AQUATIC PLANT CONTROL RESEARCH PROGRAM

MISCELLANEOUS PAPER A-77-1

A CONCEPT FOR THE DEVELOPMENT OF LONG-TERM MANAGEMENT PLANS FOR AQUATIC PLANT CONTROL

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June 1977
Final Report

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper A-77-1	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A CONCEPT FOR THE DEVELOPMENT OF LONG-TERM MANAGEMENT PLANS FOR AQUATIC PLANT CONTROL		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Dana R. Sanders Joseph L. Decell		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Mobility and Environmental Systems Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE June 1977
		13. NUMBER OF PAGES 24
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aquatic plant control
Environmental management
Management methods

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This paper describes a general concept that will serve as a basis for developing well-conceived aquatic plant management plans, as well as a step-by-step guide for implementing measures for long-term aquatic plant control while giving proper consideration to their potential long-term effects on the environment. More specifically, the concept provides a procedure for federal, state, and local agencies to use in the systematic assessment of the aquatic plant

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued).

problem in a water body, the objective evaluation of all potential control measures, the consideration of water body user demands and environmental constraints, and the development of an operational plan including provisions for monitoring and updating.

The various tasks involved in the development and implementation of an aquatic plant management plan are identified and arranged in a conceptual framework that provides for the proper flow of information from one step to another so that each step or task can be properly accomplished in the proper time frame. The various tasks are grouped into five phases as follows:

Phase I: Problem Identification and System Description
Phase II: Data Collection and Analysis
Phase III: Selection of Control Techniques
Phase IV: Operational Plan Development
Phase V: Operational Plan Implementation and Monitoring

The framework provides a basis for development of an aquatic plant management plan that properly considers unpredictable environmental, economic, or political influences that may arise within the time frame during which a management plan is being implemented.

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Preface

The concept described herein was developed by Mr. J. L. Decell and Dr. D. R. Sanders, Chief and Plant Physiologist, respectively, of the Aquatic Plant Research Branch (APRB), Environmental Systems Division (ESD), Mobility and Environmental Systems Laboratory (MESL), under the general supervision of Messrs. W. G. Shockley, Chief, MESL, and B. O. Benn, Chief, ESD. Funds were provided by the Office, Chief of Engineers (OCE), Department of the Army, under authorization 96X3122. The OCE Technical Monitor was Mr. Roger Hamilton.

Acknowledgment is made to Mr. Howard Roach, Chief, Pest Control Branch, South Carolina Public Service Authority, and Dr. Norris Jeffrey, Research Coordinator, South Carolina Department of Fisheries and Marine Resources, for providing both the impetus and continued assistance during the development of this concept.

Commander and Director of the WES during this study and preparation of this report was COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

Contents

A CONCEPT FOR THE DEVELOPMENT OF LONG-TERM MANAGEMENT PLANS FOR AQUATIC PLANT CONTROL

Introduction

1. The multitude of reservoirs, lakes, rivers, and canals that exist in the United States are normally subjected to management plans that are designed to enhance wildlife, fisheries, navigation, and industrial, commercial, and private water supply systems. However, seldom do such plans include provisions for considering the impact of troublesome aquatic (water) plants on the use and management of these multipurpose waterways, much less for solving real or potential aquatic plant problems. Interest in this aspect of an overall lake or river system most often arises only after one or more plant species have grown to such a problem level that user interests or demands on these waterways are drastically affected by the presence of the plants. Resulting demands for an immediate solution to the problem often prompt the use of expedient, short-term, or ill-applied measures for control that often attack only the symptoms of the problem. The decision to use a specific control technique is too often made by individuals whose knowledge of the true nature of the problem does not extend beyond the fact that a problem exists. At best, some measure of control is obtained without seriously considering long-term effects on the total lake or river system or other demands.

2. The situation described above makes it worthwhile to emphasize that the selection of an aquatic plant control method should be the result of a systematic consideration of all existing control measures and the potential benefits of their use in each water body. Such considerations can result in a well-conceived management plan that provides guidance for complete and continual assessment of the problem, evaluation of control alternatives and their effects, and step-by-step implementation of control procedures. Adhering to such a plan can reduce cost of materials and labor, decrease the time required to achieve plant control,

increase the degree of plant control, and prevent duplication of effort. It can additionally provide confidence in the prediction of future needs because implementation of the plan should provide for measuring the degree of success in decreasing the quantity of selected aquatic plant species for each treatment used. The concept discussed herein is intended to be (a) a basis for developing aquatic plant management plans that will be well conceived and (b) a step-by-step guide for implementing measures for long-term aquatic plant control while giving proper consideration to their potential long-term effects on the environment.

Purpose and Scope

3. The U. S. Army Engineer Waterways Experiment Station (WES) has formulated a concept for development and implementation of an aquatic plant management plan for large bodies of water, such as rivers and man-made reservoirs. The concept is presented in this report at a general level for use by management as a planning tool and as a means of monitoring an aquatic plant management plan by operations personnel. A more detailed concept will be presented in another report for use by operations personnel in the actual development and implementation of a management plan.

4. The concept provides a step-by-step procedure for the systematic assessment of the aquatic plant problem in the water body, the objective evaluation of all potential control measures, the consideration of water body user demands and environmental constraints, and the development of an operational plan including provisions for monitoring and updating. It is intended for use by the various federal, state, and local agencies that are confronted with the problem of aquatic plant control as part of their responsibilities.

Concept Phases and Procedural Steps

5. The aquatic plant management concept is composed of the five following phases:

a. Phase I: Problem Identification and System Description.

b. Phase II: Data Collection and Analysis.

c. Phase III: Selection of Control Techniques.

d. Phase IV: Operational Plan Development.

e. Phase V: Operational Plan Implementation and Monitoring.

The relation of the work efforts in the five phases of the concept is illustrated in a flow diagram (Figure 1). Flow diagrams of various types are widely used in many branches of science and engineering to portray complicated processes, thus making them more readily understandable. These diagrams are especially valuable when the process incorporates decision points that trigger two or more alternative procedures, depending upon the nature of the decision. There need not be many sets of decision-induced divisions before the overall pattern can become quite elusive. The same may also be said for processes in which two or more events must necessarily occur at the same time, all timed in such a way that results of the concurrent subprocesses develop at the proper time to be incorporated in some later step.

6. Methods of identifying, evaluating, and rendering operational a management plan for the control of aquatic plants include both kinds of complexities. As a consequence, it is difficult to keep all parts of the processes in mind and in balance, which is necessary if events are to be kept on schedule. The flow diagram is intended to provide a logically ordered framework that not only organizes complexities into an understandable pattern but also provides a basis for the development of the management plan. Although the concept is presented at a very general level, it is emphasized that it can be readily expanded to the level of detail needed for a comprehensive aquatic plant management plan.

7. Each procedural step identified in the flow diagram (Figure 1) has been coded to identify the phase (see paragraph 5) in which it is accomplished. Also, each step or "block" has been numbered, and in the following discussion, block number refers to the equivalently numbered procedural step in Figure 1. The flow diagram is not arranged within a rigorous time frame. Time generally flows from left to right, but no

uniform time scale is implied, and one should not assume that placing blocks one under the other implies that the steps are necessarily to be performed simultaneously. Time flows with arrows between blocks, not with position in the diagram. The following paragraphs present a discussion of the procedural steps in the five phases of the concept.

Phase I: Problem Identification and System Description

8. Phase I (blocks 1-13) is needed to identify the basic aspects of the lake or river ecosystem. Each block is assessed on the assumption that the system has (or may have) a particular complement of aquatic plants at some point in time. Information generated from blocks included in this phase is used in accomplishing tasks set forth in blocks of later phases.

9. Block 1. The first step in the development of a management plan is to determine whether any aquatic plants are currently a problem or are likely to become a problem in the future. This can be accomplished by a general species survey of the water body, a general assessment of the area occupied by each species, and a consideration of complaints about aquatic plants by individuals using the water body. The mere presence of most aquatic plant species does not necessarily mean that an aquatic plant problem exists. When large quantities of aquatic plants interfere with normal system use and cause complaints by the public sector, they can properly be termed a problem. Also, the presence of certain plant types, such as hydrilla (*Hydrilla verticillata* Royle), which possess the ability to rapidly become a problem, demands immediate attention and should be categorized as an immediate problem. Preliminary field observations are necessary to address the question. A positive determination immediately establishes a need for initiation of several lines of independent investigation (blocks 5, 7, 9, and 11). It is important to accomplish the tasks at these blocks independently to avoid excluding important data needed to objectively select a control plan. A negative determination in block 1 denotes that no aquatic plant problem exists or is likely to exist in the future.

10. Block 2. The areas of the water body in which environmental

conditions are suitable for the establishment and growth of aquatic macrophytes are determined by utilizing maps and conducting surveys of the water body. If the water level fluctuates sufficiently, the water flows are adequate, and the water is extremely turbid and sufficiently deep and open, areas suitable for the development of troublesome quantities of aquatic plants probably do not exist, and the pathway leads to block 3. If such areas are found to exist, block 4 is next.

11. Block 3. If there are no areas of the water body capable of supporting large quantities of aquatic plants, then no aquatic plant management plan is needed at this time.

12. Block 4. If the determination made in block 2 is positive, a program of preventive control should be initiated. This is an important aspect of construction and maintenance of a water body that is often overlooked. The most effective method of preventing species, such as hydrilla, from becoming a problem is to prevent the initial establishment of the problem plant species. This requires a variety of preventive activities, including periodic inspection of shallow, protected areas and boat launch areas. Careful planning and successful implementation of this program can effectively prevent establishment and spread of many problem aquatic plant species. The elements necessary for effective preventive control are identified and discussed in another report.

13. Block 5. If a positive determination is made in block 1, one line of investigation to be followed is the identification of system users, such as fishermen and hunters, hydroelectric production interests, and flood control interests. It is vital that all system users be identified, but the resulting system users list should not reflect an attempt to rank the importance of the identified users because there is usually not enough data available at this point to do so. Identification of an aquatic plant problem suggests that one or more of these user demands are or may be limited by the presence of aquatic plants. At the same time, other users may actually benefit from these same existing levels of aquatic plants.

14. Block 6. For each system user identified in block 5, data

concerning user demands must be identified and compiled for future consideration in the development of the management plan. This can best be accomplished by obtaining directly from the individual users such information as the economic value of the water body to the specific user (e.g., hydroelectric production capabilities can be related to each foot of depth that the water body exceeds the normal pool stage), the specific demands of each user of the water body (e.g., hydroelectric production cannot occur if the water level falls below that minimal level below which the water supply is insufficient), and the time frame within which user demands occur (e.g., the critical time when the water level approaches the minimum allowable). This approach not only provides a primary source of data pertaining to user demands but also has the advantage of bringing the various interest groups into the active development of the management plan early in the developmental sequence. Most users of the system will have a primary demand, and it is expected that almost all will exert more than one demand on the system.

15. Block 7. A second line of needed investigation is a survey of literature to determine the control agents and techniques that either have been or are now being used to control the aquatic plants identified in blocks 1 or 11, including promising experimental methods. This survey will result in an unranked list of specific agents or techniques that potentially could be used in the aquatic plant management effort. This list may include some methods that subsequently will be judged to be either not useful or useful only under specific circumstances. However, it is important not to prematurely bias the list by excluding any method that may have present or future potential use. Examples of agents or techniques that might appear on the preliminary, unranked list in this block (7) include 2,4-D BEE (2,4-dichlorobutoxyethanol ester), water-level fluctuation, white amur (Ctenopharyngodon idella Val.), and mechanical harvesters.

16. Block 8. Each control agent/technique identified in block 7 should be surveyed to obtain information vital to the determination of its potential use in the project under consideration. Information sought includes plant species controlled, effectiveness, cost,

environmental constraints, use hazards, availability, instances where previously used (including degrees of success), equipment required to apply, practicality of use, possibility of use in integrated control, treatment rates, etc. Cost is included for later use but should not, at this point, affect decisions concerning the management plan development.

17. Block 9. The various environmental components of the aquatic ecosystem being considered (e.g. physicochemical properties of the water, physiographic factors, energy budget of the water body, and hydrosoil characteristics) play an important role in influencing the nature of the plant communities that can develop in the system and are identified in this block. This can be accomplished by surveying the literature for previous environmental studies of the water body and the area in which it is located and by preliminary observation of the area. The resulting list of environmental quality categories should be ranked and portrayed so that those factors critical to the maintenance of a high-quality aquatic ecosystem are identified.

18. Block 10. The levels of certain environmental components that were ranked in the top positions on the list developed in block 9 may exert a special or critical influence on the maintenance of a quality aquatic ecosystem. Certain levels of these components (e.g. biological oxygen demand, cyclic dissolved oxygen concentration, water temperature, nitrate nitrogen content of the hydrosoil, etc.) are critical to the maintenance of the high quality of an environment and of a stable ecosystem; therefore, they are important in terms of limits they may place on potential control techniques. For example, the quality of an aquatic ecosystem may be destroyed when the dissolved oxygen concentration falls below 1.5 mg/ℓ.* The effort depicted by this block is accomplished by compiling data through a literature search and a preliminary investigation of the water quality in the water body.

19. Block 11. The plant species (types) that either now are or may become a problem must be identified. The general species survey

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* mg/ℓ = parts per million.

(block 1) and a gross estimation of the present role of each plant species in the water body can be used as the basis for identifying those plant species requiring attention and for developing a list of problem plant species. Some plant species may require immediate attention, such as any species currently impinging on one or more user interests or species currently present that are capable of spreading rapidly, e.g. hydrilla and Eurasian watermilfoil (Myriophyllum spicatum L.). Evaluation of aquatic plant population trends is often necessary to predict future changes in the aquatic plant community of the water body.

20. Block 12. Comprehensive literature surveys must be undertaken to obtain information for each species identified in block 11 regarding growth habits, competitive ability, growth rates, geographic distribution, environmental tolerances, growth cycles, reproductive capabilities, nutrient requirements, and response to various control measures. Often, information obtained from this block will provide a vital key to the successful evaluation of the aquatic plant problem.

21. Block 13. By combining information from blocks 6 (i.e. the degree to which one or more plant species is currently restricting the use of the water body) and 12 (i.e. the plant species present and their potential rate of spread), the necessity for short-term (interim) control can be determined. If the response to the question in this block is positive, information from blocks 8 (data concerning control agents/techniques), 12 (data pertaining to plant species), and 16 (desired level of control) can be combined to develop a list of agents/techniques capable of providing control of the specified plant problem (block 17). A positive response also provides the impetus for the later combination of information from blocks 25 (control agents/techniques ready for immediate use) and 27 (control agents/techniques ranked on the basis of environmental and user constraints) to select the "best" set of control agents/techniques for solving the immediate aquatic plant problem (block 30). Depending on the urgency of the need for short-term control, the level of attention given each block in the above combinations will vary. Often, short-term control is necessary because no serious attention is given a developing plant problem until it is out of hand. If

the response at block 13 is negative, this will lead to block 14 (design and implement a data collection program).

Phase II: Data Collection and Analysis

22. To develop a viable long-range management plan for a water body, much information is needed to adequately describe and assess the problem. It is important not only to know the areal extent of the problem but also to describe the rate of or potential for growth of the problem, and to identify the pertinent data required to rationally select the eventual control agent and the necessary data for monitoring the effects of treatment. Blocks 14-15 describe the data collection and analysis phase, the result of which provides an assessment of the problem.

23. Block 14. The first task in this phase is to design and implement a data collection plan. Inherent in this design is identification of necessary data and selection of the most efficient data collection methods. In nearly all cases, the data that must be collected will require both ground sampling (e.g. species distribution in the water body, species biomass data, and light intensity and depth distributions in the water body), and remote sensing for mapping the distribution of the problem plants (e.g. aerial photography). To produce high-quality data bases and products, it is important to coordinate the ground sampling and the remotely sensed data. There must be a measure of flexibility in this aspect of the management plan because the nature and size of the water body will influence the comprehensiveness of the data collection plan. Implementation of the data collection plan consists of collecting the various data identified as essential (e.g., biomass samples are collected from prescribed locations in the water body, and an aerial reconnaissance mission is flown to map the distribution of the problem plants to provide a base map according to a previously determined plan). The result will be a mass of raw data that will be analyzed and portrayed in block 15.

24. Block 15. The data resulting from the tasks performed in block 14 must be analyzed so as to select the best control measures related to the problem plant species (block 30) and to develop an

operational plan for control (block 34). Data analyses will result in quantitative parameters that will have application to control plan development. Each parameter represents a factor, and the various factors can be portrayed simultaneously in a manner that describes their interrelations. For example, a relation obviously exists between light intensity and depth in a water body. Another relation obviously exists between species and biomass distributions in the water body. By combining aerial photographs to form an aerial mosaic of the water body and then producing overlays of the distributions of the four factors mentioned above, the areas of the water body requiring treatment can be delineated. Such is the type of information from block 15 that affects operational control plan development (block 34).

Phase III: Selection of Control Techniques

25. The data and products resulting from Phases I and II must be further evaluated, analyzed, and combined to develop an operational management plan. During this phase, consisting of blocks 16-33, the information on problem plants, potential control agents, user demands, and environmental considerations converge, with the result that a control system is selected (block 30). It is assumed that the level of control provided by the resulting agent or combination of agents (resulting from trade-offs made in this phase) represents the maximum possible level of plant control that does not exceed system constraints. Control methods resulting from this process do not necessarily represent the methods or agents that will eventually be used, because nontechnological constraints (e.g. political or social pressures and operational costs) might render the most effective agents nonusable.

26. During this phase of the management plan development, four lists identifying possible control measures are compiled. One list identifies potential control measures that are deemed capable of controlling the identified problem plant species compiled on the basis of previous use experience (block 17). A second list ranks these potential control measures on the basis of public user and environmental quality constraints (block 19). A third list, compiled independently of the

list in block 19, ranks the potential control agents on the basis of efficacy (block 26). The second and third lists are combined to rank the control agents on the basis of efficacy and user and environmental constraints (block 27). These lists are compiled independently to ensure a high degree of objectivity and to minimize premature exclusion of a possible control agent. The rankings are made to establish a basis for the trade-off process necessary to produce a final list reflecting consideration of all of the system constraints. The following paragraphs discuss this phase of the plan development.

27. Block 16. Any time an effort is made to manage aquatic plants, the desired level of control must be established. What is the desirable population level of the target plant species? This may range from zero (eradication) to a sizable acreage, depending on the nature of the target plant species and its location within the water body relative to water-body uses. Eradication of the target species may be impossible or undesirable in most cases, but there are some instances where this has been accomplished. Many factors will dictate the desired level of control (the role of the species in the ecosystem, the lake structure, the competitive ability of the species, etc.). The level of control provided by the individual control agent or technique will vary depending on the nature of the agent (block 8), growth characteristics of the target species (block 12), and timing and conditions under which the methods are applied. The primary constraint that establishes the level of control will also vary from situation to situation. For instance, if a particular species can be effectively controlled only by water-level fluctuation and the species occurs at a water depth greater than the minimum tolerable, the limits placed on the degree of water-level fluctuation will be the primary constraint on the maximum achievable level of control. Nevertheless, the desired level of control must be established in terms that can be related to future assessments of applied treatments.

28. Block 17. By combining data on control agents (block 8) with an established desired level of control (block 16), it is possible to identify those agents capable of controlling the aquatic plants in

question at that level. Many existing control agents are effective in controlling only selected species. For instance, certain waterhyacinth weevils are specific to waterhyacinth (*Eichhornia crassipes* (Mart.) Solms.); consequently, these same waterhyacinth weevils would be ineffective in controlling waterlettuce. Completion of the task in this block will produce an unranked list (or lists) of control measures that could be used to obtain the desired level of control of the specified target plants, exclusive of any consideration of environmental effects, user constraints, or costs.

29. Block 18. Environmental and user constraints must be assessed to determine the impact they will exert on the choices of control measures to be implemented in the operational plan (block 34). Both the legal and the desired environmental quality limits must be identified and established. The legal environmental quality limits are available from various governmental regulatory agencies. For example, the legal permissible minimum dissolved oxygen content for a particular water body may be 4.0 mg/ℓ; therefore, the use of any method likely to reduce the dissolved oxygen concentration to a level lower than 4.0 mg/ℓ would be prohibited. On the other hand, desired environmental quality limits represent levels of critical environmental quality factors that exceed legal limits of that factor as dictated by law. These may be either more restrictive (e.g. 3.5 mg/ℓ of dissolved oxygen in the water as a desired limit as compared with 1.0 mg/ℓ for short durations as prescribed by law) or less restrictive (e.g. cases in which some legal limits must be relaxed to grant a special use permit). Desired environmental quality limits are determined by those who develop the management plan. By contrast, user constraints were previously determined at block 6 (e.g., hydroelectric production requires some minimum water level). The urgency for short-term control can affect the level of detail at which this block (18) is considered. The results of this block will be a list of environmental and user constraints, together with the operating range for each constraint within which any control measure must function.

30. Block 19. From a combined list of environmental and user constraints (from block 18) and potential measures capable of controlling

the target plant species (block 17), control agents can be ranked according to their abilities to operate within the prescribed constraints. A control agent priority list for each environmental and user constraint will result, which can be collated to produce a list of ranked control agents for each problem plant species. In this manner, the control agent at the top of the priority list for hydrilla control, for instance, will be the agent most compatible with user interest and environmental quality constraints. However, this same agent will not necessarily provide the best level of control of hydrilla.

31. Block 20. To prevent premature exclusion of an agent, the determination made in this block must be made independently of other considerations related to potential control measures. The development status of potential control agents in the list from block 17 must be determined by using information obtained from block 8, which identifies how and when the particular control agents have previously been used. Each control agent must be categorized as (a) requiring additional research and development prior to field experimentation (block 21), (b) ready for future use and awaiting a ruling or permit for use (block 22), (c) ready for use within the management plan time frame (block 24), or (d) ready for immediate use (block 25).

32. Block 21. Those agents from block 20 that will require additional research and development are disregarded from any further consideration for the purpose of the management plan under development. Some of these agents might eventually be tested and cleared for operational use in the future, but it is unlikely that they will be of benefit even in an updated version of the plan.

33. Blocks 22 and 23. Control agents from block 20 that are not currently available but may be ready for use outside the management plan time frame (e.g. *Sameodes albiguttalis* Warren for waterhyacinth control) are identified and categorized in block 22 and can be incorporated into the management plan at such time that it may be updated (block 23) in the future. These agents are also disregarded from futher consideration herein.

34. Block 24. Other control agents or techniques from block 20

can be identified that will be ready for use within the management plan time frame but not at its implementation. These are control agents or techniques for which petitions have been submitted that would enable them to be readily used in aquatic plant control operations (e.g. diquat). Especially promising agents or techniques, which will provide better control of the target species than immediately available agents, should be earmarked for use in the management plan. Agents identified in this block should be combined with data from block 25 to establish ideal priority lists of control agents or techniques based on effectiveness.

35. Block 25. Control agents from block 20 that are ready for immediate use are identified in this block. All necessary clearances have been obtained for these agents (e.g. 2,4-D BEE, waterhyacinth weevil, and Aqua-Trio system*). Agents to be considered for short-term control are included in this group.

36. Block 26. All control agents from blocks 24 and 25 are ranked in this block, with the ranking based only on efficacy of control (i.e., how effective each agent is in controlling the population level of a target species). There will be a list of ranked control agents for each target species, but the urgency for interim control will play a major role in the composition of these lists. Obviously, only those agents currently ready for use can be considered for interim control.

37. Block 27. From a combined list of agents from block 19 (based on user interests and environmental quality constraints) and those from block 26 (based on effectiveness and degree of availability), new control agents and techniques lists are developed. These lists should provide the basic information required to eventually select the best control system for use in the water body under consideration.

38. Block 28. The possibility of achieving integrated control must be considered by surveying priority lists from block 27 for single agents that might be combined with other single agents or agent

* A mechanical harvesting system developed by Aquamarine Corporation, Waukeska, Wisconsin.

combinations to produce a level of control exceeding that possible when the various components are used individually. For example, combining water-level fluctuation and diquat at 1.0 mg/ℓ can produce more effective control of hydrilla than either agent used alone. If a survey of the agent lists from block 27 supports the possibility of an agent combination that will produce more effective control than any agent used alone, the pathway leads to block 29 (test potential combinations and compare lists from block 27). A negative determination will indicate that integrated control is not feasible; thus the lists from block 27 would suffice for determining the best control system at block 30.

39. Block 29. Agent combinations identified in block 28 are evaluated in this step by either determining compatibility from a careful survey of literature or by applying the two (or more) agents in an area of the water body large enough to adequately assess their combined impact on the target species. The field testing would be incorporated as an integral part of the first-year control plan if the urgency of the situation demands immediate treatment. Results must be compared with areas in which each agent is applied singly. Those combinations indicated by favorable results will be collated with the lists from block 27 and to select the best control system (block 30).

40. Block 30. All data accumulated from blocks 16-29, which relate to various agent descriptions, comparisons, and rankings, are brought together at this point to select the "best control system" that can be used against the target plant species. The best control system is, by definition, the agent or combination of agents that can provide the highest degree of target species control while producing the least detrimental effects on the ecosystem. There must be provisions in the control system for effecting control of each problem plant species determined from block 11. If a single agent can provide effective control of all target species, it could well be the only control agent used. If a combination of agents is required to control one problem plant species, then the system must include each component of the combination. The selection of the best control system at this point does not involve consideration of cost nor availability of an agent delivery system.

41. Block 31. After a control system has been selected, the operational status of each component of the control system must be determined. Each control agent must be examined to determine if the necessary support system is available to adequately deliver it to the problem plant. Also, agent compatibility must be assessed. For example, two chemical agents selected for use may negatively influence each other because of their physical properties, rendering both ineffective. If the selected system is deemed fully operational, information from block 30 can be combined with information from block 15 to produce a control plan (block 34). If the system is not fully operational at this point, the pathway leads to block 32.

42. Block 32. If the selected control system is not fully operational, the possibility of altering the system must be examined. If it cannot be altered, a reevaluation must be made at block 30 to determine if a control system can be selected that is fully operational. If the system can be altered, the pathway leads to block 33.

43. Block 33. Aspects of the selected control plan (block 30), previously identified as requiring alteration, can be changed to render the system fully operational. For example, it is possible that a particular selected chemical requires application equipment that is not readily available commercially. However, if it was determined at block 32 that the equipment could be fabricated, this alteration would then result in a fully operation system. This would then lead to block 34.

Phase IV: Operational Plan Development

44. After all the evaluations and trade-offs in Phase III have been completed and a control system has been selected for use, a detailed operational plan (presented in blocks 34-38) must be developed to ensure that control agent distribution is accomplished on a rational basis and in the proper sequence. For example, in a water body where waterprimrose, *Ludwigia uraguayensis* (Camb.) Hara., grows over surface areas also containing egeria (*Egeria densa* Planchon), 2,4-D must be used first to kill the waterprimrose in order to expose the egeria for diquat applications, which control this latter plant. If the reverse procedure were to be used, the waterprimrose would be controlled by the

diquat, but the egeria would not be controlled by the 2,4-D.

45. Block 34. A control plan, complete with maps identifying treatment areas and instructions for agent application, is produced in this step. The control plan map and instructions must be of sufficient detail to allow implementation exactly as specified. Types of information required in the control plan should include the quantity of each agent needed, timing of agent application, agent application pattern and rate, and equipment needed.

46. Block 35. The cost of the selected control plan is determined in this step. Operational costs are excluded from consideration until this point in the development of the management plan to prevent the premature exclusion of a potentially effective control agent solely on a cost basis. Care should be taken to include all real costs for the duration of the control plan. Long-term control that can result from operational plan implementation may never be realized if funds are not available for total plan implementation. Fiscal planners cannot budget for future funding needs if the cost of the overall management plan is not determined prior to plan implementation.

47. Block 36. The operational plan must be presented to the public and all necessary governing bodies for consideration. This procedure will be unique for each water body because of the great diversity in governmental agencies that regulate or manage water bodies in the nation. Regardless of the procedure for presentation, approval of the plan by both the public and governing agencies, supported by allocation of funds to implement the management plan, must be obtained. If the plan is accepted and approved, the pathway is cleared for material procurement (block 37). If approval is not obtained, the control plan must be modified by considering recommendations made by either the public or governing bodies (block 38).

48. Block 37. All material, control agents, equipment, and personnel needed to implement the control plan are obtained in this step, and any preliminary preparations that pertain to equipment are made.

49. Block 38. If the plan presented in block 36 is unacceptable in its original form, an effort can be made in this step to modify it in

a manner that will conform to alterations required by the governing agencies. This could involve such alterations as reducing the total acreage treated to stay within financial limits imposed by the governing body, changing the time for initiation of the operational plan to acknowledge public use, or substituting one control agent for another. These modifications should not produce drastic changes in the expected level of control. The cycle involving block 38 might have to be made several times prior to acceptance of a control plan by the governing agencies and the public.

Phase V: Operational Plan Implementation and Monitoring

50. All work devoted to the development of a management plan has been accomplished at this point, and all that remains is implementation of the operational plan (blocks 39-43). This plan provides for distribution of each selected agent in the control system(s) and monitoring of treatment effects.

51. Block 39. The operational plan is put into effect in this step. Control agents can be applied at the prescribed times and rates following the plan specifications. Provisions included in the operational plan for the monitoring of treatment effects can be initiated.

52. Block 40. Ecosystem responses to the applied control agents must be monitored. This involves the assessment of not only the efficacy of control agents but also the effects on water quality and plant and animal species. This monitoring must continue on a regular basis for an extended period of time to verify that the effects do not, in fact, exceed environmental or desired quality limits. (These effects on the ecosystem can continue for several months after treatment applications.) Care should be taken to perform these activities accurately and objectively, as the resulting data will often be used to decide on the next course of action taken in a long-range management plan (blocks 41, 42, and 43).

53. Block 41. By use of the data obtained from work performed in block 40, a continual assessment must be conducted to determine the benefits or detriments of the implemented control plan (block 39).

Benefits and detriments must be weighed to determine whether the management plan should be continued without change, updated to account for control achieved by the implemented control plan (block 42), or modified significantly enough to require approval again by the governing agencies (block 43).

54. Block 42. If the implemented plan produces acceptable results and is deemed worthy of continuation, the operational plan can be updated in this step. Updating would probably consist of treating previously untreated areas or treating old problem areas at new treatment rates. Lowering the treatment rate could be the result of lower biomass levels achieved from control by the initial treatment, or the result of some detrimental environmental effect encountered after the initial treatment (block 39), regardless of level of control.

55. Block 43. If the implemented control plan (block 39) is wholly or partially unacceptable, major changes can be made in the operational plan in this step. This might consist of substituting one agent for another, or the complete control system used originally (block 39) can be discarded in favor of an alternative plan. This is a distinct possibility if agents from block 27 become cleared for general use, especially if these agents prove to be more efficacious on the target species than those already being used. One good example of this possibility is the white amur (Ctenopharyngodon idella Val.). Regardless of the reasons for the necessity for major revisions in the original control plan, it is necessary that the revised plan gain acceptance by the governing bodies and the public.

Concluding Comments

56. The concept presented in the previous paragraphs provides an objective generalized framework for the development of management plans directed toward the identification and implementation of viable aquatic plant control operations. By systematically carrying out the post-implementation monitoring, periodic quantified assessments of effectiveness are provided in relation to the original goal of achieving

acceptable control of the problem plant species. Without these periodic assessments, the degree of success cannot be determined in any meaningful terms that will allow management to judge the cost-effectiveness of its investment. It should be noted that a desirable quality of an aquatic plant management plan is flexibility regarding unforeseen or unpredictable environmental, economic, or political changes that often occur, which may preclude the use of any portion of an operational management plan. The conceptual framework for management plan development can be effectively reused to effect plan modifications made necessary by unpredictable influences.

FIGURE 1. FLOW DIAGRAM FOR DEVELOPMENT OF AQUATIC PLANT MANAGEMENT PLAN

Figure 1. Flow diagram for development of aquatic plant management plan

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A concept for the development of long-term management plans for aquatic plant control, by Dana R. Sanders ₍and₎ Joseph L. Decell. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1977.
24 p. illus. 27 cm. (U. S. Waterways Experiment Station. Miscellaneous paper A-77-1)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.

1. Aquatic plant control. 2. Environmental management. 3. Management methods. I. Decell, Joseph Lewis, joint author. II. U. S. Army. Corps of Engineers. (Series: U. S. Waterways Experiment Station. Vicksburg, Miss. Miscellaneous paper A-77-1)
TA7.W34m no.A-77-1