Interdepartmental Memorandum
Bureau of Water Management
Lakes Management Program

TO: William Evans
Bureau Chief
Bureau of Financial and Support Services

FROM: Charles Lee
Bureau of Water Management
Div. Planning and Standards
Lakes Management Program
2333

SUBJ: Lake Drawdown Reports

DATE: November 23, 1997

Pursuant to a request from the Bureau of Financial and Support Services, staff from the Bureau of Water Management, the Natural Resource Center, and Fisheries Division reviewed impacts to lake ecosystems from winter drawdowns. As part of this assessment, we reviewed the accompanying documents. These documents include two memos from DEP staff, a paper published in the "Water Resources Bulletin" by Dennis Cooke, and a literature review funded by the Lakes Grant Program entitled "Effects of Winter Drawdown on Fish and Benthic Macroinvertebrates: A Literature Review".

Additionally, the Lakes Management Program has observed decreased water clarity and increased anoxia during summers following winter drawdowns. These conditions were documented with DEP monitoring data at Highland Lake in 1987 and Crystal Pond in 1991. Winter drawdowns allow sediments and organic debris from the exposed area to erode into a lake increasing nutrient loading, turbidity, and oxygen demand. Also, these unvegetated areas are susceptible to sediment resuspension by wave action when water levels are restored.

Winter drawdowns can also lead to other lake vegetation problems. The natural progression of a lake ecosystem is usually from upland to wetland to emergent aquatics to open water. Regular winter drawdown can disrupt this transition by eliminating native aquatic vegetation. With the loss of native vegetation, habitat for more problematic invasive exotic plants becomes available. Furthermore, nutrients once used by rooted vegetation is available for algae often leading to decreased water clarity.

I have also been discussing the impacts of winter drawdown to lake fauna with the Natural Resource Center. They will be reviewing the literature and forwarding pertinent reports to me. I will forward these reports to you when I receive them.

Department of Environmental Protection
Bureau of Natural Resources
Fisheries Division
INLAND FISHERIES SECTION

MEMORANDUM

Date: December 9, 1997

To: Ernest E. Beckwith Jr., Director

From: James C. Moulton, Asst. Director for Inland Fisheries

Subject: **Winter Drawdown Fisheries Concerns**

....

1) Direct Winterkill of Fishes

Shallow lakes are naturally prone to winterkill, a phenomenon in which fish die under the ice due to anoxic conditions (Everhart et al. 1975). For example, Pine Acres Lake in Hampton, CT has historically experienced at least three winterkills since 1969. In addition, species such as landlocked alewife are susceptible to winterkill mortality due to lake supercooling. Lake supercooling can occur when waters are exposed to cold water temperatures for extended periods (Schluntz and Bender 1993). Drawdowns in shallow lakes increase the likelihood of fish mortality from winterkill anoxia and/or supercooling since lake levels are drawn down too far leaving minimal useable fish habitat and refugia. In extreme cases, a large proportion of the fish population can be lost in a single drawdown event. Such events have been documented in Pine Acres Reservoir when the lake was drawn down for weed control purposes and in Hampton Reservoir when the reservoir was drawn down due to dam repairs. After widespread mortality, it can take years for resident fish populations to reach pre-mortality population levels. The Fisheries Division must rely upon fish reproduction and recruitment processes to restore fish populations since it does not raise and stock warmwater fish.

2) Loss of Juvenile Fish Habitat

Juvenile fish use the littoral zone and nearshore vegetation as a sanctuary from predators (IEP 1990). If little submerged vegetation is left after a drawdown, overpredation of juvenile fish can cause recruitment failure which will severely impact the fishery. Water supply reservoirs in Connecticut are drawn down each summer, resulting in depletion of nearshore vegetation. These reservoirs tend to have extremely erratic fish recruitment with certain species (such as black crappie) being absent from many of them, quite likely as a result of drawdown practices.

3) Loss of Spawning Habitat for Some Fish Species

Certain coolwater fish species such as chain pickerel and yellow perch spawn from March to early April in and around shoreline vegetation (Whitworth et al. 1968). Presentdrawdown protocol requires lakes to be refilled by opening day of fishing in mid-April to provide boat access. Chain pickerel and yellow perch reproduction might be impacted and perhaps impossible under conditions in which suitable spawning habitat is limited or unavailable. Anglers have reported that chain pickerel populations are much smaller in Candlewood Lake since winter drawdowns began there. Chain pickerel were common in Lake Saltonstall prior to 1964 when annual water supply drawdowns began (Fish. Div., unpublished data). They have since disappeared from the lake. In Pickerel Lake (mean depth = 6.0ft), yellow perch densities dropped by 50% (electrofishing catch/effort 1986-89 = 18.7 perch/hr vs. 1990-94 = 9.7 perch/hr), after at least two years of severe drawdowns (1991 and 1992 by 3.5-4.5 feet).

4) Increased Winter Mortality of Juvenile Fishes

Winter is the period of greatest stress, and therefore greatest natural mortality for most fish species, especially among juveniles (Adams et al. 1982, Oliver et al. 1979). Most fish species feed very little under the ice, and spend the winter months in a state of semi-dormancy. During this time, they survive primarily off their bodies' fat reserves. For juveniles of most fish species, the amount of fat they can store by the fall of their first year is marginally enough to survive the winter (many perish even under normal conditions because they cannot achieve this critical amount of fat storage). Juveniles of most fishes spend the winter in relatively shallow water in the mud or leaf litter. Displacement into deeper water during a winter drawdown puts additional stress on these young fish by increasing inter and intraspecific competition for available habitat. Thus, a by-product of habitat displacement may be increased winter mortality rates.

5) Loss of Forage Species Habitat

Submerged aquatic vegetation serves as food and/or habitat for a variety of invertebrate and vertebrate animals including aquatic insects, crayfishes and amphibians. In turn, adult and juvenile fish are dependent upon these animals as food sources for growth and survival. Loss of nearshore habitat due to lake drawdowns has been shown to either totally eliminate macroinvertebrates such as molluscs and crayfish via dewatering/strandingor diminish overall population abundance (IEP 1990). The repercussions of these littoral zone impacts to the fish community are decreased growth rates and production (IEP 1990).

6) Degradation of Downstream Fisheries Resources

Many lakes and ponds outlet to streams which support viable fish and macroinvertebrate communities. Typically once a drawdown is completed, the lakes' control structure is completely closed in order to start the lake refilling process. Depending upon watershed size and other characteristics, the refilling process may take several weeksor even months. As a result, stream resources in areas immediately below the dam experience "zero" flow conditions whereas further downstream, flows are only generated from lateral inflow (tributary streams) or groundwater inputs. The impacts of reduced stream flows on fish communities are wide ranging (Tyrus 1990) and include impacts to survival of fish eggs and juveniles, fish migration and spawning, spatial requirements, abundance, size and condition of fishes, and species diversity.

During the lake drawdown process, a lake's control structure is partially or fully opened resulting in increased flows to downstream areas. These waters may contain excessive amounts of sediments in suspension resulting in turbid waters and degraded water quality downstream. High turbidity levels can irritate and clog gills of fishes negatively impacting respiration (Karr and Schlosser 1977). High flows can also cause instream erosion and sedimentation. The negative effects of sedimentation to fisheries resources have been well documented (Cordone and Kelley 1961; Richie 1972) and include such impacts as degradation of fish spawning and rearing habitat, reduction of fish egg survival and fry emergence, reduction of macroinvertebrate survival, and reduction in dissolved oxygen levels.

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Y/A/

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EFFECTS OF WINTER DRAWDOWN ON FISH AND BENTHIC MACROINVERTEBRATES:

A REVIEW OF THE LITERATURE

10 October 1990

Prepared for:

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EFFECTS OF WINTER DRAWDOWN ON FISH AND BENTHIC MACROINVERTEBRATES:

A REVIEW OF THE LITERATURE

Drawdown of water level is a technique that has been used in efforts to attain a variety of management goals for lakes and reservoirs. A review of the literature on drawdown indicates that the technique can have a diverse range of effects on an aquatic ecosystem. These include changes in sediment characteristics, water quality, and populations of aquatic organisms including plankton, macrophytes, macroinvertebrates, and fish. Also evident from the literature is that the overall response of a lake or reservoir to drawdown will consist of a suite of changes unique to that particular ecosystem. Few generalizations about drawdown can be made due to the importance of basin morphometry, the hydrologic budget, the nutrient budget, climate, and biota in determining the effects on a certain lake or reservoir. These features, combined with the timing, duration, and magnitude of the drawdown, result in an overall impact unique to each ecosystem.

Despite the limited generalizations that can be made about drawdown effects, potential benefits and hazards that are inherent in the technique can be evaluated for a particular lake or reservoir. Winter drawdown has been used successfully in Candlewood Lake to control an infestation of Eurasian watermilfoil (*Myriophyllum spicatum*). However, faced with the prospect of a continuing program of winter drawdown, lake users and management authorities are concerned about the impact that repeated drawdowns may have on the fishery and populations of fish food organisms of Candlewood Lake. Benthic macroinvertebrates are a vital link in the food chains that support fish populations. A review of previous drawdown studies focused on macroinvertebrates and fish has been generated to provide a perspective on the potential impacts to these organisms in Candlewood Lake.

Effects On Fish

Drawdown has long been recognized as a technique that can be used to advantage in a fisheries management program. Changes in relative abundances, trophic structure, and productivity of fish communities due to drawdown have been documented (Wood and Pfitzer, 1960). Some of the beneficial effects of drawdown on fisheries include accelerated growth of predatory fish, thinning of panfish populations, and reduced predation on game fish eggs and young (Hulsey, 1958). However, drawdown also has the potential to adversely affect fisheries.

The most important considerations for designing a winter drawdown strategy that is compatible with the goals of fisheries management are the following: (1) the need for normal (high) water levels during spawning in spring, (2) the need for suitable habitat for young fish, (3) the need for suitable populations of prey species (including benthic macroinvertebrates; see next section), and (4) avoidance of conditions that make the lake susceptible to oxygen depletion and "winterkill".

When water levels are below normal, fish will be prevented from using optimum spawning areas. This can result in poor reproductive success and a weak year-class (Johnson, 1957). Even if preferred areas are inundated, lower than normal water levels can interrupt spawning due to an increase in wave action and temperature fluctuations (Franklin and Smith, 1963; Summerfelt, 1975). Excessive wave action or temperature fluctuations in shallow spawning areas damage eggs and nests and can cause atresia (degeneration of ova) in female fish (June, 1970).

Young fish depend for survival on cover afforded by macrophytes in the littoral zone. Elimination of macrophyte beds due to drawdown can result in reduced food availability and increased predation on young fish (Brouha and Von Geldern, 1979; Estes, 1972). Adult fish of certain species prey upon the macroinvertebrates that are associated with littoral zone vegetation. Elimination of macroinvertebrate populations due to drawdown can adversely effect the growth of fish (Hunt and Jones, 1972a). In Waterbury Reservoir in Vermont, trout grow poorly until they reach a size at which they can prey on other fish. The poor growth below this size threshold is attributed to the lack of invertebrate food organisms resulting from annual winter drawdown (Vermont Agency of Natural Resources, 1989).

The potential for oxygen depletion in the residual volume of a drawndown lake or reservoir must be evaluated to avoid "winterkill" of fish. Loading of organic sediments in spring runoff can cause winterkill due to excessive biological and chemical demand for oxygen in the residual volume (Shaw, 1983). Lengthy periods of ice cover and reduced photosynthetic rates can also contribute to oxygen depletion in the residual drawdown volume. Oxygen depletion and winterkill resulted from an early (March) and rapid drawdown of Cross Lake, Manitoba (Gaboury and Patalas, 1984).

Effects On Benthic Macroinvertebrates

Macroinvertebrate communities are composed of organisms with varying responses to fluctuating water levels and a range of capabilities for survival and re-colonization in an area exposed during drawdown. Drawdown has been documented to eliminate certain organisms from the macroinvertebrate community including crayfish (Dendy, 1946; Snow, 1971) and molluscs (Dendy, 1946; Fisk, 1989). The response of mussels to drawdown in Lake Sebasticook, Maine consisted of random movement resulting in the stranding and death of most of the population (Samad and Stanley, 1986). Some molluscs, including *Lymnaea palustris*

(Gastropoda), are less susceptible to dewatering due to their ability to form a protective epiphragm (Eckblad, 1973). In certain situations, gastropods are eliminated in the drawdown zone, but increase in abundance below the limit of drawdown (Grimas, 1961). Crustaceans other than crayfish are also sensitive to drawdown. Severe reductions in littoral zone populations of amphipods and isopods have been reported (Grimas, 1961; Hunt and Jones, 1972b).

Certain groups of aquatic insects avoid stranding by migrating to deeper water. Chironomid larvae and *Hexagenia* (Ephemeroptera) nymphs migrate in response to fluctuations in water temperature and/or water level (Cowell and Hudson, 1967; Swanson, 1967). Some macroinvertebrates are able to survive drawdown by burrowing into the substrate. Chironomid larva have been observed to survive in dewatered areas up to 85 days (Fillion, 1967). Oligochaete worms survive drawdown by burrowing (Frey, 1967) and can increase in abundance following reflooding (Hynes, 1961). Successful survival of drawdown by burrowing depends on the available substrate. Organisms inhabiting coarse, well-drained substrates such as gravel, will be killed by drawdown whereas organisms on fine-grained substrates can burrow to a depth that affords protection from dessication (Frey, 1967). Although most studies document that only tolerant organisms, such as chironomids, survived in exposed substrate, survivors of winter drawdown of a reservoir in southern Ontario also included certain species of caddisflies (Trichoptera) and molluscs (Paterson and Fernando, 1969).

Another response that enables certain macroinvertebrates to maintain their population in the face of drawdown is recolonization of habitat when reflooding occurs. Rapid re-establishment of populations in inundated areas has been observed for certain macroinvertebrates and is attributed to mass immigration from permanently submerged areas or the deposition of eggs by adults (Claflin, 1968; Davis and Huges, 1965; Moon, 1935). The rate at which immigration into newly inundated areas occurs can be dependant on the availability of algal biomass (Moon, 1935). In reflooded areas underlain by fine-grained substrates, burrowing organisms such as chironomids, *Hexagenia* (Ephemeroptera), *Caenis* (Ephemeroptera), oligochaetes, and ceratopogonids can become the dominant component of the community that becomes established (Benson and Hudson, 1975). This pattern of recolonization may be especially true of littoral zone areas where luxurient macrophyte growth has been eliminated by drawdown.

Macroinvertebrate organisms that depend on aquatic macrophytes for habitat/substrate will be reduced in proportion to the loss of macrophyte beds. This effect was observed in Lake Bomoseen, Vermont where snails (Gastropoda), caddisflies (Trichoptera), dragonflies and damselflies (Odonata), and water bugs (Hemiptera) were diminished in abundance after drawdown (Fisk, 1989). A program of macrophyte control by periodic drawdown may progressively shift the composition of the macroinvertebrate community from one of high diversity, inhabiting a variety of microhabitats, to one of low diversity, dominated by stress-tolerant organisms. This disparity in macroinvertebrate communities was documented in the Big Eau Pleine Reservoir of Wisconsin (Kaster and Jacobi, 1978). This reservoir had undergone annual winter drawdown over a ten year period and, in comparison to the macroinvertebrate fauna of non-fluctuating reservoirs, was depauperate in caddisflies (Trichoptera), mayflies (Ephemeroptera), stoneflies (Plecoptera), snails (Gastropoda), and amphipods (Crustacea).

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MEMORANDUM

TO: Chuck Lee
DEP-Water Mgmt., Lake Management Unit, 79 Elm Street

FROM: Nancy Murray, Environmental Analyst III
DEP-NRC Natural Diversity Data Base, 79 Elm St, Store Lvl

DATE: March 28, 1996

SUBJ: Lake Drawdown - Endangered Species Issues
Native Aquatic Plant Issues

The following information is provided to assist in developing best management practices for DEP controlled lake drawdowns.

Endangered Species (vascular plants, vertebrates and invertebrates)

I have reviewed Natural Diversity Data Base (NDDB) information for the 15 lakes listed on the Eastern District Lake and Pond Drawdown Schedule. Ten of those lakes do not have any reports of endangered species that would be affected by drawdown activities. Five lakes, however, did have reports of state listed species (see attached A). Many of these reports are considered to be historic records. Prior to any future drawdown activities these areas should be inventoried to determine if any state-listed species are still present.

Furthermore, those lakes that do not have known reports of state listed species should also be inventoried to rule out the occurrence of state listed species. As we all know, just because the NDDB does not have any information on a particular site it does not mean the site was inventoried for state listed species.

To develop best management practices for lake drawdowns conducted by DEP, I recommend we establish an internal review and comment process. This process would allow us to address potential endangered species concerns, as well as other areas of concern. The Forestry Division uses a "Staff Project Review" form that might be adapted for our purpose (see attached B). If significant concerns are identified through this process a diversion permit may be necessary according to Bob Gilmore, Inland Water Resources Division. NDDB information is constantly being added to and updated. The official state list is re-evaluated and species are added, deleted or undergo status changes (e.g. endangered to threatened). Due to these dynamics NDDB would need to review drawdowns prior to each annual drawdown activity.

Native Aquatic Plants

Looking at the list of drawdown lakes, it is unclear to me if any of the drawdowns are actually being done to control "nuisance" aquatic plants. The "purpose category" on the lake drawdown schedule indicates maintenance in every case. Whether the purpose of the drawdown is maintenance (dock and retaining wall repairs) or aquatic plant control the impact to aquatic plants is generally the same. It is commonly accepted that lake drawdowns can have a significant impact on aquatic vegetation, both native and non-native species. Annual or regularly occurring drawdowns can also disrupt the balance of the entire aquatic ecosystem.

I have little background and no experience with the dynamics of lake drawdowns and have consulted Dr. Don Les at the University of Connecticut. Dr. Les is a leading authority in aquatic plant biology and systematics. He has worked with aquatic plant management issues for many years in a number of states. Dr. Les has indicated that perhaps the best way to deal with the issue of lake drawdowns is to establish a list of target species for which lake drawdowns could be considered as a control action. This list would be based upon whether a species was non-native and if such species responded appropriately to a drawdown. I have requested Dr. Les' assistance and Les Mehrhoff's (formerly of DEP, now at UConn) assistance in coming up with such a list. If DEP agrees to develop such a policy I will enlist their help to draft such a list.

Of course, there would need to be a caveat for lake drawdowns to be considered when there are no "target" species. An example of such a "special situations" would be situations where a native aquatic plant species exhibits excessive growth due to nutrient input.

Once developed, such a policy may also be appropriate for the DEP-Pesticide Program to consider. I would encourage development and implementation of this policy. DEP needs to ensure that we are not authorizing or promoting destruction of aquatic plants. According to State Statutes (C.G.S. Section 22a-1) it is the responsibility of the state "to conserve, improve and protect its natural resources and environment". Aquatic plants are a natural resource that need to be conserved. Without more stringent controls, lake drawdown actions could easily cause a number of these more common aquatic plant species to become imperiled and possibly need to be added to the State Endangered Species List.

I'm sure these comments will generate some lively discussions at our next meeting. Please contact me with questions or comments you may have.

NMM/dmd

Enclosures: A - Species/Lake Summary
B - Staff Project Review Form

cc: B. Robinson, DEP-Pesticides
D. Les, UConn
L. Mehrhoff, UConn

Attachment A

Lake Name
Species Name, State Status, Date of Last Observation

Beseck Lake, Middlefield

Sagittaria cuneata, State Special Concern (Historic), 1933
Najas quadalupensis, State Special Concern, 1986

Mashapaug Lake, Union

Potamogeton pusillus var. *gemniparus*, State Special Concern, 1902

Pachaug Pond, Griswold

Rotala ramosior, State Endangered, 1938
Potamogeton pusillus var. *gemniparus*, Special Concern, 1902

Pattagansett Lake, East Lyme

Myriophyllum tenellum, State Special Concern, 1985
Lachnanthes caroliana, State Endangered, 1909
Rhynchospora macrostachya, State Endangered, 1909

Wyassup lake, North Stonington

Juncus debilis, Special Concern (Historic), 1932

Attachment B 742

FORESTRY UNIT

DEPARTMENT OF ENVIRONMENTAL PROTECTION

CUTTING PLAN E-757

DISTRICT: EASTERN

LOCATION: TOWN: VOLUNTOWN

PURPOSE: To salvage a dying red pine plantation

MANAGEMENT UNIT: Pachaug State Forest, Stone Hill Block Compartments 2, 6, 11 - Stands 5, 1, 1

ACRES: 8.5

TYPE OF OPERATION: Salvage

PRODUCT (S): Red Pine Sawtimber - 128 MBF

PREPARED BY: K. Grady

DATE SUBMITTED: 10/31/95

* *

DISTRICT REVIEW:

DISTRICT SUPERVISOR:

DISTRICT FORESTER: [signature] 11/16/95

STAFF: Operations Peter B. Houle

Wildlife PR 11/27/95

Fisheries Brian D. Murphy 11/27/95

Recreation 11-29-95 [initials]

HARTFORD OFFICE REVIEW:

STATE FORESTER:

UNITS/STAFF:

Q74 Voluntown

(26) Williamsonia lintneri

1983 IIODO34020.002

(5) Parula americana

ABPBX0200.002

1970

STAFF PROJECT REVIEW

PROJECT TITLE: Phillips Pond Red pine salvage

PROJECT NUMBER:

ORIGINATOR COMPLETE: *To be reviewed by:* ☐ Deputy Comm ☐ Parks & Rec. ☐ O & M ☐ Property Mgt. ☐ Water Resources ☐ Fisheries ☐ Law Enf ☐ Wildlife ☐ Forestry ☐ Other (s) ____

EASTERN DISTRICT	HARTFORD
DISCIPLINE: Park & Recreation Supervisor I would like to see this completed before the mud season and hopefully before an accumulation of snow. The purchase and installation of a "swing" gate may be needed at the North end of trail I to make access to the area easier for the loggers. INITIALS: MR DATE: 11 / 8 / 95	DISCIPLINE: INITIALS: DATE: / /
DISCIPLINE: Forestry This job will be stopped if 6"+ snow for dogsleds to use road. Also no trucking 1 March - 30 April without approval of supervising forester to avoid damage to road. INITIALS: HMH DATE: 11 / 21 / 95	DISCIPLINE: INITIALS: DATE: / /
DISCIPLINE: Fisheries No Fisheries resource concerns. INITIALS: BDM DATE: 11 / 27 / 95	DISCIPLINE: INITIALS: DATE: / /
DISCIPLINE: Wildlife No wildlife problems foreseen INITIALS: PR DATE: 11 / 27 / 95	DISCIPLINE: INITIALS: DATE: / /

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Excellent Article

LAKE LEVEL DRAWDOWN AS A MACROPHYTE CONTROL TECHNIQUE[1]

G. Dennis Cooke[2]

ABSTRACT: Lake drawdown as a management or restoration technique for controlling macrophytes in eutrophic lakes is reviewed for effectiveness, longevity, and positive and negative impacts. Drawdown can be effective but is species specific, and some nuisance plants are resistant or stimulated. The responses of 63 nuisance plants are reviewed. Advantages of the technique include low cost, absence of toxic chemicals, enhancement of fisheries, and the opportunity to carry out other lake improvements. Drawbacks include nutrient release, algal blooms, low dissolved oxygen, lake user dissatisfaction during the process, and failure to refill. The technique is recommended for situations where susceptible species are the major nuisance and where prolonged (1-2 months) dewatering of sediments under rigorous conditions of heat or cold is possible.
(KEY TERMS: eutrophic; lake management; lake drawdown; macrophyte control; water quality).

INTRODUCTION

The protection, management, and restoration of lakes is the subject of an intense international research effort (USEPA, 1979). Water withdrawal or lake drawdown to manage nuisance macrophytes is an established technique. The objective is to retard macrophyte growth by destroying seeds and vegetative reproductive structures through exposure to drying and/or freezing conditions, and by altering their substrate by dewatering and consolidation of sediments. There are several secondary objectives which include turbidity control by sediment consolidation, reduction of nutrient release from sediments, management of fish populations and waterfowl habitats, repair of shoreline structures (e.g., dams, docks, and swimming beaches), and simultaneous use of other restoration methods such as sediment covering. Among the first uses of this technique was the control of vegetation in Tennessee Valley Authority reservoirs to suppress malaria-carrying mosquitos (*Anopheles* spp.) (Hinman and Hess, 1940).

Part of the current research program in eutrophication by the U.S. Environmental Protection Agency is to summarize the state of our knowledge of the effectiveness and problems with the several lake management techniques (Peterson, 1979). As part of that effort, this report was prepared to describe some case histories, to list those macrophyte species which are susceptible, resistant, or do not change after a summer, winter, or whole year drawdown, to evaluate the technique, and to make recommendations for its use and for further research.

REVIEW OF SELECTED CASE HISTORIES

Murphy Flowage, Wisconsin

Beard (1973) describes the response of Murphy Flowage to two consecutive winter drawdowns to control the dominant *Potamogeton robbinsii* (Robbin's pondweed), and subdominants *Nuphar* sp. (water lily), *Ceratophyllum demersum* (coontail), *P. natans* (floating-leaf pondweed), and *Myriophyllum* sp. (water milfoil). In 1967 and 1968 the flowage was lowered 1.5 m from November to March and refilled in April. There was a 92 percent reduction in area covered by macrophytes after two drawdowns, 89 percent of which occurred after the first drawdown. All five species were controlled or essentially eliminated. In 1969, the dominants were *Potamogeton natans*, which was common but not dominant before drawdown, and *Megalondonta beckii* (bur marigold), *Najas flexilis* (naiad), and *Potamogeton diversifolius*, which were previously rare.

In 1967, 42 percent of the flowage (303 ha) was obstructed with macrophytes to the extent that fishing was not possible. The first drawdown restored fishing to 87 percent of this area. The increased density of resistant plants had much less effect on fishing that the previous dominants. Although this was a successful treatment, resistant species began to spread after the second drawdown, and there was a heavy algal bloom in August in the year after drawdown. Dissolved oxygen remained adequate for fish in the channel during winter due to the flow through of water.

Further evaluation was ended when a flood destroyed the flowage in 1970.

Mondeaux Flowage, Wisconsin

Potamogeton robbinsii was also the dominant higher aquatic plant in Mondeaux flowage, which was drawn down during the winters of 1971-72 and 1972-73 (Nichols, 1975b). Forty

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percent (66 ha) of the 166 ha was free of nuisance plant growth after one drawdown, compared to complete coverage before. The second drawdown gave little additional control except for a further reduction in the abundance of *Nuphar variegatum*. In 1974 the abundance of plants returned to pre-drawdown levels and *Ceratophyllum demersum* became the dominant. In this regard, the treatment was unsuccessful. Dissolved oxygen levels during water withdrawal became very low but there was no fish kill.

Nichols (1975b) suggests that a drawdown every 2-3 years would be more effective than an annual water withdrawal since resistant plants might not then become established.

Louisiana Reservoirs

Lantz, *et al.* (1964), describe the lowering of water levels in the Louisiana reservoirs Anacoco, Bussey, and Lafourche, for vegetation management. Forty percent of Anacoco was closed to fishing due to macrophytes, but one year after a summer drawdown, only 5 percent was closed. An area of 283 ha, or 30 percent of the total surface area of Bussey Reservoir was closed, but after a fall-winter drawdown less than 12 ha remained closed. On Lafourche, 60 percent of the reservoir was cleared of nuisance vegetation by a drawdown from winter 1961 through summer 1963.

Drawdown each year was continued on Anacoco, although shifted to the winter season, and several other reservoirs were also drawn down for vegetation control and fish management (Lantz, 1974). Some macrophyte species were very susceptible to drawdown, while others increased or were unaffected (Table 1). Lantz suggests that the water level should be fluctuated each year for 2-3 years, rather than for 1 year, and then 2 years of no fluctuation before lowering again. This schedule gives the best plant control and fish production in Louisiana reservoirs. Lantz concludes that eradication using this or any other macrophyte control technique is unwise and probably not possible. Instead, he believes that the reservoir should be managed to retain desirable or innocuous vegetation, possibly through a combination of techniques.

Summary of Case Histories

The response of 63 macrophyte species to drawdown are listed in Table 1, along with the season of the drawdown and the literature source of the data. The table, modeled after Nichols (1974), illustrates the paucity of quantitative data and the apparent absence of a clear response in many species. Only three species, *Brasenia schreberi* (water shield), *Hydrochloa caroliniensis*, and *Potamogeton robbinsii* always seem to be controlled. *Nuphar* spp. and *Myriophyllum* spp. have also been reported to be controlled. *Alternanthera philoxeroides* (alligator weed), *Lemna minor* (duckweed), *Leersia oxyzoides* (cutgrass), and *Najas flexilis* always increase after a drawdown.

The case histories outlined above illustrate these common features of many drawdowns for macrophyte control:

1. The technique is species specific (e.g., *Potamogeton robinsii*).

2. The invasion of resistant species (e.g., *Najas flexilis*) may be rapid.

3. There may be undesirable changes in the system, including algal blooms and low dissolved oxygen.

EVALUATION OF DRAWDOWN

Macrophyte Control

Drawdown will bring about at least short-term (1-2 years) control of some, and usually most, rooted species if there is nearly complete dewatering of the sediments and a sufficient (1 month or more) period of cold (freezing) or heat. Rigorous conditions of exposure of the thallus and reproductive structures are apparently needed. In many lakes, ground water seepage is an important water source and dewatering of the sediment is very difficult after drawdown. Some species, incuding *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Lemna minor*, *Najas flexilis*, and *Potamogeton pectinatus* are strongly resistant to exposure (Goldsby, 1978; van der Valk and Davis, 1978; Wile and Hitchins, 1978). *M. spicatum*, a serious pest, requires 3 weeks or longer of dewatering during the winter to achieve control. The increased density of *N. flexilis* after drawdown (Tables 1 and 2) is thought to be due not only to the improved nutrient conditions which may occur in partially dewatered sediment, but also to the fact that some lake soils have remained moist after water withdrawal (Kadlec, 1962). Under such moist conditions, *Utricularia gibba* (bladderwort) and *Myriophyllum scabratum* will survive 2 or more weeks of exposure (Hall, *et al.*, 1946).

Beard (1973) attributed the control of *Nuphar* sp. in the Murphy Flowage, Wisconsin, to the light snow cover and the resultant deep frost layer in the exposed sediments. When the flowage was refilled portions of the bottom lifted, ripping *Nuphar* roots out. This condition of deep frost is not always achieved in winter (Gorman, 1979) and perhaps may be a condition limited to the northern climates of Wisconsin, Minnesota, and other areas of that latitude.

In some species reproductive structures are very resistant and exposure can be stimulating to growth (Nichols, 1975a). van der Valk and Davis (1978) describe the drawdown of an Iowa prairie marsh in which seeds and other propagules of species such as *Potamogeton pectinatus*, *Scirpus validus* (soft stem bulrush), *Sparganium eurycarpum* (bur reed), *Lemna minor*, *Sagittaria latifolia* (arrowhead), and *Najas flexilis* remained viable at least 1 year in the exposed marsh soil.

It is not clear whether drawdown and exposure of lake sediments to dry, hot conditions is more effective than exposure to dry, freezing conditions. There have been many more reports of winter drawdowns than summer (Table 1). The advantages of a winter drawdown are that there will be no invasion by terrestrial plants nor development of aquatic emergents, and little interference with recreation. However complete dewatering is more difficult, particularly in areas of heavy snow or of frequent winter rain. Reservoirs drawn down in winter can usually be refilled in spring, whereas refill in autumn after

TABLE 1. Responses of Macrophyte Species to Annual (A), Winter (S), or Summer (S) Drawdown (numbers refer to authors in Literature Cited Section).

	Decreased			Increased			No Change		
	A	W	S	A	W	S	A	W	S
Alternanthera philoxeroides				11	8	15			
Asclepias incarnata		18							
Bidens sp.					1				14
Brasenia schreberi		15.18	14.16						
Cambomba caroliniana	12				15			15	
Carex spp.						14			
Cephalanthus occidentalis					15				
Ceratophyllum demersum	12	1		24	19.7		15	18	14
Chara vulgaris		15							
Dulichium arundinaceum						14			
Eichhornia crassipes	11,12				15				15
Eleocharis acicularis		18.22				14			
Elodea sp.	12								
Elodea canadensis		7			19				
Glyceria borealis					18				
Hydrilla verticillata					4				
Hydrochloa caroliniensis	21	22.21							
Hydrotrida caroliniana									
Jussiaea diffusa		8							
Lemna minor				24		14			
Leersia oryzoides				24	18	14			
Myriophyllum sp.	15	1							
Myriophyllum brasiliense									
Myriophyllum heterophyllum					15			15,8	
Najas flexilis				24	1,18.7	15.14		15	
Najas quadalupensis	11								
Najas minor									
Nelumbo lutea		15.8							
Nelumbo pentepetala								8	
Nuphar spp.		1,18.19							
Nuphar adyena		21							
Nuphar variegatum									14
Nymphaea odorata		15							
Nymphaea tuberosa		18							
Polygonum coccineum					18,8		14		
Polygonum natans					18				
Pontederia cordata		18					11		14
Potamogeton sp.		16	16	9					
P. amphifolius		1,18			19				
P. crispus								7	
P. diversifolius		15			1			15	
P. epihydrous					18				
P. foliosus			14		18			7	
P. gramineus					18,19			7	
P. natans								1	14
P. pectinatus						24		7	
P. richardsonii					18			1	
P. robbinsii	11	19							
P. zosteriformis					19				
Potentilla palustris		18							
Sagittaria sp.				24	19	14	11		
Sagitarria heterophylla		18							
Salix interior					18				
Scirpus cyperinus	11					14			
Scirpus validus				24	18				14
Sium suave					18				
Sparganium chlorocarpum								1	14
Typha latifolia					18		11		14
Utricularia sp.								8	
Utricularis vulgaris		18.21							
Vallisneria americana	11							18	
Zizania aquatica									14
Zizaniopus miliacea		22							

summer drawdown may be difficult and may actually continue into winter. But winter drawdown may be adverse to projects where establishment of emergent vegetation for waterfowl habitat development was an object since these emergent species may be susceptible to the cold. Summer drawdown may not be possible on some reservoirs where an assured potable or industrial supply during summer drought is important, or where summer recreational uses could be seriously curtailed.

TABLE 2. Responses of Some Common Nuisance Aquatic Macrophytes to Drawdown (number of observations and seasons in parentheses; numbers refer to authors).

A. INCREASED

1. *Alternanthera philoxeroides* (alligatorweed) (3; all seasons) Ref: 8, 11, 15.
2. *Najas flexilis* (naiad) (7; all seasons) Ref: 1, 7, 14, 15, 24.
3. *Potamogeton* spp. (pondweed) (most increase or do not change; see Table 1).

B. DECREASED

1. *Chara vulgaris* (muskgrass) (1; winter) Ref: 15.
2. *Eichhornia crassipes* (water hyacinth) (2; annual) Ref: 11, 12.
3. *Nuphar* spp. (water lily) (3; winter) Ref: 1, 18, 19, 21.

C. NO CHANGE OR CLEAR RESPONSE

1. *Cabomba caroliniana* (fanwort) (3; annual, winter) Ref: 12, 15.
2. *Elodea canadensis* (elodea) (2; winter) Ref: 7, 19.
3. *Myriophyllum* spp. (milfoil) (5; annual, winter) Ref: 1, 8, 15.
4. *Utricularia vulgaris* (bladderwort) (3; winter) Ref: 8, 18, 21.

The decision to employ a summer or a winter drawdown for macrophyte control therefore must be based not only upon the rigorousness of the climate in a particular area, but also upon uses of the reservoir and any secondary management objectives. Until there has been further documentation, particularly of summer drawdown, it is not possible to recommend one or the other for control of a particular plant nuisance.

Positive and Negative Impacts of Drawdown

Game fishing often improves after a drawdown (Pierce, *et al.*, 1963; Beard, 1973). According to Lantz, *et al.* (1964), winter drawdowns in Louisiana are effective in removing populations of sunfish and shad, whereas summer drawdowns are more effective in preventing spawning of these species. In reservoirs where there have been 5 or more consecutive years of fluctuation there was an increase in fish standing crop, a rapid increase in game fish size and reproduction during the first years of fluctuation, and a leveling of standing crop change after several fluctuations (Lantz, 1974). Others (e.g., Halsey, 1958) have used drawdown as a means not only of increasing predation by concentrating fish but also as an opp tunity to engage in a fish removal program. Where ana mous fish are involved, drawdown must be timed to minir adverse effects on migration either through or out of the la

In many lakes, the sediments are loose and flocculent w high nutrient release, and may be a significant source of bidity through the action of motor boats and wind. The periments of Fox, *et al.* (1977), demonstrated that sun-d sediments lose a great deal of water and remain consolid after reflooding, and Kadlec (1962) reported that org marsh sediments exposed to a summer drawdown became enough to walk on, and also remained firm after refloo Presumably reservoirs with turbidity problems could be proved by sediment consolidation.

Halsey (1958) has pointed out that drawdown can b opportunity for lakeshore residents to improve docks, dams, clean and repair shorelines, and deepen areas suc swim beaches. Also drawdown provides an opportunity install other lake management devices such as sediment co ings.

Some impoundments lose their attractiveness to water after several years due to a succession of the macrophyte c munity towards plants which do not provide as much foo waterfowl as before (Kadlec, 1962). Drawdown has been to renew such systems (e.g., Uhler, 1944; Steenis, 19 Emergent plants attractive to waterfowl will develop from seed bank in the sediments (van der Valk and Davis, 1978).

Algal blooms after reflooding may be one of the most tive impacts of drawdown, although such blooms are far preferable than macrophytes for some boating activities cause of these algal blooms is not clear. It has been bel that drawdown and exposure of sediments, and the subse aeration and oxidation, may bring about considerable nu release at reflooding (Cook and Powers, 1958; Halsey, Kadlec, 1962; Wegener and Williams, 1974; Harris and shall, 1963). The experiments of Fox, *et al.* (1977), for m type sediments from Lake Apopka, Florida, indicate tha ing and consolidation followed by reflooding does not about a breakdown of organic matter and nutrient re However, Plotkin (1979) observed substantially increas terstitial phosphorus concentrations in rewetted, highl ganic sediments following 2, 3, or 4 months of drying. lying water also became enriched and caused algal bl Similar to Lake Apopka sediments, these sediments Lake, Washington) were consolidated by 50 percent, bu organic content did not change under experimental tions. Nevertheless, the increased interstatial P levels thought to be related to mineralization of organically bou

Fish kills may occur after drawdown, particularly in mer when rates of metabolism and oxygen demand of the ments are higher (Geagan, 1960). However, dissolved o following a 2 m summer drawdown of Long Lake, Wa ton (max. depth 3.5 m) remained above 5 mg/l with parent acute effects to fish (E. B. Welch, personal comm.

The fauna of the littoral zone may exhibit great char species composition and density following drawdown flooding (Kadlec, 1962; Hunt and Jones, 1972; Wegener, 1974). While there may be an increase in invertebrate density after refiooding, as reported by Wegener, *et al.* (1974), there may be a great decrease in species diversity (Hunt and Jones, 1972). Not only is repopulation slow, but a summer drawdown and subsequent hardening of soils could reduce colonization by insects (Kadlec, 1962). Such changes in benthic invertebrates could be very detrimental to waterfowl and fish.

Failure to refill the reservoir after drawdown may be due to an insufficient watershed drainage area, to failure to close the dam at the proper time, and/or to unexpected drought. This problem points out the need to have an estimate of the water budget of the system before drawdown so that refilling time can be predicted.

Drawdown may also bring about other significant negative impacts, including those to downstream users of discharged water, to docks, and to potable water wells around the periphery of the lake.

Areas for Additional Research

The reports of success with drawdown to control macrophyte problems, with the exception of the Louisiana reservoirs (Lantz, 1974), have been short-term studies (1-2 years). As with many other lake manipulations, little followup has been possible. What interval between drawdowns is required to maintain vegetation control? Does the interval vary with summer or winter drawdowns?

Can the effectiveness of this technique be enhanced by combining it with other plant management methods such as sediment covering (Gorman, 1979; Cooke and Gorman, in press) or dredging (Fox, *et al.*, 1977)? The exposure of sediments provides an opportunity to proceed with other restorative steps, perhaps at a lower cost than when the lake is full.

What is the impact of dewatering on sediment chemistry and the release of material to the water column after reflooding? Do the factors vary with sediment type? Fox, *et al.* (1977), report that peat-type lake soils lose almost no water upon drying (7 percent in 180 days) but organic muck-type sediment consolidate 40-50 percent in the same period. Plotkin (1979) observed similar consolidation of highly organic sediment.

There is a need to develop a more systems-level perspective to the evaluation of this and all other lake restoration techniques. With regard to drawdown, major changes in nutrient cycling and energy-flow must occur as vertical zonation, water and nutrient income and flow through, consolidation of sediments, oxidation of detritus, elimination of plants, animals, and microbes which process organic matter, and changes in fish populations, take place. While questions about some or all of these processes have been addressed for some lake restoration techniques, little evidence is yet at hand for lake drawdown. An example of this approach is provided by the work of E. B. Welch, *et al.* (1979; personal communication). A 2 m drawdown was completed on Long Lake, Washington, during summer 1979. The dominant plant species is *Elodea densa* (water weed) and 40 percent of the P loading is internal, much of which could originate from *Elodea* and *Potamogeton* decomposition. Plants readily dried up upon dewatering and if regrowth is delayed 1-2 years a marked decrease in summer internal P loading may occur and result in less algae and clearer water.

SUMMARY AND RECOMMENDATIONS

Summary

Water level drawdown is an effective technique for at least the short-term control (1-2 years) of susceptible nuisance macrophyte species, and can be accomplished at relatively low cost without the introduction of chemicals or machinery. This technique is species specific and requires careful identification of the target plants before drawdown. Rapid establishment of resistant forms may occur. There is insufficient information to determine whether a summer or a winter drawdown will be most effective, but freezing to kill reproductive structures apparently required a deep frost which may not occur with heavy snow cover or with the milder, rainy winter which is found in large portions of the most macrophyte-impacted areas of the United States. It is apparently essential to achieve dewatering of the sediments, and this can be difficult where seepage is a significant portion of the water budget. This points out the need to determine a water budget before drawdown.

Among the positive changes which may occur, in addition to macrophyte control, are enhanced populations of game fish, consolidation of loose, flocculent sediments and thus possible control of turbidity generated by waves and motor boats, and the provision of an opportunity to improve docks, dams, and swimming areas.

There can be important negative changes following drawdown, including establishment of resistant macrophytes, algal blooms, fish kills, changes in littoral fauna, failure to refill, decline in attractiveness to waterfowl, lowered levels in potable water wells, and unavailability of open water or access to open water for recreation.

Recommendations

Lake level drawdown for macrophyte control is recommended for situations where prolonged (1 month or more) dewatering of lake sediments is possible under rigorous conditions of cold or heat, and where susceptible species (Table 2) are the major nuisances. As pointed out by Fox, *et al.* (1977), lakes with gradual basin slopes are ideal since small drops in lake level will expose large areas. The technique appears to have potential to be very effective if used in combination with other lake restoration methods such as dredging, sediment covering, game fish management, and herbicides. The introduction of exotic species, such as was done by Mather (1965) with the stocking of Israeli carp, may be very effective in combination with drawdown, but additional research is needed on possible adverse environmental effects before exotic species can be stocked in lakes and ponds.

An estimate of the water budget is very important so that the contribution of seepage, and thus the degree of dewatering, is known, and also the rate of refilling will be established.

There are many areas of additional research needed with the drawdown method, including long-term monitoring to establish frequency of drawdown needed, and studies of the contribution of reflooded consolidated sediments to the nutrient budget of the system, as well as the possible reduction of P loading internally because of macrophyte decrease.

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