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Residential Flood Control Benefits of Aquatic Plant Control

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ABSTRACT

Management of nonnative species of aquatic plants is an ongoing problem throughout the United States, particularly in the South. This paper reports the findings from a simulation analysis of the flood control benefits of aquatic plant control in South Florida. Flood control benefits were measured as the expected value of avoided personal property damages. The results show that substantial flood control benefits exist at current levels of plant management. A comparison of flood control benefits to plant control costs shows the mean benefit-cost ratio is 148:1 for the study area.

Key words: economic benefits, drainage canals, simulation model.

INTRODUCTION

Management of aquatic plants has been an ongoing problem throughout the United States particularly in the Southern region. In lakes and reservoirs aquatic plants can diminish the quality of and access to sportfishing. Aquatic plants can diminish the aesthetic quality of a lake, and can impede the enjoyment of recreational boating activities. In moving water systems such as rivers or canals, the presence of aquatic plants can be a navigational impediment and can exacerbate water supply and flooding problems. The latter problem can be particularly acute in small canals used for irrigation and drainage.

As aquatic plant control efforts have increased, so too have control program expenditures at the Federal, State, and local levels. However, since the reduction in the Federal cost share rate mandated by the 1986 Water Resources Development Act, many states have become more judicious in the way they allocate limited resources to plant control. To that end, knowledge of the economic benefits relative to the cost of aquatic plant control would provide resource managers with more complete information with which to make plant control allocation decisions.

Unfortunately, little economic research has been conducted to examine the economic benefits of aquatic plant control. Milon, Yingling and Reynolds (1986) and Milon and Welsh (1989), examined recreational fishing benefits of aquatic plant control in selected Florida lakes. Milon (1989) analyzed the economic effect of aquatic plant infestations on property values. To date no economic research has been conducted to estimate the flood control benefits of aquatic plant control. The purpose of this paper is to report the methodology and results from a study of flood control benefits from aquatic plant control in South Florida.

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METHODS

The overall research design adopted a case study approach where the Property Damages Avoided (PDA) method was used to estimate flood control benefits for an aquatic plant control project (U.S. Water Resources Council 1983). The PDA technique uses simulation to estimate the cost to repair and replace flood damaged structures currently existing or projected to exist in a flood plain. For selected flood events the sum of probability weighted damages is calculated for with and without project conditions. The difference between flood damages under with and without project conditions is a measure of the total flood damages that are avoided under the with project condition. These avoided damages are an estimate of the economic benefit of flood control.

For an aquatic plant control program, the principles underlying the calculations used in the PDA method can be illustrated graphically. Figure 1 depicts the effect on canal efficiency when aquatic plants are present using a hypothetical canal cross-section under progressively greater levels of aquatic plants. The ability of a canal to move water depends upon the size of its hydraulic radius, i.e. the area through which water passes. The larger the canal, the greater the hydraulic radius, and the greater the volume of water that can flow through the canal. The efficiency of a canal is affected by the presence of obstructions which serve to reduce the hydraulic radius. Thus, canal efficiency can be defined as the proportion of the hydraulic radius that is unobstructed. For example, a canal that is 35% obstructed by the presence of aquatic plants may be said to be only 65% efficient.

The amount of obstruction caused by aquatic plants can be quantitatively represented with Manning's coefficient of roughness (Chow 1959). For canal systems, the greater the biomass of aquatic plants the greater the coefficient of roughness and the lower the canal efficiency. Under these conditions, flow rates are reduced causing water levels to rise and spill out onto the flood plain. Furthermore, higher levels of aquatic plant biomass will lower canal efficiency and increase flood levels for equivalent rainfall events.

Given a unique canal efficiency level and a unique rainfall event, a unique level of flood damages can be estimated. Holding the canal efficiency constant and varying rainfall events yields a stage-damage relationship such as

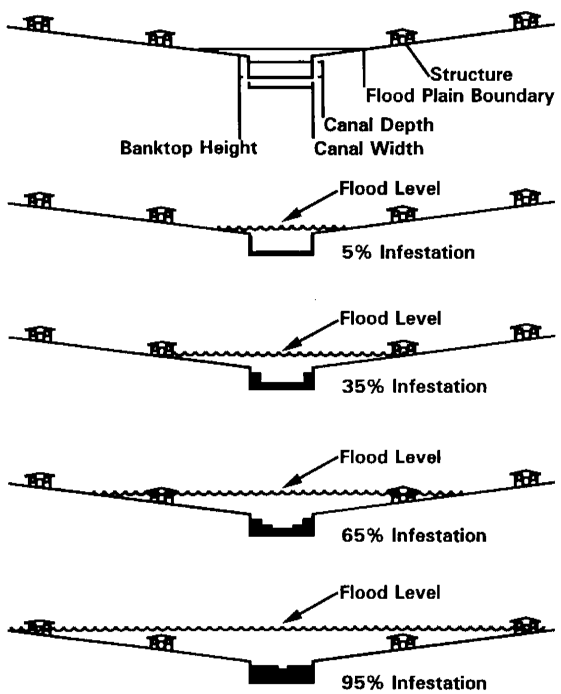

Figure 1. Canal cross section showing different obstruction levels caused by aquatic plants.

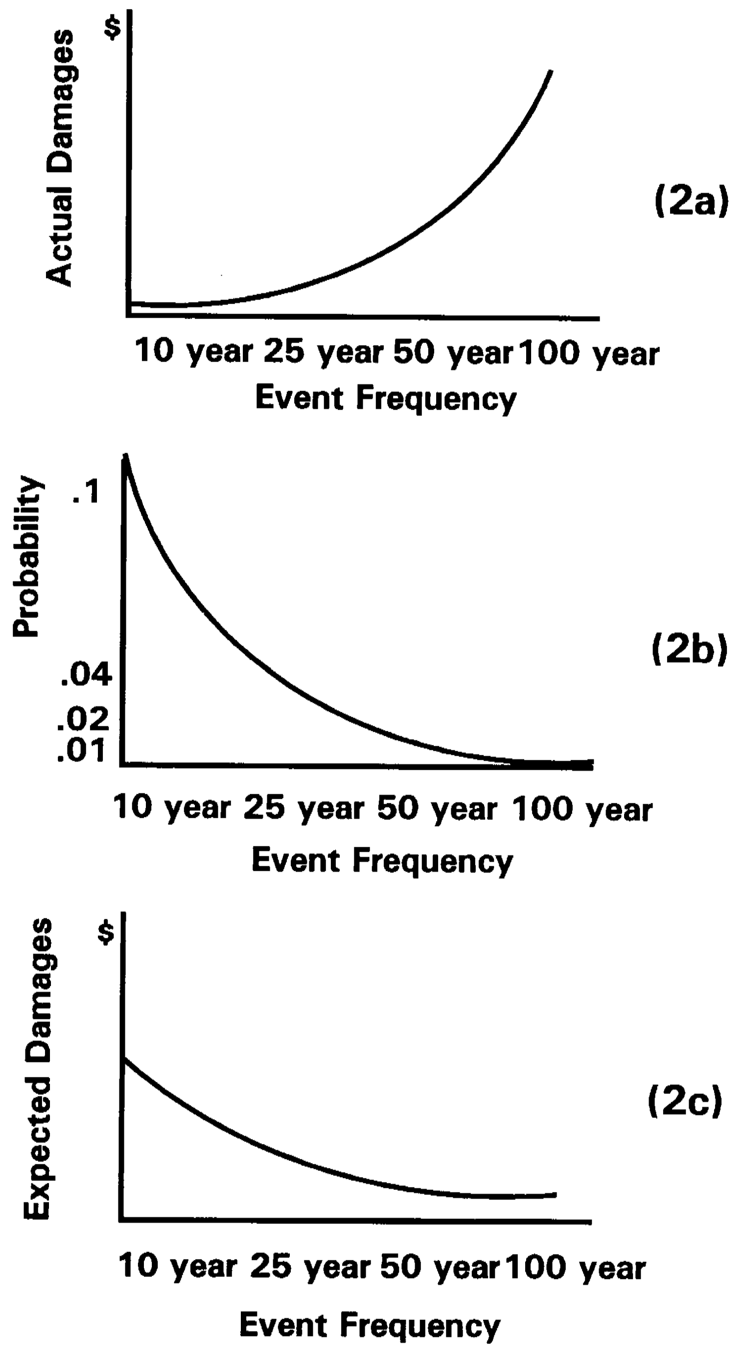

Figure 2. Graphical representation of the calculation of expected flood damages.

that shown in Figure 2a. Assigning a probability of occurrence to each rainfall event results in a stage- probability curve (Figure 2b). Multiplying the stage-damage curve by the stage-probability curve results in the expected value of flood damages (Figure 2c) by flood event for a given level of canal efficiency.

Under the PDA method, the benefit of an aquatic plant control program is equal to the expected value of the flood damages that are avoided by controlling aquatic plants as compared to an alternative lower level of control. Figure 3 depicts this calculation. The upper curve in Figure 3 shows the expected damages curve for a lower canal efficiency/higher aquatic plant biomass canal relative to a higher canal efficiency system as represented by the lower curve. The expected value of property damages avoided, as represented by the shaded area between the curves, is the flood control benefit of aquatic plant control.

Case study area. The city of Old Plantation, Florida was chosen as the case study site. The aquatic plant control program is administered by the Old Plantation Water Control District (OPWCD) which also maintains the water drainage canals that protect the city from flooding. There are 36 miles of maintained canals in the district. When constructed, they were dredged to uniform specifications in most areas. The canals are linear and can be classified as medium sized.

The City of Plantation is a densely populated city. The water control district which lies within the current city limits is composed of large residential subdivisions common to the South Florida area. The possibility of a severe flood event due to torrential rains or a hurricane is of great concern. Several species of aquatic plants are found in this canal system, but several submerged species pose the most significant problem in this district system. The district supervisor is currently pursuing a policy of maximum control of *hydrilla*, *hygrophila*, *cabomba*, and other aquatic plant species given current levels of control technology.

Avoided property damages simulation model

The simulation model that was developed for this study draws on guidelines published by the South Florida Water Management District (1987), established hydraulic relationships, and the depth/damage relationships used by the Army Corps of Engineers in calculating flood damages

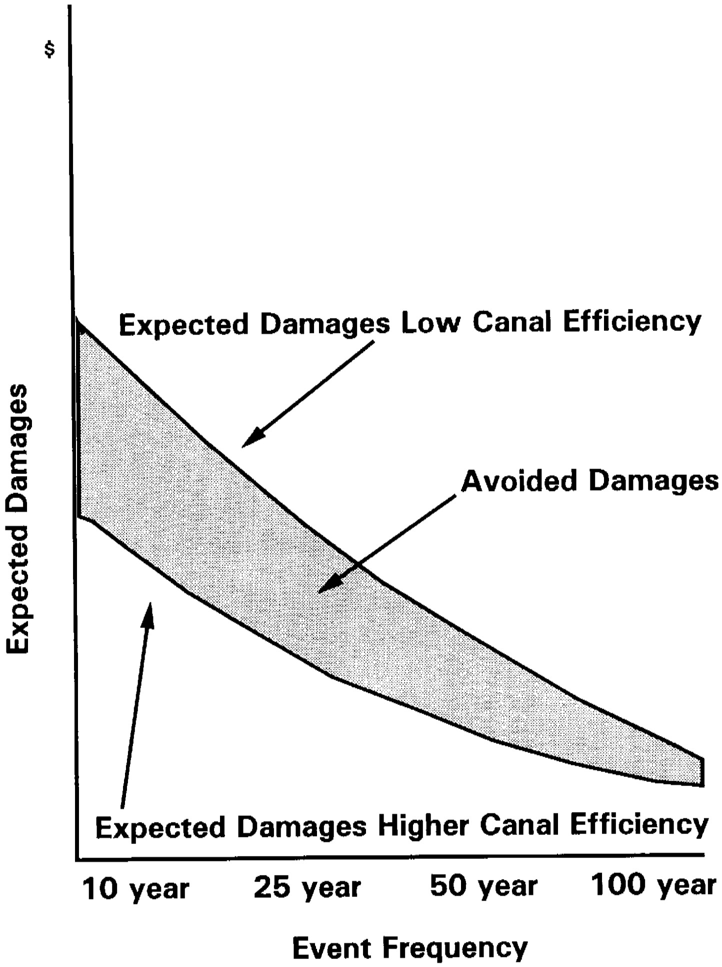

Figure 3. Graphical representation of the calculation of the expected value of avoided property damages (the shaded area represents the flood control benefits of an aquatic plant control program).

to residential property. The simulation model has three basic components: a data base, an hydraulic model, and a set of equations to compute flood damages. The model structure is shown in Figure 4.

The first part of the model consists of a data base describing base flood elevations (above sea level), base pad elevations for residential structures, the building use code, the total number of residential structures and the assessed replacement cost of each structure. The data base provides the information from which expected avoided flood damages are computed.

The hydraulic simulator is designed to estimate the height in feet above sea level to which flood water would rise for a given rainfall event. Space considerations do not permit a detailed description of the hydraulic model, but the model details are documented in Pearson (1991) and are available from the authors upon request. The hydraulic model uses volumetric calculations to compute flood depths after accounting for the volume of water being pumped out of the system and the volume of water being absorbed into the ground. Flood water depths are recalculated on a real time basis at specified intervals during the hypothetical rain event. For purposes of analysis, rainfall

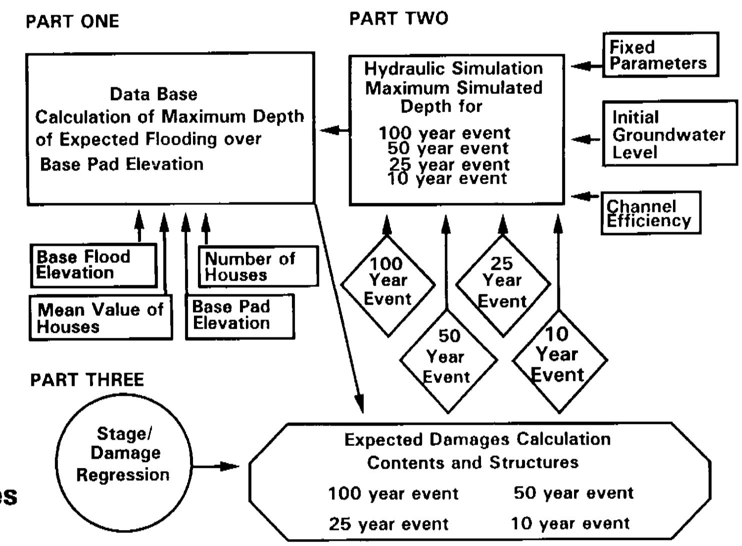

Figure 4. Flow chart of the simulation model used to calculate the flood control benefits of an aquatic plant control program.

levels that would be associated with 100, 50, 25, and 10 year flood events were used. At the end of the rain event the hydraulic model simulation provides the maximum depth of flood water in the OPWCD system for that rain event. This water depth is then used to compute the maximum water depth that would enter residential structures in the district.

The key considerations in the hydraulic model are initial groundwater levels and the canal or channel efficiency. Ground water levels are important because under certain rainfall events ground water storage capacity may become exhausted and surface runoff begins to occur. If rainfall continues to occur at a rate that exceeds the flow out of the canal system, then flood waters begin to rise. The actual depth of flooding is then a function of the duration of the flood event. The efficiency of the drainage canal is a function of fixed channel parameters such as width and depth and the level of obstructions, ie. aquatic plants in the channel. Thus, flood depths for different levels of aquatic plant control can be iteratively calculated for each specified rain event.

Holding groundwater levels and aquatic plant control levels constant, the final stage in the simulation model is to compute the difference between residential structure base pad elevations and the flood depth associated with a specific rain event. This calculation yields the maximum height of water inside a residence. US Army Corps of Engineers relationships between flood depths and structural damages as a percentage of total structural value are then used to estimate the flood damages to each residence in the community. Total damages are estimated by summing across all structures. The simulation is repeated for each of four different rain events to compute the total damages under each of the different events. By weighting each flood damage calculation by the associated probability of occurrence, an estimate of the expected annual flood damages associated with given ground water levels and canal efficiency levels is obtained. Different assumed levels of canal efficiency can be used to estimate a range of expected annual damages.

Simulation model data. The simulation model requires data on pad elevations and structural values for all residential structures. Data on all residential structures within the water control district boundaries were obtained from the City of Plantation property appraiser. The data contained information on 21,064 residential structures which were sorted by the number of stories and the building use code for each structure. The latter descriptor was necessary to match residential structures with the Corps of Engineers damage tables by type of structure.

Any structure in excess of two stories or for which the structural value lay more than three standard deviations above the mean structural value for that section was eliminated. These structures were eliminated because it was not possible to adjust the damage equations to account for the fact that a multi-story building would have a very high structural value and yet may have less than a foot of water standing in the bottom floor. After eliminating these structures, the mean structural value for each section by number of stories and use code was recalculated. Each structure was then given a different classification depending upon whether it fell within one, two, or three standard deviations from the mean. The mean structural value and the total number of structures for each structural value classification was then recorded. Finally, for each section, a 6 by 7 grid was created in which each cell recorded the total value of all structures having common pad elevation, structural value classification, number of stories, and use code. This process was repeated for each of the fifteen sections within the OPWCD boundaries to create the data for the simulation model.

RESULTS AND DISCUSSION

The annual expected value of property damages was simulated for each of four different flood events, (100 year, 50 year, 25 year, and 10 year floods), for 12 different levels of canal efficiency and for three different groundwater levels. The latter scenarios were conducted to test the sensitivity of the results to assumed groundwater levels. Column 1 of Table 1 indicates the simulated canal efficiency levels. From Figure 1 the canal efficiency was shown to be a function of the amount of a canal's hydraulic radius that is obstructed by aquatic plants. Thus, a canal efficiency level of 95% means that 5% of the hydraulic radius is obstructed by aquatic plants.

TABLE 1. ANNUAL FLOOD CONTROL BENEFITS IN $1,000'S BY GROUNDWATER LEVEL AND CANAL EFFICIENCY

Canal efficiency	Groundwater levels			Season adjusted benefits
	0 ft	1 ft	2 ft	
.05	--	--	--	--
.10	159	150	62	106
.20	477	480	184	332
.30	795	800	2606	1703
.40	1113	1120	2656	1888
.50	1432	1440	2708	2074
.60	1750	8334	2758	5547
.70	2069	8580	2810	5695
.80	2389	8824	2870	5847
.90	2708	9072	2912	5992
.95	2868	11826	2940	7383
1.0	3028	11952	2970	7461

The results reported in Table 1 can be used in two ways. First, the annual flood control benefits associated with any given canal efficiency level can be read directly from columns 2 to 5 for the various initial groundwater levels. For example, the target control level for aquatic plants in the case study area is consistent with a canal efficiency level of 95%. Consequently, the average annual flood control benefits, measured as avoided property damages, of such a control level are $2,868,000, $11,826,000, and $7,383,000 for groundwater levels of 0, 1, and 2 ft below the surface, respectively.

The second way in which the results can be used is in making decisions regarding the marginal benefit of incrementally increasing aquatic plant control levels. If, for example, an aquatic plant manager were achieving a 70% canal efficiency but was considering going to an 80% efficiency level the marginal benefit of such an increase can be calculated by subtracting the benefits associated with a new higher level of aquatic plant control from those of the current program. For this example, the marginal benefits of increased plant control range between $60,000 and $320,000 depending upon groundwater conditions.

These figures show the importance of groundwater levels in determining flood control benefits. When the soil profile is saturated, the ability of the canal system to control floods may have less to do with the presence of aquatic plants than it has to do with other aspects of the system's engineering design. Similarly, when groundwater levels are relatively low, the level of damages associated with any given flood event may have more to do with the availability of groundwater storage capacity than it has to do with the presence of aquatic plants.

Taking the fluctuations in groundwater into account permits calculation of an annual benefit-cost ratio that reflects seasonal groundwater levels. In South Florida monthly data from well depths indicate that water table depths range between 18" and 21" below the surface for six months of the year and between 15" and 13" below the surface during the rainy summer months. To adjust the estimated flood control benefits for this seasonal fluctuation in ground water levels the average annual damages for ground water levels of 1 ft and 2 ft were both weighted by .5 and summed to form the seasonal adjusted measure of flood control benefits indicated in column 5 of Table 1.

Expenditures by the OPWCD on aquatic plant control have remained constant at approximately $50,000 annually with a control level consistent with a 95% canal efficiency rating (Mr. Les Bitting, personal communication). Using these figures together with the avoided property damages reported in Table 1, gives the following benefit-cost ratios 57:1, 237:1, and 59:1 for groundwater levels of 0 ft, 1 ft, and 2 ft below surface levels respectively. This means that for every dollar spent for aquatic plant control by the OPWCD between $57 and $237 in expected annual flood damages are avoided. The seasonal adjusted benefit-cost ratio is 148:1. The marginal benefit of increased aquatic plant control levels to achieve a 100% canal efficiency are estimated to be $78,000. As long as the cost of the additional aquatic plant control to achieve this efficiency level was less than $78,000 the added aquatic plant control effort would be economically justified.

Several factors need to be taken into consideration when interpreting these simulation results. First, all relationships in the simulation model are linear, therefore, marginal benefits of increased aquatic plant control are constant with two exceptions. City building codes require that all structural pad elevations be either 7.5 or 8.5 ft above sea level. The line between the two requirements lies roughly in the center of the OPWCD dividing the district into high and low sections. Assuming a ground water level of 1 ft below the surface, marginal benefits are constant at $159,000 until the canal efficiency increases to 55 percent where a change from 50% to 55% efficiency results in marginal benefits of $6,734,000. Canal efficiency levels beyond 55% become constant once again. At canal efficiency levels greater than 50% flood damages to structures in the high elevation portion of the city are dramatically reduced. The same phenomenon occurs when ground water levels are assumed to be 2 ft below the surface, but the large change in marginal benefits occurs at a lower canal efficiency level because the ground water storage capacity is so much higher when ground water levels are low. Marginal benefits for saturated ground water levels are constant because there is no ground water storage capacity to serve as a buffer from rising flood waters.

Finally, the damage calculations, and therefore the benefit measures, include only residential structural and contents damages. No commercial properties were included in the analysis. Furthermore, the benefit estimates do not include any consideration of lost business and personal income that may be incurred during or in the aftermath of a flood, nor do they include any consideration of the psychological and personal costs of flooding. Therefore, the benefit figures reported here should be considered a lower bound estimate of the economic benefits of aquatic plant control in the OPWCD.

Aquatic plant control programs are continuing throughout the United States with little or no attention to the potential benefits of these programs relative to their costs. This research is the first to estimate the benefits of the flood control services provided by aquatic plant control. The research results show that in the case study area the flood control benefits of aquatic plant control are substantial and justify the control program without even considering the other services that the aquatic plant control program may provide. The magnitude of the estimated flood control benefits are site-specific. But it is likely that in other residential drainage systems with small to moderately sized channels, canals, or river systems flood control will be an economically important component of aquatic plant control. The simulation model developed for this research has been designed to run on LOTUS-123 spreadsheet software. Therefore, the model can be readily adapted to other case study areas.

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