). Copper sulfate can be toxic to sensitive fish species even at recommended application rates, particularly in soft or acidic waters where the free cooper ion is the major species. The toxicity of copper to fish is temperature dependent, becoming more toxic with increased temperature. This is an unfortunate coincidence as nuisance aquatic plant growth occurs under conditions of increased water temperature.

Chelated copper compounds, such as PolyPro® (PMRA, 2004) and K-tea, have been developed to overcome some of the geochemical barriers to the use of copper sulfate. Chelated copper compounds can be used in water of greater hardness without precipitation and deactivation. These compounds are also less toxic to aquatic organisms, while still maintaining relatively high efficacy as an algaecide. Another advantage of chelated copper is that it's greater solubility allows for use at lower concentrations than copper sulfate.

Copper sulfate and chelated copper compounds have been the algaecide of choice in many jurisdictions for a number of years, due in part to their efficacy and largely to their low cost. Regardless, there are some disadvantages to their use.

Copper is an element, and as such has no potential for degradation or breakdown. Treatment with copper sulfate for extended periods can result in sediments with concentrations of copper that are toxic to aquatic and sediment dwelling organisms. Additionally, some organisms have shown developed resistance to copper sulfate treatment after long periods of use. A 26 year study of blue-green algae in copper sulfate treated lakes in Minnesota found increasing resistance to the algaecide, resulting in increased dosage rates (Extoxnet, 2007).

8.1.4 Glyphosate

Glyphosate is the most common selective broad leaved herbicide used throughout the world, and is marketed under the trade names Gallup, Landmaster, Pondmaster, Ranger, Roundup, Rodeo, Touchdown, and Vantage. It is an organophosphate, broad spectrum, non-selective, systemic herbicide used for the control of annual and perennial plants including grasses, sedges, broad leaved weeds, and woody plants (Extoxnet, 2007).

Because glyphosate is taken up by the leaves and transported to the entire plant, including below ground structures, it is important to time application to maximize potential for transport of the herbicide. Annual plants are easily controlled with glyphosate, because they germinate from seeds rather than underground reproductive organs (Lancar and Krake, 2002). Glyphosate can be applied to annual plants anytime after emergence.

Perennial plants tend to be hardier and effective control requires the destruction of underground reproductive structures. Destruction of above ground structures does not eradicate the plant as surviving reproductive structures send up new growth. For best control of perennial plants, glyphosate should be applied when food conveyance to underground parts is at its maximum; after the growth stage has finished and fruiting or flowering bodies appear (Extoxnet, 2007; Lancar and Krake, 2002).

Glyphosate efficacy has been shown in some cases to be increased by combining herbicide application with vegetation cutting (Renz and DiTomaso, 2006). This is particularly true for some perennial plants where treatment with glyphosate only has poor results. An example of this is perennial pepperweed. Studies of glyphosate effects on pepperweed observed an increase in biomass relative to controls at not mowed plots treated with 1.7 and 3.3 kg/ha glyphosate (Renz and DiTomaso, 2006). Mowing combined with glyphosate application at a floodplain site reduced pepperweed biomass by 81%.

Symptoms of glyphosate application generally occur after 2-3 days, and complete kill typically occurs within 2-3 weeks. Plants treated with glyphosate should not be disturbed for 7-10 days after herbicide application, and a rain-free period of 2 hours after application is required to ensure effectiveness (Round-Up Technical Label). Glyphosate has no soil activity and will not leach or run off to affect nearby plants or crops. Plant foliage has to be treated directly for phytotoxicity to occur. In an aquatic setting, submerged foliage will not be affected by glyphosate addition to the waterbody (Sytsma and Parker, 1999; Lancar and Krake).

Glyphosate has a half-life in water of 12 days to 10 weeks; however, it is strongly adsorbed to suspended organic material and is primarily broken down by microorganisms. One advantage of glyphosate is that it is practically non-toxic to fish, and only slightly toxic to aquatic organisms. The reported 96-hour LC50, the concentration that causes 50% mortality in test organisms after a 96 hour exposure, is 120 mg/L in bluegill sunfish, and 86 mg/L in rainbow trout. The 48 hour LC50 in Daphnia is 780 mg/L.

There is no restriction to water use after treatment of emergent aquatic plants with glyphosate (Sytsma and Parker, 1999)

8.1.5 Vanquish - Dicamba

Vanquish is a Dicamba based broad spectrum herbicide. It can be applied to leaves or soil for the control of annual and perennial broad leaved weeds and legumes. Dicamba is effectively non-toxic to birds, and has low toxicity to fish and other aquatic organisms. The 96 hour LC50 for Dicamba in rainbow trout is 135 mg/L, and the 48 hour LC50 for Daphnia is 110 mg/L.

A significant drawback to the use of Dicamba is that it does not bind to soil particles, and is highly soluble in water. The potential for leaching and groundwater contamination is high, and increases with precipitation and herbicide application rate (Extoxnet, 2007). The half-life of Dicamba has been observed to vary from 4 to 555 days, making it difficult to assess its safety for use in temporarily drained irrigation canals. A review of field and laboratory data indicates that in the Canadian perspective the half-life of Dicamba in soils should be <12 weeks, and moist high temperature conditions favouring microbial activity should reduce this time to < 4 weeks (Caux et al., 1993). The half-life of Dicamba in surface waters is ~ 7 days, although residues have been found in surface water supplies in Alberta up to six months after application (Caux et al., 1993).

8.1.6 Diquat

Diquat is a non selective broad spectrum contact herbicide that has been shown to provide effective control of submerged aquatic weeds and algae. Diquat should be applied in concentrations ranging from 0.5 – 1.0 mg/L before weed growth reaches the water surface (Lancar and Krake, 2002). Diquat is moderately to practically non-toxic to fish and aquatic invertebrates (Extoxnet, 2007). The 8 hour LC50 is 12.3 mg/L in rainbow trout. The 96-hour LC50 is 16 mg/L in northern pike, 20.4 mg/L in fingerling trout, and 170 mg/L in black bullhead. Laboratory toxicity studies have translated to field studies where concentrations slightly above recommended use levels did not adversely affect fish (Emmett, 2002).

The half-life of Diquat is very short when applied to open water, less than 48 hours in the water column but may persist, bound to sediments on the order of 160 days. This is due to its high affinity for suspended sediments. Diquat is very soluble in water, and if not for its binding efficiency with particulate materials would likely leach through soils. Fortunately Diquat has been shown not to move through soils, remaining within the top inch of soils for long periods during field and laboratory experiments (Extoxnet, 2007).

Diquat should be applied at concentrations ranging from 0.5-1.0 mg/L prior to weed growth reaching the surface (Lancar and Krake, 2002). Diquat efficacy is highly dependent on water clarity, as it will readily adsorb to charged particles in the water column (Lancar and Krake, 2002). A mixture of diquat and chelated copper has shown effective control of *Hydrilla verticallata* (Lancar and Krake, 2002).

Water treated with Diquat should not be used for animal consumption, spraying, irrigation, or domestic purposes for 14 days after treatment (Sytsma and Parker, 1999).

Diquat is not currently registered for aquatic use in Canada; however, it is registered for aquatic use in the United States, and New Zealand. Diquat has been successfully used to control nuisance aquatic plants in New Zealand since the 1960s (Hofstra and Clayton, 2001).

8.1.7 2,4-D

2,4-D is the oldest aquatic herbicide registered for use in the United States. It is a translocated herbicide that can provide effective control of floating submerged and emergent broadleaved plants. Successful control of floating and emergent broadleaved weeds have been reported from the U.S., Europe, Africa, Asia, and Australia (Lancar and Krake, 2002). There are currently more than 30 2,4-D formulations registered for aquatic weed control in the United States (Compliance Services International, 2001a); however, the amine salts and butoxyethyl ester formulations are the most widely used (Sytsma and Parker, 1999). Plant roots absorb the amine salt formulations most readily, while foliar uptake is promoted by ester application (Lancar and Krake, 2002).

2,4-D provides excellent control of milfoil (*Myriophyllum spp.*), and good control of cattail (*Typha spp.*), spadderdock (*Nuphar spp.*), and fragrant water lilies (*Nymphaea spp.*) (Compliance Services International, 2001a; Sytsma and Parker, 1999).

The ester formulation is considerably more toxic to fish species (LC50 = 0.3 - 5.6 mg/L) than the acid formulation. This is deceiving, however, as the acid formulation is considered to be more representative of the functional toxicity, owing largely to the rapid hydrolization of the ester to the acid formulation. The acid formulation is less toxic to fish species (LC50 = 2.5 - 358 mg/L) (Compliance Services International, 2001a).

A risk assessment of 2,4-D use conducted by the Washington State Department of Ecology (Compliance Services International, 2001a) has indicated that the levels of concern for protection of free swimming biota are not exceeded, and that it should be possible to use 2,4-D ester according to the label without significant acute or chronic risk to aquatic animals. Benthic organisms are exposed to higher concentrations of 2,4-D than fish and other free swimming organisms. There is a potential risk to benthic organisms; however, field studies indicate that benthic organisms are not greatly affected by concentrations of 2,4-D typical of sediments (Compliance Services International, 2001a).

The half life of 2,4-D in the aquatic environment ranges from 0.02 to 26 days; however, it persists longer in sediments (Sytsma and Parker, 1999). Water should not be used for irrigation, animal consumption, or domestic purposes for three weeks after treatment (Sytsma and Parker, 1999).

8.1.8 Endothall

There are two different salts of endothall, a dipotassium salt and a mono alkylamine salt, marketed as Aquathol® and Hydrothol®, respectively. These are used as contact herbicides, and are registered for aquatic use in the United States. The two endothall salts have different phytotoxic properties, with Hydrothol® providing effective control against submersed plant species and algae. Aquathol® provides effective control of submersed plants, but is ineffective for algae control.

These two compounds in addition to having different phytotoxic properties also have different toxicities to aquatic organisms. The dipotassium salt of endothall has been shown to be relatively non toxic, and is safe to fish at concentrations from 100 – 500 mg/L (Extoxnet, 2007). Aquathol®, a dipotassium endothall salt has been shown to be suitable for use in sensitive environments with minimal non target effects (Reinert et al., 1988). Amine salts of endothall, such as Hydrothol®, have been shown to be toxic to fish species. The LC50 of Hydrothol® ranges from 0.34 mg/L for cutthroat trout to 1.7 mg/L for bluegill sunfish (Compliance Services International, 2001b).

Endothall has been shown to provide effective control against pondweed species (*Potamogeton* sp.), Milfoil and Eurasian watermilfoil, parrotsfeather, and hydrilla. Additionally, Hydrothol has been shown to provide effective control of American waterweed, and the algal species *Cladopahora spp.*, *Pithophora spp.*, *Spirogyra spp*., and *Chara spp*.

Water holding times for endothall use range from 7 days for dipotassium salt formulations (Aquathol®) to 7-25 days for alkylamine formulations (Hydrothol®).

Endothall is not registered for aquatic use in Canada.

8.2 Physical / Mechanical Control

Physical/mechanical techniques for the prevention of or removal of aquatic weeds and algae have been used by irrigation districts long before chemical alternatives became available. The selection of the best prevention, removal or exclusion method depends upon the size of canal/reservoir, proximity to the bank, bed materials, canal construction, and the physical and reproductive characteristics species being removed.

8.2.1 Hand-pulling/cutting

Hand-pulling or cutting, although effective for some aquatic weeds in small canals and nearshore areas (Sytsma and Parker, 1999) is likely only suitable for small areas around critical structures due to the manual labour cost (Sytsma and Parker, 1999).

In Oregon, tests within the Talent Irrigation District showed that high costs ($1100/mile/day), moderate removal efficiency (82%), excessive sediment suspension and significant increased plant fragments in the downstream canal, as well as limitations of access due to channel width, depth and velocity made hand-pulling inefficient for large-scale application (Sytsma and Parker, 1999).

Hand-pulling, including use of hand-operated cutting equipment, remains a good option around intakes and control and measurement structures where other methods cannot be used.

8.2.2 Cutting with Powered Equipment

Use of a cutting accessory such as a sickle attached to powered equipment (loader, hoe or tractor) is effective in removing cattails where they become too large or dense to treat with glyphosate. Larger units can be used to cut cattails near the canal bank at a rate of ½ mile (800 m) per hour (Tamminga, Pers. Commun.). The selection of glyphosate or cutting as a control method for cattails is determined by timing. As both glyphosate treatment and cutting require low water levels, high irrigation demand during high cattail growth periods may result in access not becoming available until only the cutting alternative remains. Stem rigidity and the sharpness/cutting effectiveness of the attachment are limits on the use of this method for other emergent weeds such as Reed Canary Grass. Pre-season bank excavation, early glyphosate treatment or traditional mowing may be more effective for these.

8.2.3 Chaining

Chaining involves attaching a heavy chain between two tractors or other heavy equipment and dragging it along the bottom of the canal and requires access to a driving bank on both sides. The chain pulls on the stems and leaves of submerged macrophytes and dislodges them from the bed. Addition of weights and/or scrapers to the chain may improve the removal efficiency; however, their use must be weighed against potential sediment disturbance and damage to the canal bed. Collection and removal of dislodged plant material downstream of the chained canal is required. The effectiveness of this technique and the required frequency of repeat treatment depend on the tolerance of the target species to disturbance and the efficiency of removal or destruction of reproductive plant fragments (Sytsma and Parker, 1999).

Chaining remains a viable alternative for control in large canals where Magnacide® H treatment is not cost effective or cannot be used for environmental reasons.

8.2.4 Excavation

Excavation involves physical removal of submerged and emergent aquatic weeds with a hoe, dragline or other similar equipment. Employed during the irrigation season, this method can damage the canal bed/liner and produces abundant plant fragments and high turbidity (Sytsma and Parker, 1999). In a test within the Talent Irrigation District in Oregon, the high turbidity in turn made it difficult for the operator to see, affecting removal efficiency (Sytsma and Parker, 1999). Regeneration was rapid (2 weeks) and resulted in greater biomass than before.

Pre-season excavation of earthen canal banks and scraping/dredging of canal beds can restore the original cross-section by removing sediment trapped by emergent vegetation and submergent weeds respectively. This will reduce the nutrient base for rooted vegetation and may set back the progressive choking of canals and restore freeboard.

8.2.5 Mechanical Harvesting

Mechanical harvesters typically use an adjustable cutter bar or rotating cable for dislodging aquatic weeds and a basket or conveyor and container for storing the cut plants (Sytsma and Parker, 1999). Variations include floating weed/debris collectors and cutters (no collection and storage). The equipment can be operated from a bank or mounted on a barge for reservoir coverage or running along rivers or long canals. This equipment is expensive and is typically used in ponds and lakes where there are navigation or aesthetic visual and odour concerns and a sufficient tax base to support the capital and operating cost. This equipment is also used in irrigation systems where restrictions in chemical use and extensive weed growth leave no other alternative. Allan observed that re-growth starts immediately after cutting and develops a bushier structure with more vegetative reproduction capability (Allan et. al., 1989).

Interception posts and removal of debris with a hoe is effective in eliminating large, intact weed masses such as cattail islands or floating algal mats before they can clog trash racks or screen systems.

The benefits of harvesting are that it is a non-toxic method of removing large volumes of plant material and their removal helps prevent downstream problems. Harvesting removes the physical biomass as well as the associated nutrients fixed in the plant material, interrupting the nutrient cycle. There is also a benefit to the aquatic ecosystem where harvesting occurs upstream of a reservoir by reducing the contribution of decaying plant matter. As organic matter decomposes, it depletes oxygen from the water column and adversely affecting fish (Allan et. al., 1989).

An alternative harvesting technique for floating debris and plants familiar to southern Alberta districts involves use of sweep-up-the-bank and traveling screens systems. Although early systems were prone to mechanical failure, inefficient brushing or under-sizing, the industry is working toward more effective designs. These systems are not typically designed for harvesting and are normally oriented in the canal to minimize collection of plant material. Where the pipeline inlet draws a significant proportion of flow or exhibits a significant velocity perpendicular to canal flow, collection of material can be substantial. Installation of large traveling screens with conveyor discharge has been used for removal of water hyacinth in tropical and subtropical areas with some success (International Water Screens, 2007).

8.2.6 Screening

Screening of aquatic weeds and algae is required to prevent free-floating or dislodged plants from becoming clogged in pumping and field irrigation systems. There is very little peer-reviewed research that compares the effectiveness of screening systems. Most of the information in this section was obtained from irrigation district interviews and discussions with suppliers.

There are three basic philosophies that irrigation districts can use for screening aquatic weeds and algae. These are:

1. No district screening – large trash only
2. Screen and remove
3. Screen and pass downstream.

8.2.6.1 No District Screening

The no screening approach is used in at least one southern Alberta irrigation district, where irrigators are responsible for screening their irrigation water prior to use. This requires good control of weeds and algae in irrigation canals to minimize complaints from irrigators. The irrigators themselves must make use of available on-farm screening systems. These include:

- Upstream of pumps (with or without backwash nozzles)
  - Static drum
  - Rotating drum
  - Single screen
  - Twin screen

- Downstream of pumps
  - Pressure filter.

Rotating drums with static backwash nozzles or static drums with a rotating backwash arm nozzles use the pump discharge pressure to spray against the screen material. Screens with high pressure backwash features are generally more effective than passive screen systems as they are continually cleaned. Lakos is a popular manufacturer of a rotating drum screener. The Riverscreen product includes a floatation device, can be placed directly in a canal or dugout and appears to be quite effective in maintaining a clean screen surface (http://www.riverscreen.com/). Various irrigation suppliers have their preferred products – a detailed product-by-product assessment was not considered within the scope of this report.

Riverscreen Screener

Upstream screen systems work best when the irrigator has access to and is permitted to install their screen on the irrigation canal as the flowing water will send backwashed debris downstream. When pumping from dugouts, more maintenance is required and so typically a coarser screen is used so that smaller debris will pass through the pumping system and be filtered on the downstream side with a pressure filter. A pressure filter passes the source flow through the center of a screened cylinder. The screened water collects in the outer cylinder and is then discharged to the pipeline. As the screened inner cylinder fills up with debris, a pressure differential develops between the inlet and outlet. The irrigator observes the downstream gauge and when the pressure drops below a certain level, the pumps are stopped and the inner screen is backwashed, brushed or removed and cleaned with a pressure washer, depending on the severity of the blockage.

Pressure Filters

Depending on the mesh size of the pressure filter, or whether or not the irrigator chooses to use a pressure filter, debris that enters the pipeline can become clogged in the sprinkler head. The problems associated with clogging of low pressure drop sprinklers are discussed in Section 6.8 (Problems in On-Farm Systems). The solution is to either use a pressure filter or, if only small amounts of debris is catching on the cross-hair of the nozzle, install flow-through sprinkler heads (W. Hacker, Pers. Commun.).

8.2.6.2 Screen and Remove Debris

District screening that removes debris at laterals typically involves using an automated sweep-up-the-bank style screener with a static perforated steel plate on a steel frame, all mounted in a concrete inlet structure (See photos of Sweep-up-the-Bank Screeners).

Sweep-up-the-Bank Screeners

The brushes are mounted parallel to the bank and chain-driven. Operation is typically on a timer, but can be overridden by the ditchrider when accumulations of debris due to upstream mowing or other weed removal is occurring. Smaller systems can be remote-mounted using a solar panel to trickle charge the battery. Sweep-up-the-bank systems have a history of problems, particularly with adhesion of weeds on the plate, and have been discontinued in at least two districts in southern Alberta.

Travelling screens are quite effective in removing debris as the entire screen pulls the debris out of the water (See Photos of Travelling Screen Systems). Cleaning the screen is accomplished with high pressure backwash nozzles mounted on the bank.

Travelling Screen Systems

http://www.internationalwaterscreens.com/

The major advantage of removing debris at laterals is that it collects at structures only once before removal because nothing is sent downstream with potential for further clogging. This is a particular advantage in narrow canal reaches that tend to collect debris across the entire downstream canal width. An additional advantage is the corresponding removal of nutrients as discussed in Section 8.2.5 (Mechanical Harvesting), where these devices can be considered a method of mechanical harvesting. In smaller canals, it may be possible to install one of these systems across the full canal for this purpose. At dead end canals, where the canal ends in pipeline, these systems are particularly useful in removing accumulated debris. A further advantage compared to the no screening option is in reducing problems for the irrigators. This may not eliminate the requirement for on-farm treatment or screening, but will likely reduce the maintenance.

The primary disadvantage is that the distributed area over which these systems are spread result in multiple stockpiles of rotting debris. In cases where the system is located in reaches where the bulk of floating debris tends to pass by, this is not as much of a problem.

8.2.6.3 Screen and Pass Debris Downstream

District screening that passes debris downstream uses passive vertical screens, automated side-sweep systems or gravel infiltration systems.

The **passive vertical screen** is made of a smooth-surface grating, such as 1-1/2” x ¾” flat expanded metal (galvanized). This material allows a manual scraper or brush to remove debris without catching on the screen. The corner of the diamond shape has a bit of an edge that assists in shearing off material that is hanging through. The angle of the upstream and downstream portion of the screen is important if this area is to be accounted for in calculating the friction loss through the screen. Katopodis et al. (2005) and Rajaratnam et al. (2006) have developed methods for calculating the flow distribution across vertical angled screens that may be useful in designing these systems.

Passive Vertical Screen

The **side-sweep** system uses the same principal as the sweep-up-the-bank system, but with the debris swept in the direction of flow. The current assists the brushes in moving the debris. Keeping the debris in its current state (floating or suspended) instead of pulling it out of the water is another factor in the superior performance of the side-sweep compared to the sweep-up-the-bank.

Infiltration systems consist of bank or bed-mounted infiltration galleries, gabion walls or gravel berms. An infiltration gallery is a buried network of slotted or perforated pipe embedded in a highly permeable gravel pack and would be used as a buried pipeline intake system. The difference in water level between the upstream and downstream water surfaces creates the hydraulic gradient to cause water to pass through or “infiltrate” the gravel into the pipe. A bed-mounted infiltration gallery is located in the bottom of the canal, reservoir or settling pond. A bank-mounted gallery is integrated into the bank and is possible where sufficiently deep water exists adjacent to shore. Infiltration galleries have been used successfully at high flows (>3,500 USgpm) for irrigation intake designs completed by UMA Engineering Ltd. An irrigator within the Taber Irrigation District has used a modified bed-mounted design located in a settling pond for his pipeline intake. This same irrigator has also constructed a gabion wall infiltration system for larger demand, again built into a settling pond. Infiltration systems rely on a very large equivalent open area to keep intake velocities low enough to prevent entrainment of and exclude weeds, algae or sediments and minimize head losses. Observed results indicate that these systems, when designed properly, are very effective.

Infiltration Gallery in Settling Pond

Gabion Wall Infiltration System - Empty

Gabion Wall Infiltration System - Filled

The major advantage is in avoiding the maintenance associated with piles of rotting debris distributed through the district. The disadvantage is the increasing accumulation of downstream debris passing into successively narrower canals. This philosophy works better in terms of debris removal where a reservoir or spillway return flow exists downstream. Effects on aquatic life in the receiving reservoir or river should also be considered where the potential for large amounts of rotting debris may affect dissolved oxygen levels.

8.2.7 Shading

Shading reduces available light to aquatic weeds and algae for photosynthesis. The influence of light on aquatic plant growth is discussed in Section 7.1.3.2 (Light Availability). Shading techniques can include use of dyes, shade fabrics, canal vegetation and piping (Sytsma and Parker, 1999). Dyes such as Aquashade are available in standing water, but cannot be used in flowing waters. The large areas required make this option uneconomical. Although the shading effect of ditch bank vegetation has been shown to impact growth of aquatic plants (Sytsma and Parker, 1999), the additional water loss due to evapotranspiration, the maintenance associated with trimming and branch removal as well as potential damage of canal liners by roots, may offset potential gains (Sytsma and Parker, 1999).

Leaving a strip of tall grass on the inside shoulder of the bank may reduce the time of sun exposure with little added maintenance and have the additional benefit of acting as a vegetative filter strip to trap nutrients in runoff.

Although installation of fabrics with shade densities greater than 80% have been shown to be effective in substantially reducing plant biomass in irrigation canals (Sytsma and Parker, 1999), southern Alberta winds make this option non-feasible.

The ultimate shading is accomplished through installation of buried pipeline, as is discussed in Sections 6.7 (Problems in Pipeline Systems) and 6.9.1 (Prevention Programs).

8.3 Biological Control

Biological control involves using aquacultured species (fish, eels, shrimp, mussels, snails, crayfish etc.), competitive plants, pathogens or insects to consume aquatic plants directly, or filter water to improve water quality (Allan et al., 1989; Sytsma and Parker, 1999). Microbes can also be use to amend water and soils to compete with algae for nitrogen (EcoChem, 2007). A complex set of interrelationships exist, requiring a holistic ecosystem approach.

8.3.1 Fish

Much research has been on use of grass carp and other aquaculture and native species (Allan et al., 1989; Sytsma and Parker, 1999) to consume aquatic plant material or filter the water. These work best in tropical and subtropical areas where overwintering is not a problem, although some success has been achieved in the northern United States. They have been shown to be effective in controlling chara, water plantain, Sago pondweed, Canada waterweed and filamentous algae (AAFRD, 2004). The use of triploid (functionally sterile) grass carp was tried in the Eastern Irrigation District in the mid to late 1990s in conjunction with Alberta Agriculture and in the early 2000s on their own, but was a complete failure due to the cost of managing them. They were difficult to corral and the fine mesh of the containment screens caused them to be easily plugged and reduced flows more than the weeds (E. Wilson, Pers. Commun.).

8.3.2 Microbes

The use of microbes in removing available nutrients is commonly referred to as biological nutrient removal (BNR) and is well studied in the area of wastewater treatment (Jeyanayagam, 2005). Nitrifying bacteria are obligate chemolithotrophs, meaning that they must use inorganic sources of nutrients, usually in the form of ammonia (NH_4-N) and nitrites ($N0_2^-$) (Fritz Industries, 2007). Nitrification requires aerobic (oxygen present) conditions, preferably at dissolved oxygen levels exceeding 80% (Fritz Industries, 2007). Nitrosomonas and nitrobacter are discussed briefly in section 7.1.3.3 in discussing their activity in substrate. Denitrification must follow nitrification to eliminate nitrogen from the system in the form of nitrogen gas, and requires anaerobic (no oxygen) conditions (Jeyanayagam, 2005). Various products are available for use in ponds; however, no information was found on attempting large scale treatments in irrigation systems.

Applying microbes as a canal bed amendment prior to startup may have potential to inhibit growth of rooted weeds; however, no studies were available to assess this strategy.

8.3.3 Planted Floats, Biofilters and Constructed Wetlands

Planted floats have been shown to remove phosphorus (Wen and Recknagel, 2002), and involves containing horizontally spreading water plants in a constructed matrix for later harvest. The use of water hyacinth (Eichhornia crassipes) has potential in Canada as a means of extracting nutrients from dugouts and other contained water bodies. After seeding in late spring, they uptake nutrients in the water as they grow and then the plants can be harvested and composted. This technique is actually being used on a large scale in India and other areas for treatment of effluent and generation of biogas during the composting process (Malik, 2007). Water hyacinth is a major problem in tropical and subtropical environments. Although some studies indicate that this potentially invasive species is unable to overwinter in the northern United States (Julien, et al., 2000), further study would be required to determine the risk of establishment in Canada before large scale use.

Biofilters can be an effective means of cleaning irrigation water. A chopped wheat straw biofilter was found to efficiently capture nitrogen, phosphorus, clay, algae and organic carbon while maintaining high hydraulic conductivity and low clogging potential (Diab et al., 1993). The mechanism is two-fold, involving nitrogen immobilization as well as through a nitrification-denitrification sequence. Phosphorus was also taken up, likely in parallel to the nitrogen immobilization process. Effective clay removal was due to adsorption on the mucilaginous biofilm that developed on the degraded straw. Adsorption of algae to the wheat straw decreased downstream algae content, while providing a continuous source of carbon for the nitrification-denitrification reaction. The low nitrogen and phosphorus content in the wheat straw was found to provide microbes with the required carbon and energy, but required them to obtain N and P from the inorganic water source. Addition of wheat and barley straw to dugouts and ponds has also been used for algae control in Alberta (AAFRD, 1999), England (Newman, 2007), Ireland (Caffrey, 1999) and the United States (PSU, 2002; Lynch, 2002). The consensus for success based on empirical evidence (including more than 100 trials in the UK and Ireland) and available research is that:

- Aerobic conditions are required
  - Loose straw in a cage or loose bales
  - Run water through or place around shoreline or shallow areas
- Application should be in fall, winter or no later than early spring
  - Takes up nitrogen/phosphorus in the water

  - o Has little effect on existing blooms

- ➢ Although wheat straw is effective, barley straw is preferred
  - o Rotting barley straw has anti-algal properties
  - o Appears to release a toxin

- ➢ Treatment has effect in large water bodies, but more effective in smaller water bodies
  - o Review of recommended application rates is required.

Constructed wetlands can dramatically improve downstream water quality and can offset the upland influence of agricultural land (Romero et al., 1999; Ray and Inouye, 2007). Weller et al., (1996) found that 1 ha of riparian wetland could sequester more phosphorus than was released by 35 ha of agricultural land (Ray and Inouye, 2006). A further study found ratios of 17:1 and 32:1 with nitrogen and phosphorus removal rates of 37% and 22%, respectively (Ray and Inouye, 2006). Constructed wetlands have also been integrated in gravel dams to further improve the effectiveness of infiltration gallery filters (Steinmann et al., 2003). Reservoirs provide some mitigating effect and are discussed with respect to the Bow River Irrigation District (BRID) in section 6.5; however, the relatively deep waters and low biomass do not approach the effectiveness of wetlands. Large scale use of wetlands in southern Alberta irrigation districts is limited to Ducks Unlimited projects and for mitigation of return flows.

8.3.4 Vegetated Filter Strips and Shelterbelts

Vegetated filter strips have been found effective in sediment and nutrient removal. The optimal width of 15 m was shown to maximally reduce sediment and to reduce phosphorus by 89% (Abu-Zrieg et al., 2003). Even a 2 m wide filter strip, a suitable width for use adjacent to canals, was shown to reduce phosphorus loading by 31% (Abu-Zrieg et al., 2003).

Shelterbelt trees and shrubs can be used as a shading method to prevent aquatic weed and algae growth (section 8.2.7), and as a means of capturing tumbleweeds and weed seeds carried by the wind. This is only practical where sufficient land is available adjacent to the canal.

8.4 Operational Control

Operational control of aquatic weeds and algae refers to using the available irrigation infrastructure and control systems to deliberately modify water levels, flows, and other parameters to affect weed and algae growth.

8.4.1 Water Level Manipulation

The ecological basis of drawdown and flooding as a means of controlling aquatic weeds is discussed in section 7.1.2 (Hydrology).

8.4.1.1 Reservoirs

Essentially water level manipulation can be used to control macrophyte abundance, macrophyte community structure and also water chemistry. Water chemistry in turn affects aquatic plants that obtain their nutrients from the water, especially floating (non-rooted) weeds and algae.

Winter drawdown of reservoirs is a common practice in southern Alberta to prevent ice damage to spillways, gates and other structures. The drawdown of primary reservoirs such as St. Mary and Waterton also allows capacity for attenuating high runoff events. In following the operational guideline curve (target water level) for winter operation, water is released from primary reservoirs at rates matching natural inflows, to pre-defined maxima and minima, via low level outlets and/or winter operable spillways. (S. Holgate, Pers. Commun.). Inflows greater than the maximum result in temporary storage, with release occurring once the high inflow event subsides. The effect of winter drawdown of primary irrigation reservoirs on aquatic weed and algae growth is not known; however, Crosby speculates that this is the reason there is no aquatic macrophyte growth in the St. Mary Reservoir (University of Alberta, 1990).

There may be opportunities to experiment with varying winter drawdown in reservoirs within irrigation districts, depending on operating and structural characteristics.

Summer drawdown is not an option for most reservoirs due to the risk of irrigation shortfalls. There may be opportunity for late summer drawdown for some reservoirs in areas where downstream demand is expected to be low.

The selection of reservoir drawdown level, including the option to stabilize levels to encourage competition and/or minimize ammonia production on refill, should be based on an assessment of the species of concern to be controlled. The correlation of filamentous algal blooms with ammonia levels then requires a careful consideration of the requirement to draw down reservoirs.

8.4.1.2 Canals and Dugouts

Drawdown is a more viable option for canals than for reservoirs and more so for laterals than for the main canal due to operational flexibility. Canals can be drawn down and check structures lowered during an extended period of low demand, such as following a major rain event.

Drawdown is also available as an operational control method for on-farm ponds and dugouts. The turnout gate can be closed and the pond emptied with effective treatment in as little as 10 days (Allan et al., 1989).

Flooding out or drowning aquatic plants is another method that has the best potential in normally low canals or in on-farm ponds after flowering is initiated, but before the buds open (Allan et al., 1989).

8.4.2 High Flows / Flushing

The effect of velocity on macrophyte establishment is discussed in section 7.1.2 (Hydrology). Essentially, macrophyte establishment decreases with increasing velocity and is severely limited at velocities greater than 1 m/s. Where higher velocities can be achieved, run canals with check structures set low whenever possible to keep macrophyte densities low.

Flushing relies on a surge of water being sent down an empty canal to scour the bed and send organic matter, nutrients and fine sediments downstream. Unless the flushing will discharge these materials out of the canal, they will simply be transported to a downstream reach. This practice is common prior to startup to clear up the canals and improve water quality before the water is used; however, there are no comprehensive studies evaluating the effect of this on aquatic weed and algae growth potential.

8.4.3 Cold Water Release

Cold water release from reservoirs can slow the growth of rooted submerged aquatic macrophytes (Allan et al., 1989). This situation occurs in the Colorado River where low level release of 10^{o}C water from Lake

Powell results in clear, cold water for 100 km downstream (Cole, 1994). The summer temperatures are lower and the maximum temperature is delayed. This option requires a thermocline to develop and be maintained throughout the irrigation season such that thermal constancy in the vicinity of $10^{o}C$ is maintained in the discharge water. Along with colder temperatures, the water below the thermocline during summer is high in nutrients, including hydrogen sulfide (H_2S) and ammonia (NH_4-N) (Cole, 1994).

The potential application of cold water release as a means of aquatic weed and algae control for southern Alberta irrigation districts is quite limited due to relatively shallow reservoirs, high winds that tend to disrupt the formation of thermoclines and outlets designed to withdraw from the upper few metres.

8.4.4 Competition / Leave-in-Place

Competition makes use of the concepts described in Section 7.1.4.1 (Competition) to control the relative abundance of aquatic weeds and algae.

Considering density and length relationships to Manning's n described in Section 7.2 (Effects of Vegetation on Canal Performance), it may be best in some cases to leave certain reaches of canal with submerged vegetation untreated once they have achieved high density and stem lengths longer than 0.3 m. Cutting them back will result in re-growth and require repeat treatment, while leaving them untreated may result in increased stem length and a lowering of Manning's n and water level. This would be a judgement call based on available freeboard in the canal, moderate stem rigidity, stem diameter less than 5 mm, sufficient discharge and a significant leaf structure for drag. Essentially, this means that the plant must be able to be pulled over by the current as it grows longer, without using up excessive freeboard.

9.0 Prediction of Future Weed and Algae Problems

The prediction of future weed and algae growth scenarios takes into account the potential demand, water quality and reservoir storage in the foreseeable future.

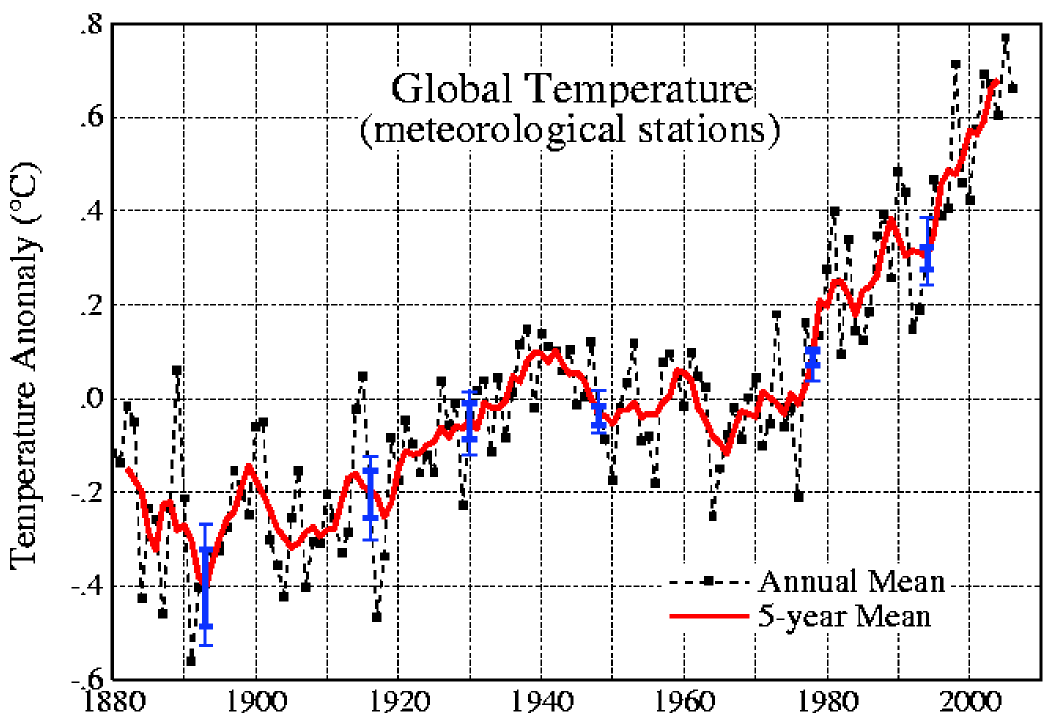
9.1 Climate Change

Climate change has happened and will continue to happen. The following considers the recent and predicted changes in temperature and rainfall.

9.1.1 Predicted Temperature Changes

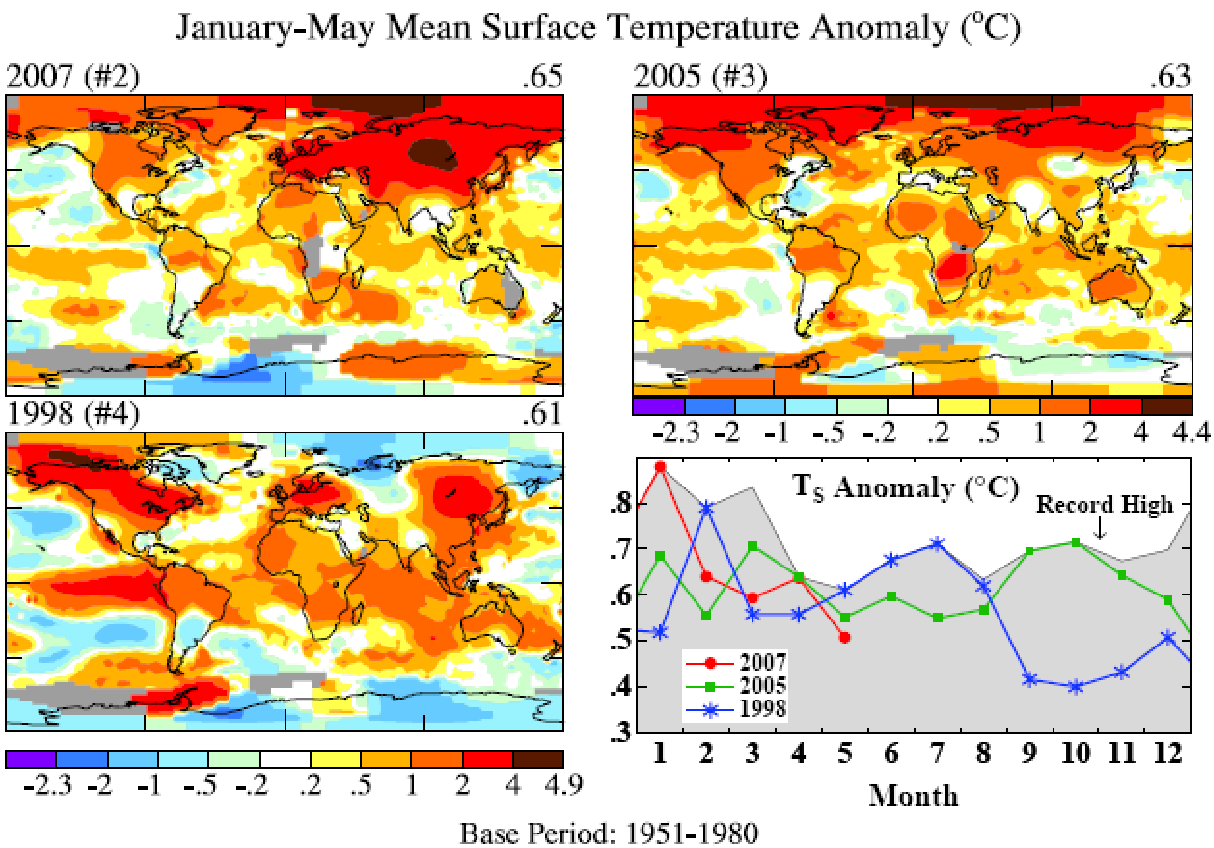
Average global temperature has climbed more than 0.6°C relative to the 1951-1980 mean, with the 10 warmest years on record occurring since 1990 (Sauchyn, 2007). Figure 9.1 shows the updated figure downloaded from NASA (2007):

Figure 9.1: Global Temperature (meteorological stations) vs. 1951-1980 Mean



Referring to Figure 9.2, North American surface temperature has increased more than 1°C:

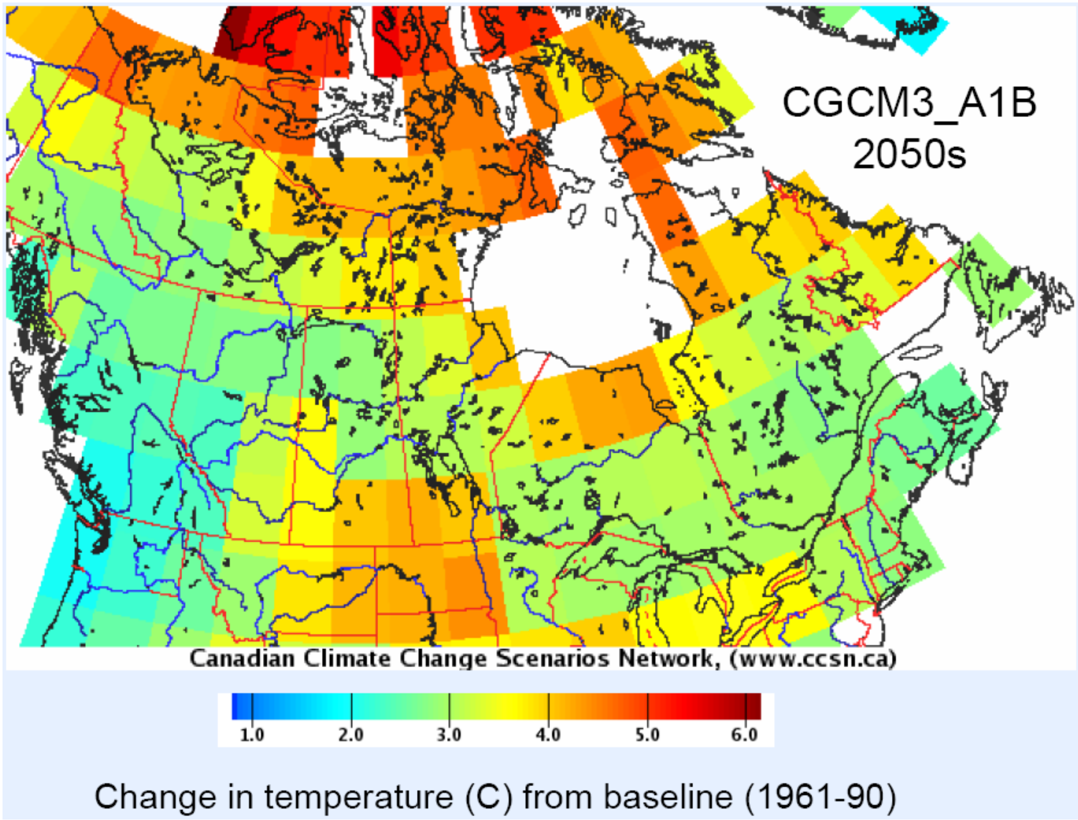
Figure 9.2: January-May Mean Surface Temperature Anomaly (°C) vs 1951-1980 Mean



(NASA, 2007)

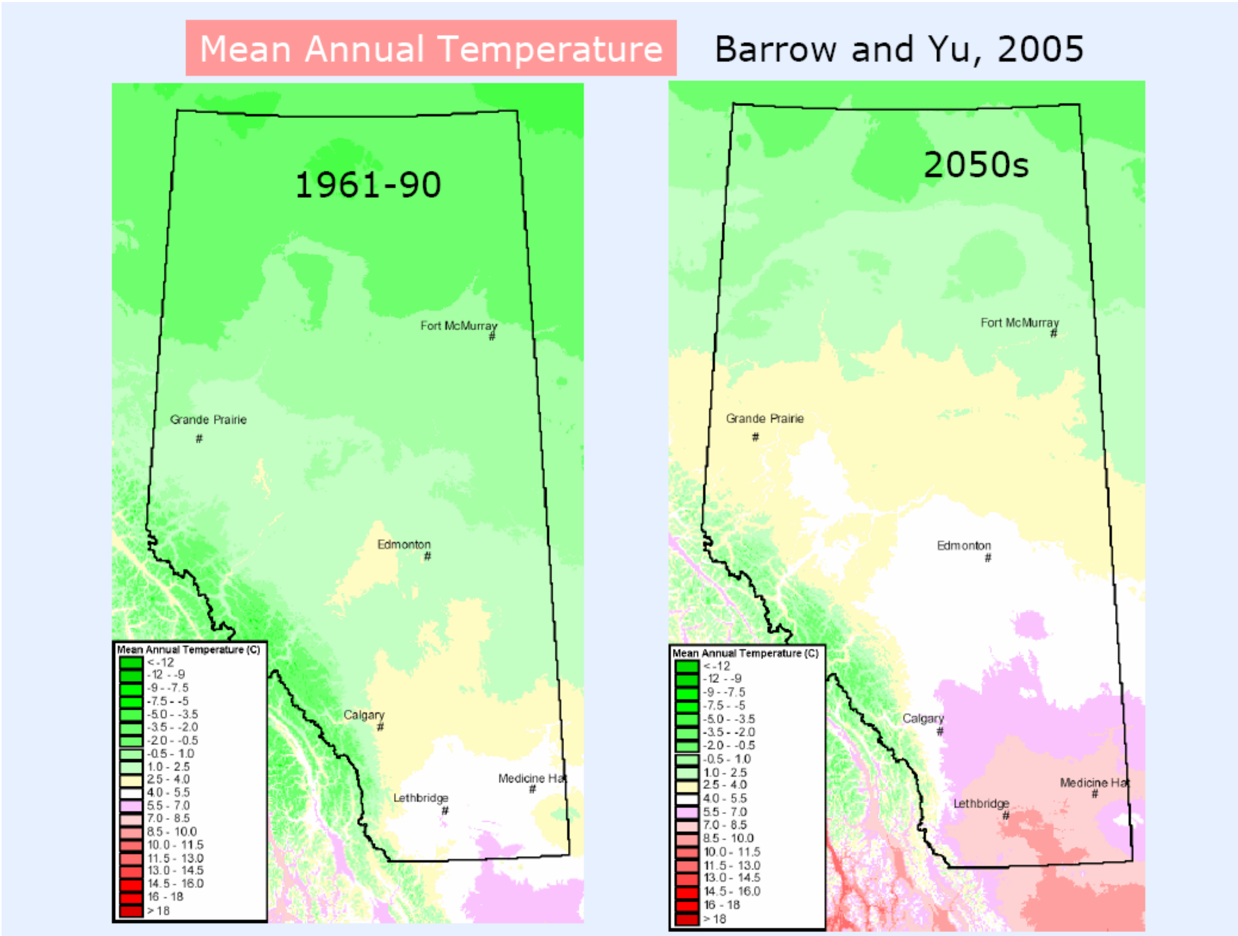
Note that the temperature increase was found to be significantly greater in the northern latitudes. The Canadian Climate Change Scenarios Network predicts that temperature will continue to climb (Figure 9.3).

Figure 9.3: North American Temperature Change Prediction – 2050s



Barrow and Yu have developed a detailed map of the predicted temperature for Alberta in the 2050s with a comparison to the 1961-1990 mean (Figure 9.4) (Sauchyn, 2007).

Figure 9.4: Alberta Temperature Prediction – 2050s

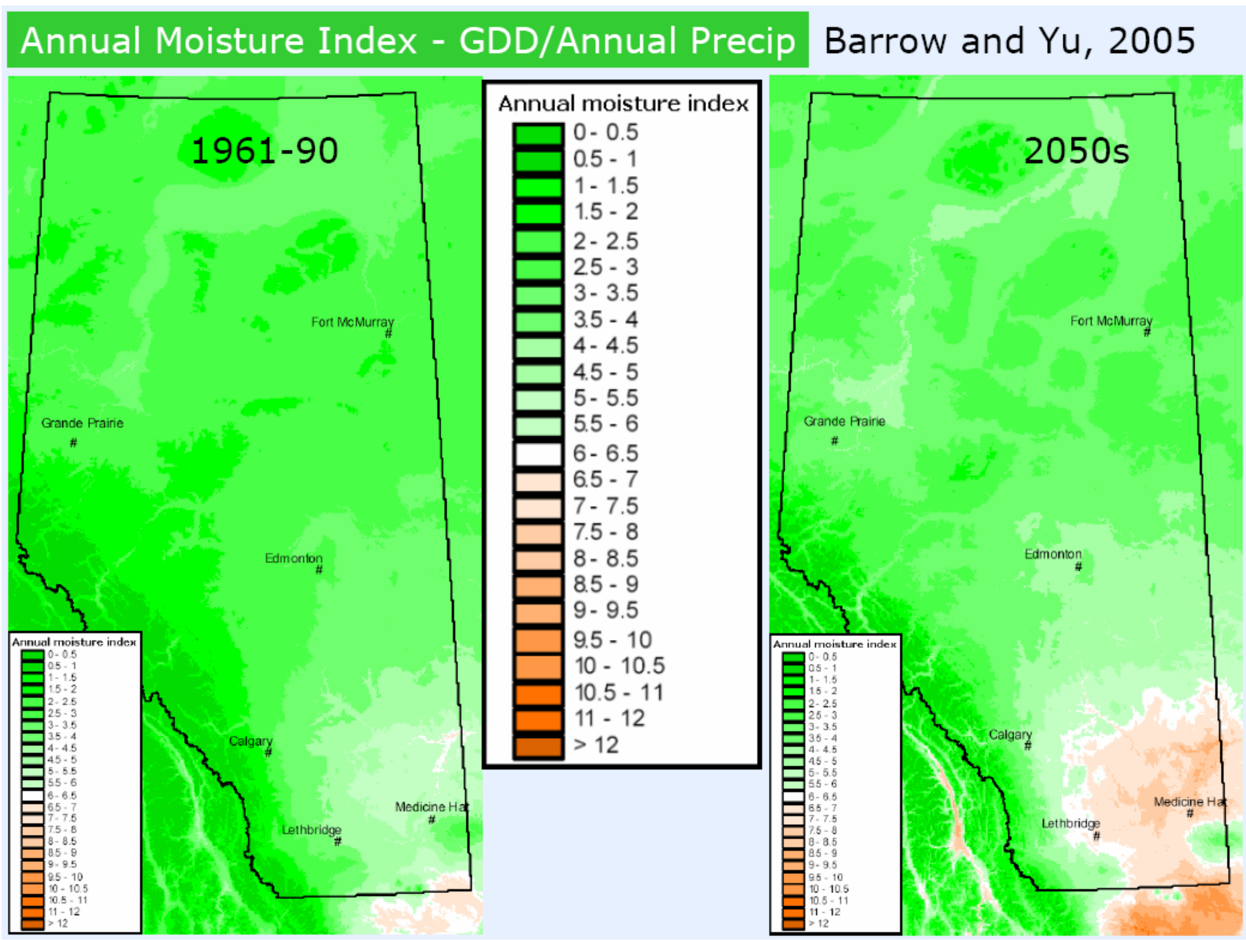


The 1961-1990 mean annual temperatures for the area covering the Alberta irrigation districts ranged from 2.5 - 7.0°C. The predicted range for the 1950's is 5.5 – 10.0°C, an increase of 3°C.

9.1.2 Predicted Precipitation Changes

Barrow and Yu also completed a prediction of the annual moisture index for Alberta in the 2050s and compared to that of the 1961-1990 mean (Sauchyn, 2007). This is shown in Figure 9.5.

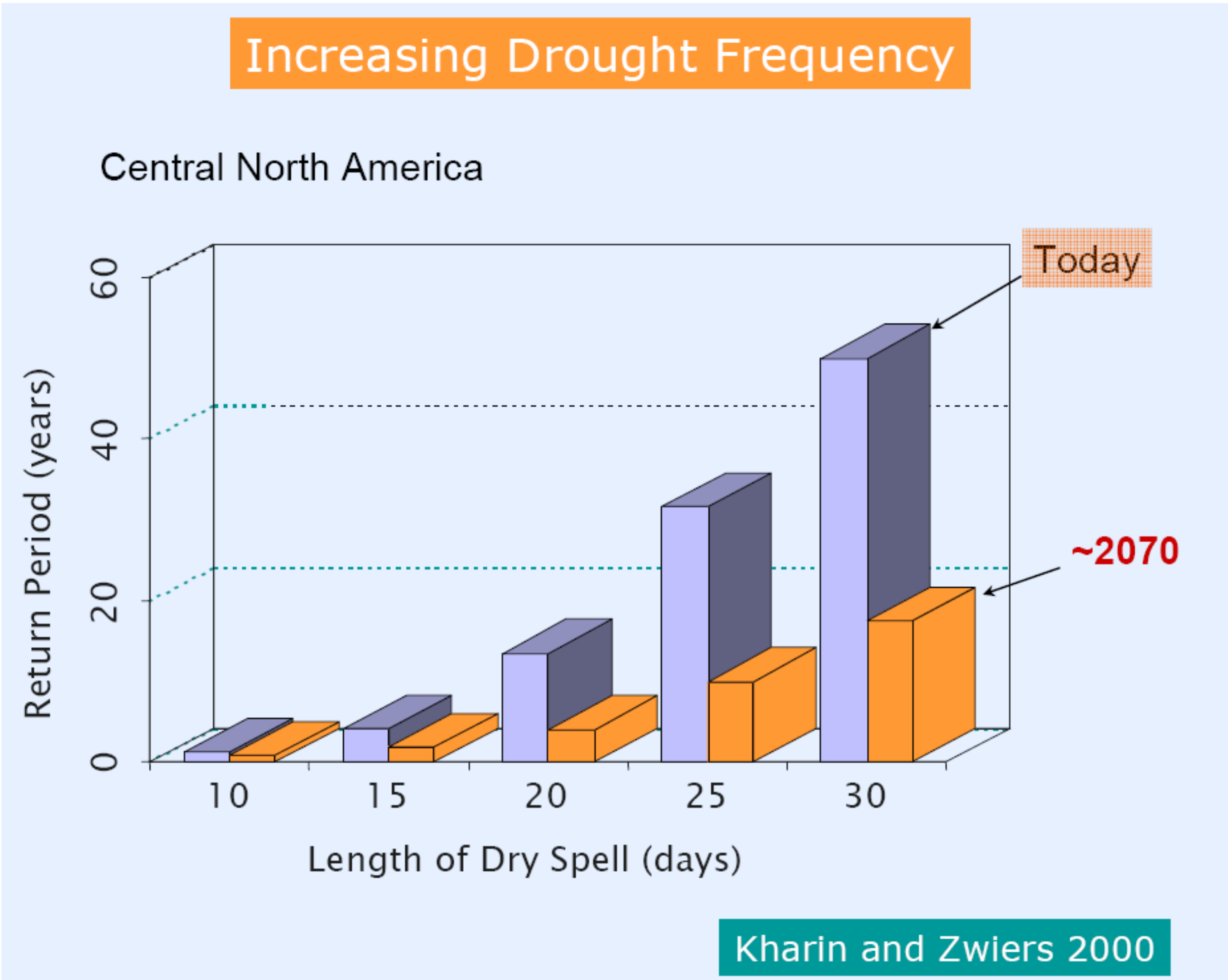
Figure 9.5: Alberta Moisture Prediction – 2050s



Sauchyn observed that although the precipitation will actually increase, the form and timing will be much different than currently experienced (Sauchyn, 2007). A larger proportion of precipitation is expected to come in the form of spring rain. The ensuing hot summers will be drier than those of recent history. The phase of increased contribution of flow from glaciers due to global warming is past (Sauchyn, 2007). Fortunately for the irrigation districts, annual glacier contribution is only 0.6% and contribution during the irrigation season is only 2.4% (Sauchyn, 2007).

The return period for drought is anticipated to decrease, while the severity measured in terms of number of dry days is expected to increase (Figure 9.6) (Sauchyn, 2007):

Figure 9.6: Central North American Drought Frequency and Severity – 2070s



The anticipated changes in climate will result in:

- Higher overall rainfall expected in southern Alberta
- More precipitation falling as rain and less as snow
- High spring runoff and flooding
- More frequent and more severe storms
- Wetter springs and drier summers
- Summer drought conditions

The implications for irrigation are:

- High summer and fall demand

- Larger annual applications (more irrigators will use their full allocation)
- Fewer shut-downs in summer and fall
- Greater runoff in spring and less in summer
  - More nutrients in **sediments** due to heavy spring runoff events
    - Greater and more frequent reservoir mixing
    - Large events contribute to sediment loading
  - Fewer nutrients in **water** in summer due to less summer precipitation
    - Fewer periods of high turbidity
- Greater dependence on irrigation
- Greater need for storage to capture more spring runoff.

Considering the concepts in Section 7 (Understanding the Problem of Aquatic Weeds and Algae in Irrigation Systems), the following scenarios may occur:

- The early establishment of aquatic macrophytes in sediment-laden canals and shallow reservoirs due to reaching the minimum threshold temperature for problem species sooner
- Less winter die-off of aquatic macrophytes, contributing to early establishment and changes in macrophyte populations
- Extensive algae growth during the drier summers due to low turbidity (increased light availability) and the ability to quickly take up nutrients in the water
- Faster and wider spread of aquatic weeds and algae due to reproductive structures carried by storm events.

Specific invasive aquatic weeds and algae that should be tracked include, but are not limited to:

- Hydrilla (*Hydrilla verticillata)*
- Eurasian Watermilfoil (*Myriophyllum spicatum L*.)
- Brazilian Elodea / Anacharis (*Egeria densa*)
- Water hyacinth (*Eichhornia crassipes*).

These are discussed according to their aquatic plant group in Section 6.1 (Aquatic Weeds and Algae Present). There are likely to be many others that should be tracked. This is discussed in Section 10.0 (Recommendations for Further Study). Sauchyn, (2007) concluded that adaptation is required for the entire irrigation industry. The management of aquatic weeds and algae is a small but important component in this process that, if overlooked, could prove critical.

10.0 Recommendations for Further Study

Research in the prevention and control of aquatic weed and algae in irrigation systems in southern Alberta is limited. The vast majority of information contained in this report has been obtained from research conducted in other regions. Local information is either indirectly related, out of date or based on informal observations. This section identifies areas of research that have potential to directly benefit southern Alberta irrigation, and the surrounding ecosystem as well. The emphasis is on seeking practical solutions with long-term application.

10.1 Scoping Study

The recommendations in this section arise from observations made in preparing this report and as such are somewhat limited. An integrated approach with a centralized plan will greatly improve the speed and effectiveness of implementing aquatic weed and algae prevention and control strategies, while ensuring the results are shared among all irrigation districts.

It is recommended that a scoping study be conducted to identify, prioritize, evaluate, track and communicate results for both (1) research opportunities and (2) strategies for immediate implementation.

10.2 Survey of Aquatic Weeds and Algae

There is a lack of information on the occurrence, prevalence and abundance of aquatic weeds and algae in southern Alberta irrigation districts. The extent of the problem needs to be identified in order to provide effective long-term solutions.

It is recommended that a survey of aquatic weeds and algae be designed and conducted in southern Alberta irrigation district reservoirs, canals and dugouts.

10.3 Tracking of Current and Potential Invasive Aquatic Weeds and Algae

There is limited tracking of potentially invasive aquatic weeds and algae.

It is recommended that a system be put in place to coordinate with other jurisdictions in tracking the occurrence and progress of invasive aquatic weeds and algae. This could be done through the Pest Management Association of Alberta, or through a related body of Alberta Environment.

10.4 Predictors of Aquatic Weed and Algae Growth

The environmental factors that influence the growth of aquatic weeds and algae in southern Alberta canals are not well understood.

Technology is available to provide automated monitoring of many of the environmental factors that influence aquatic weed and algae growth described in Section 7.1. Modern sensors can, either directly or indirectly, measure instream conditions such as depth, flow, velocity, temperature, pH, dissolved oxygen and several other water quality indicators. These can then be recorded automatically into a data logger at defined intervals. Regional or local weather station data (air temperature, light intensity, precipitation, wind speed/direction) as well as non-automated water quality parameters can then be added to produce a comprehensive dataset of potential environmental influences with time. Regular comprehensive surveys of the growth of individual species of aquatic weeds and algae in the vicinity of the monitoring stations and in affected reaches downstream can then be correlated to the environment. Trend analysis between stations can be done to recognize patterns indicating what conditions trigger blooms of individual problem weeds and algae. This would be useful both in improving understanding of the mechanism of weed and algae growth, and in timing prevention and control strategies. The concepts of biological interaction, including competition and herbivory in Section 7.1.4 (Biological Interactions), as well as full accounting of nutrient balance as they pass through the food chain, should also be tied in.

It is recommended that a study of predictors of aquatic weed and algae growth be designed and conducted in southern Alberta irrigation district reservoirs, canals and dugouts.

10.5 Chemical Use

Southern Alberta irrigation districts are not making the best possible use of their primary aquatic herbicide.

The largest potential for immediate benefit in the prevention and control of aquatic weeds and algae is in making more effective use of Magnacide® H (acrolein). Section 8.1.2 (Acrolein) discusses this herbicide in detail; however, the research by Bentivegna et al. (2004) and the pioneering work of St. Mary River Irrigation District (SMRID) have shown that treatments of lower concentration and less time than manufacturer maximum recommendations, at a shorter time interval between treatments, will significantly reduce the reproductive potential of aquatic weeds and algae and reduce chemical requirements. This would allow irrigation districts to either reduce their use of this chemical or apply it in much longer lengths of canal.

It is recommended that controlled trials be designed and then conducted in southern Alberta canals to assess the potential benefit and provide guidelines for implementation throughout the irrigation districts.

10.6 Canal Design

Current canal design criteria do not sufficiently address the potential for aquatic weed and algae growth.

The Resource Sciences Branch of Alberta Agriculture and Food provides the criteria for engineers to follow in designing irrigation channels. The hydraulic resistance of varying levels of vegetation in a mature channel is accommodated for in the selection of the Manning's n coefficient (Hartman, 1991; Purnell, 1987). This requires judgement on the part of the engineer and the irrigation district as to the predicted weed growth and level of effort to be provided in weed control. Typically this factor is not addressed on a case-by-case basis and the recommended n factor is used under the assumption that the canal cross-section will be maintained reasonably clean (Hartman, 1991). This then results in situations where maintenance can fall behind and the design freeboard is used to accommodate the excess water depth. The relationship of canals and aquatic vegetation is discussed in Section 7.2 (Effect of Vegetation on Canal Performance), Hydrology (Section 7.1.2) and Canal Characteristics (7.1.3.7). This includes the concept of integration of canals in the reservoir-canal sequence and the surrounding ecosystem. The canal lining materials and construction are of particular interest due to the relatively small change in infrastructure design and that these changes can be applied immediately for canals slated for rehabilitation. Assessing inhibition of aquatic plant growth by armour placement method on traditional canals or use of bituminous coal membrane liners are good potential starting points.

Modelling of canals to predict the distribution of sediment deposition as referred to in Section 7.1.2 (Effects of Vegetation Canal Performance) in river systems, may be of benefit in designing future systems. Perhaps strategically located sediment traps can be added to isolate these nutrient-laden deposits for dredging. A more ecologically-based solution identified in Section 8.3.3 (Planted Floats, Biofilters and Constructed Wetlands) would be to integrate planted floats, Biofilters or constructed wetlands into reaches of canal, simulating a regular pool and riffle succession found in natural river systems.

It is recommended that irrigation canal design, materials and construction be reviewed and new guidelines prepared that take into account the various concepts included in this report.

10.7 Operational Controls

The effects of manipulation of canal and reservoir operation on growth of aquatic weeds and algae in southern Alberta canals and reservoirs are not well known.

As discussed in Section 8.4, there are a number of techniques available to control aquatic weeds and algae. The essential factors in assessing the effectiveness include knowing the species present, the species to be controlled, the environmental conditions and also having a control to measure the effect. Trials may include assessing the effectiveness of keeping test canals or reservoirs checked up during the winter, testing various drawdown levels, testing various flushing rates and timing and leaving certain reaches of canal untreated to test competition potential. Test site selection must be based on the ability to avoid damage to liners and structures.

It is recommended that studies on the effectiveness of various operational controls on aquatic weed growth in southern Alberta irrigation canals and reservoirs be designed and conducted.

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