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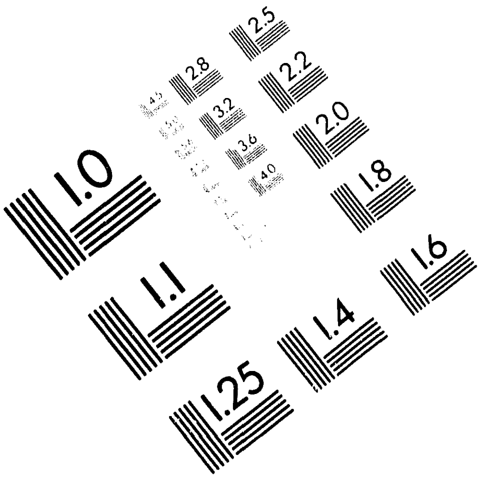

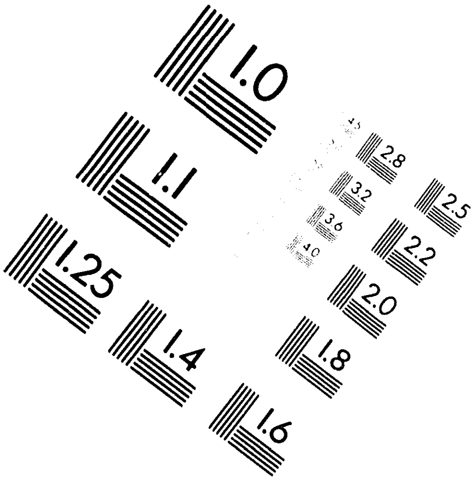

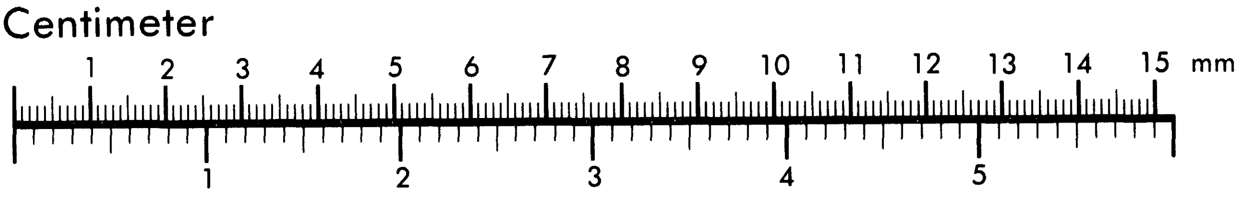

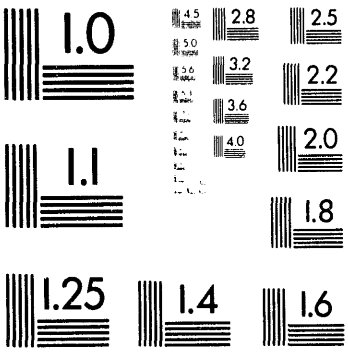

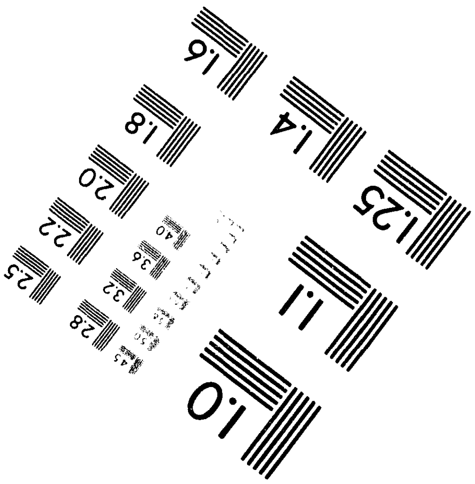

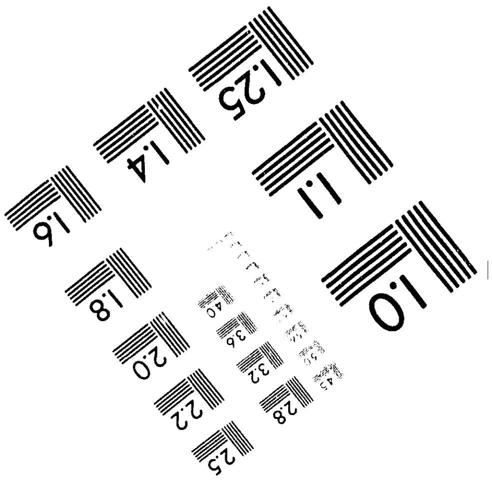

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INTEGRATION OF GEOGRAPHIC INFORMATION SYSTEMS AND LOGISTIC MULTIPLE REGRESSION FOR AQUATIC MACROPHYTE MODELING (U)

by

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A paper proposed for publication in the Journal of Photogrammetric Engineering and Remote Sensing and for presentation at the Annual Meeting of the American Society of Photogrammetry and Remote Sensing, April 25-28, 1994, Reno, NV

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INTRODUCTION

Aquatic macrophytes are an essential component of the wetland community. They are non-woody plants, larger than microscopic size that grow in water. These plants may be free-floating or rooted in bottom sediment and be submerged or protrude from the water (Patterson and Davis, 1991). Mclaughlan (1974) has stated that aquatic macrophytes are important for the aquatic environment since they play a crucial role in providing food and shelter for animals as well as regulating the chemistry of the open water.

Unfortunately, aquatic macrophytes can also hinder human activity. They clog reservoirs, reducing water availability for human needs. In addition, the proliferation of aquatic macrophytes can affect recreational activities, obstructing boat propellers and reducing access to the shoreline especially in protected areas such as coves.

Since aquatic macrophytes have an important influence on the physical and chemical processes of an ecosystem (Frodge *et al.*, 1990; Kiraly *et al.*, 1990) while simultaneously affecting human activity, it is imperative that they be inventoried and managed wisely. However, mapping wetlands can be a major challenge because they are found in diverse geographic areas ranging from small tributary streams, to shrub or scrub and marsh communities, to open water lacustrian environments (Cowardin *et al.*, 1979). In addition, the type and spatial distribution of wetlands can change dramatically from season to season, especially when nonpersistent species are present (Mackey, 1990). This research, focuses on developing a model for predicting the future growth and distribution of aquatic macrophytes. This model will use a geographic information system (GIS) to analyze some of the biophysical variables that affect aquatic macrophyte growth and distribution. The data will provide scientists information on the future spatial growth and distribution of aquatic macrophytes.

STUDY AREA

The Savannah River Site (SRS) is a 777 km^2 Department of Energy facility located near Aiken, South Carolina along the Savannah River (Figure 1). Par Pond (1,000 ha) and L Lake (400 ha) are two cooling ponds that have received thermal effluent from nuclear reactor operations. Par Pond was constructed in 1958, and natural invasion of wetland has occurred over its 35-year history, with much of the shoreline having developed extensive beds of persistent and non-persistent aquatic macrophytes.

There are, however, two species that are dominant in Par Pond - cattails (*Typha latifolia*) and waterlilies (*Nymphaea odorata*).

In June 1991, a leak occurred at the Par Pond dam and the water level was lowered from its full pool level (maintained at the 200-foot contour) to its current level at the 181-foot contour. Several authors have identified the effects of water level change on wetlands, including its impact on species composition and the abundance (or lack) of plant communities (van der Valk, 1981; Keddy and Reznicek, 1986). Nilsson and Keddy (1988) state that changes in water level is an important controlling factor on a wetland ecosystem since its effects on wetland vegetation can be quite pronounced. In the case of Par Pond, the water level has dropped 19 feet or approximately 6.3 m and the aquatic macrophyte community that was in existence prior to the leak has now been destroyed. Since the impact of change in water level is an important factor on aquatic macrophytes, it is critical to identify the ideal water level that would encourage their growth.

However, the question remains as to the appropriate water level that should be maintained in order to initiate and sustain a flourishing wetland community. Therefore, the predictive model developed in this study will be applied to seven water levels, including the 181-, 184-, 187-, 190-, 194-, 197-, and 200-foot contour intervals. The 181-foot contour is being selected because it is the current Par Pond water drawdown level. Conversely, the 200-foot contour is chosen since it is the level of Par Pond prior to the leak (or full pool level). The 197-foot and 187-foot contours are being considered since they represent the edge of the former cattail and waterlily beds respectively. Levels of 194-, 190-, and 184-foot contours are selected since they are intermediate levels between the previous four levels. Basically, an average separation of approximately 3 feet is maintained between the contour levels selected for analysis.

DATABASE DEVELOPMENT

Most predictive studies have simply identified the species composition without regard to geographic distribution. A few predictive ecological studies have attempted to retain the spatial information. Liebowitz *et al.* (1989), modeled the loss of marsh in Louisiana. Constanza *et al.* (1990) predicted future landscapes in the Atchafalaya delta. Davis *et al.* (1990), identified biotic communities and species in need of preservation management (gap analysis). Furthermore, many of these studies make extensive use of land use/land cover information and occasionally use spatially distributed biophysical data in their models.

The development of a spatially registered geographic information database with biophysical variables is largely dependent on data availability and the ease of incorporation within a GIS. In the case of aquatic macrophytes, several authors have identified the following biophysical variables as having an impact on the growth and distribution of aquatic macrophytes (Pearsall, 1920; Rorslett, 1984; Harvey *et al.*, 1987):

- water depth,
- percent slope,

- exposure (fetch),
- soil types (substrate composition),
- water temperature,
- wave action, and
- suspended sediment

For this study, it was possible to obtain spatial information for the first four (4) variables. In the case of temperature, no data were available for use in this research. The wave action and suspended sediment distribution change so rapidly that unless an intensive *in situ* investigation is performed, it is not possible to include these variables in the analysis. For each of these biophysical variables identified, a data layer was developed and digitized into the Par Pond.

In the case of Par Pond, it was necessary to develop seven databases containing information on the four biophysical variables. The full pool level (i.e., 200-foot contour) can be considered as the initial level for which the database was developed. From this, six subsets pertaining to the 181-, 184-, 187-, 191-, 194-, and 197-foot contours were derived.

Water Depth: Water depth affects the amount of light available for photosynthesis by aquatic plants. Generally, greater depths limit the photosynthesis of the plants (Barko *et al.*, 1982). Hammer (1992) also emphasized the importance of depth. The author states that vegetation zonation is largely due to the influence of water depth and much of the diversity and spatial heterogeneity of wetland systems is the result of different elevations. According to Moss (1990), depth is an important factor for aquatic macrophytes. Shallow areas of a water body will encourage the growth of aquatic macrophytes since they allow light penetration, assuming that the water is not clouded by sediment. Therefore, depth must be considered as an essential biophysical variable in the predictive model.

Large scale (1:1,200) photogrammetrically derived topographic maps (5′ contour interval) for Par Pond prior to its construction were digitized to develop its DEM. However, these maps were available for only the lower half of Par Pond. Therefore, it was necessary to supplement the topographic information from the following sources:

- 1:24,000 USGS 7.5′ topographic quadrangles
- Large-scale rectified aerial photographs for July 1991, when the lake level was at the 187′ contour and October 1991, when the lake level was at the 181′ contour.

The composite DEM is shown in Figure 2. Prior to the leak in June 1991, Par Pond used to be maintained at an almost constant 200-foot (± 0.1 foot) contour. However, at present the level is maintained at the 181-foot contour. It is this range of elevation values (181-200 foot contours) that will be examined in the study to determine the most appropriate water level for wetland restoration.

Slope: Mackey (1990), states that the smaller the slope, the greater the probability of aquatic macrophyte development in shallow water. Steeper slopes will limit the rooting capability of aquatic macrophytes. In most cases the roots are relatively flimsy and can be easily dislodged due to aquatic turbulence. However, gentle slopes allow aquatic macrophytes retain a stronger hold on the soil thus preventing their loss.

The slope data layer for Par Pond was derived from the lake's DEM using the ERDAS 3-D module. The algorithm computes percent slope for each pixel using the "tangent" trigonometric function. This involves the application of standardized mathematical interpolation techniques as described by Muehrcke (1986) and Burrough (1987). Figure 3 is a slope distribution map of Par Pond. Note that the steeper slopes lie near the dam at the southern end of the lake and in the middle arm of Par Pond.

Exposure (Fetch): Fetch may be defined as the unobstructed distance that wind can blow over water in a specified direction (Kinsman, 1984). Generally, the greater the fetch of a specific site, the higher the probability of larger waves or stronger currents developing, thus lowering the probability of aquatic macrophyte development (Keddy, 1982). Harvey *et al.* (1987) found that sheltered areas along the lake shorelines tend to support more dense communities of aquatic macrophytes since they offer protection from wind and wave action.

The importance of fetch has also been expressed by several other authors. Bailey (1988) found that wave action along exposed areas of a lake often leads to a reduction in the growth of vegetation in such areas. Scheffer *et al.* (1992) used exposure as one of the variables to explain the causality of modeled relationships between aquatic macrophytes and environmental factors.

Jensen *et al.*, (1992) developed a robust measurement of fetch which is computed for every point in a water body. The algorithm was applied to the raster dataset of Par Pond, to derive the fetch surface. Using meteorological data from a station located south of the Par Pond dam, wind data pertaining to speed and direction were statistically analyzed to determine the most appropriate dominant wind direction during the growing season of the aquatic macrophytes (May - September) for 1988-1991. The average for the four year period showed that the 5° wedge (221° to 225°) was the dominant wind direction. The application of this algorithm resulted in the creation of a fetch surface for Par Pond which ranged from 0 - 1,100 m. Invariably, pixels in the center of the lake have the greatest fetch (exposure) while those in sheltered coves are protected from the wind and wave action (Figure 4).

Soils (Substrate Composition): The influence of substrate composition on the growth and distribution of rooted aquatic macrophytes has long been recognized. Brown (1913) and Pearsall (1920, 1929) reported on aquatic plant distribution variability in relation to the nature of the substrate. Recent studies also recognize the importance of substrate composition to aquatic plant growth (Spence, 1982). Sediments provide an important source of nutrients, and the substrate composition (i.e., texture and organic matter content) markedly affects macrophyte growth rates, because of its influence on nutrition (Barko and Smart, 1986).

Unfortunately, soils in the SRS area are predominantly sandy, with a low percentage of clay and silt. An evaluation of the soil texture based on SCS description revealed that the sand content of the soils in the lake regions ranged from 50 percent to 99 percent (Soil Conservation Service, 1990). According to Brady (1984), soils with less than 90 percent sand content begin to have some loamy texture to them and could therefore provide some suitability for plant growth.

Another factor to consider, especially in the case of Par Pond, is the lacustrine environment that the soils have been in over the past three decades. It is inevitable that as a reservoir ages, the inundated soils change from a terrestrial to an aquatic ecosystem (Gunnison *et al.*, 1985; Kimmel and Groeger, 1986).

However, no data are available on the rate of change of the composite soil materials.

The standard techniques for constructing a digital soils database is through the digitization of Soil Conservation Service (SCS) maps or through the interpretation of large scale aerial photographs. In the case of Par Pond there were no reliable maps available prior to it being filled in 1958. Therefore, large scale, 1958 black and white aerial photographs of the Par Pond area taken before the lake was filled were photointerpreted. While it is impossible to specifically label each soil type with this method, one can successfully make a qualitative assessment can be successfully made. This involves the classification of soils into five categories including (1) worst, (2) poor, (3) moderate, (4) good, and (5) best soils. Photointerpretation into each of these classes was done based on the gray-level appearance of the soil. Sandy soils are highly reflective and will therefore appear brighter on the aerial photograph. In addition, such soils are the least conducive to aquatic macrophyte growth and can therefore be grouped as "worst" or "poor" soil types. Soils with moderate sand content and low quantities of silt and clay also appear lighter gray on the photograph and were classified as "poor". Conversely, soils that encourage aquatic macrophyte growth are those with high clay and silt content. They appear darker on the aerial photographs and were classified as the "good" or "best" soils based on their "grayness". Figure 5 shows the final distribution of soils at Par Pond, as interpreted from the large scale aerial photograph.

Development of Par Pond Database Subsets

Once the main database for Par Pond (full pool, 200-foot contour) was developed, the derivation of the subset databases for the six additional contour levels was easily performed. A binary mask was developed for each of the 181-, 184-, 187-, 190-, 194-, and 197-foot contour levels from the original DEM. Areas within these contour limits were recoded as "1" and all external areas were coded as "0". Since all data layers of the main database were geographically referenced to the UTM system, the masks could be easily applied to the DEM and soils data layers. These biophysical variables are not affected by the changing face of the lake.

In the case of slope and exposure (fetch) data layers, however, new surfaces had to be computed for each contour level. Slope surface will change mainly along the shoreline of the lake since pixel values are based on the average of the surrounding 8 neighborhood pixels. The ERDAS slope algorithm was applied to each of the six additional contour levels.

Fetch had to be computed, using the algorithm described in the preceding section, for the six contour intervals. As the physical appearance of a water body changes, so will the fetch surface. For Par Pond, the lake has actually become smaller and therefore the fetch will be reduced in many areas of the lake where the wind would not be blowing across the distance it did at full pool level.

DEVELOPMENT AND APPLICATION OF THE LOGIT PREDICTIVE MODEL

Braak and Looman (1987) have described regression analysis as a "statistical method that can be used to explore relations between species and environment, on the basis of observations on species and environmental variables....." (p. 29). According to Eveleigh and Custer (1985), "regression modeling involves the derivation of a mathematical relationship between a set of independent predictor variables and a specific dependent condition" (p. 451). The technique of ordinary least squares linear regression attempts to establish a linear relationship between the dependent and independent variables. Subsequently, the linear probability for a point containing a specific dependent condition is based on a matrix of "m" independent variables and be expressed as follows (Eveleigh and Custer, 1985):

$$P_i = f\,(x_1, x_2, x_3, \ldots, x_m) \qquad (1)$$

where P_i = Probability of location "i" where dependent condition exists

$x_1 \ldots x_m$ = set of independent predictor variables

Unfortunately, there are a few drawbacks to this model when applied to a raster database. First, the variance, a measure of dispersion or spread of the variables (Barber, 1988), is not constant from grid cell to grid cell. Secondly, the probability values computed from this relationship can often fall outside the 0 - 1 range of probability values which makes it difficult to relate the output to a systematic probability surface.

The logistic multiple regression (LMR) technique is often used to overcome these limitations. It accepts both dichotomous (binary) and scalar values as the independent variables. This allows the use of variables that are not continuous or qualitatively derived (e.g., soil type). The probability estimate (P_i) always varies between 0 - 1, thus producing a realistic probability surface.

LMR identifies variables important in predicting the probability of an occurrence, e.g., aquatic macrophytes, by defining the presence or absence of such an occurrence as a dichotomous, dependent variable (Harvey *et al.*, 1987). It yields coefficients for each variable based on data derived from samples taken across a study site. The coefficients serve as weights in an algorithm which can be used in the GIS database to produce a map depicting the probability of aquatic macrophyte growth.

Quantitatively, the relationship between the "occurrence" and its dependency on several variables can be expressed as:

$$P_x = p(d=1/x) = 1/1 + \{esp[(B_0 + B_1x_1 + \ldots + B_px_p)]\} \qquad (2)$$

where d = presence/absence (e.g., aquatic macrophytes)

$x_1 \ldots x_p$ = a set of biophysical variables (e.g., depth, slope, etc.)

$B_0 \ldots B_p$ = coefficients derived from logit regression

Expressed in simpler terms, d is the dependent variable and $x_1 \ldots x_p$ are the independent variables. It is therefore evident that the logistic multiple regression analysis would be ideal for developing a predictive model in this research.

The model developed in this study is designed to utilize geographically referenced spatial information on the biophysical variables from the application of the LMR technique to the Par Pond 200′ contour level data. The geographic information databases of Par Pond contained data on the four independent variables in a raster format. Each 5 x 5 m pixel was assigned a value based on the observed or interpolated data of the variable at the center of the cell. In order to derive logit coefficients, it was necessary to develop an additional data layer on the presence or absence of aquatic macrophytes. These data were obtained from the 1989 remote sensing derived classification map of Par Pond. All areas with aquatic macrophytes were recoded to "1", while areas devoid of such vegetation were recoded to "0". The binary response variable data layer (i.e., presence/absence) could then be used to investigate the relationship between response probability and the explanatory variables.

In order to apply LMR, a stratified random sample of 2,000 pixels was derived from the Par Pond database at the 200-foot contour level. To eliminate bias in the sampling process, an equal number of points (1,000 each, on presence/absence data) were selected. Each sample point had its respective binary value on the presence/absence of macrophytes, as well as information on depth, slope, fetch and soils.

The Statistical Analysis System (SAS) function LOGISTIC was used to perform the logit operation on the random sample dataset. The following algorithm describes the coefficients of the model for each independent variable:

$P_x = p(d=1/x) =$

$1/1+\{esp[-6.9071+0.4212(Depth)-0.0925(Slope)+0.0197(Fetch)-0.1138(Soils)]\}$ (3)

In assessing the model fit in equation (3), the score statistic for the joint significance of the explanatory (independent) variables had a p-value of 0.0001. Thus, it can be inferred that depth, slope, fetch and soils were significant in determining the presence/absence of aquatic macrophytes.

The analysis of maximum likelihood estimates ($P_r >$ Chi-Square) shows that the predictor variables depth, slope and fetch are significant in predicting the probability of aquatic macrophytes occurrence (Table 1). To examine this further, the stepwise LMR was used and the variables depth, fetch and slope were considered in that order. Soils were not significant and were eliminated from the stepwise procedure (see equation 8).

$P_x = p(d=1/x) =$

$1/1 + \{esp [-6.360 + 0.4209(Depth) - 0.0957(Slope) + 0.0192(Fetch)]\}$ (8)

It is important to consider the fact that soils in the SRS area are predominantly sandy. In fact the SRS lies in the geographic area known as the sandhills. With the exception of very poor soils (> 90% sand content), aquatic macrophytes may have taken root if other physical and chemical properties were ideal for their growth. Under such conditions, soils would not play a major role in determining the spatial distribution of aquatic macrophytes. Another possible reason for eliminating soils is the technique used to develop the data layer. The method, while logical, did not take into consideration the actual soil type based on the sand, clay and silt content. This would have influenced the qualitative ranking of the soils, thus reducing their significance at the 0.05 level.

The SAS LOGISTIC procedure also tests the association of predicted probabilities and the observed responses using a series of rank correlation indices (SAS, 1990). These statistics assess the predictive ability of a model using Somers' D, Goodman-Kruskal Gamma, Kendall's Tau-a and the c indices (Table 2). All correlation indices for the full model reflect a high degree of association between predicted versus observed responses. Note that the maximum value of Kendall's Tau-a is 0.5. The statistical analysis of the model, therefore, reflects that its application to the geographic information dataset would produce an accurate probability surface of the spatial distribution of aquatic macrophytes.

Table 1. Analysis of Maximum Likelihood Estimates

Variable	Individual Model P_r > Chi-Square	Stepwise Model P_r > Chi-Square	Full Model P_r > Chi-Square
Depth	0.0001	0.0001	0.0001
Slope	0.0096	0.0005	0.0007
Fetch	0.0001	0.0001	0.0001
Soils	0.7080	-	0.2652

Table 2 also shows the correlation indices derived from applying the LMR technique to the variables individually and in the stepwise procedures. A comparative evaluation between the indices of the full model and the stepwise model shows no variation. However, when each variable is considered individually, depth would determine more than 93% of the probability of aquatic macrophyte occurrence, while slope and soils would be minor variables in computing their occurrence.

Table 2. Correlation Indices for Association of
Predicted Probabilities Versus Observed Responses

	D	S	F	S	Stepwise	Full
Somers' D	0.933	0.063	0.755	0.017	0.948	0.947
Goodman-Kruskal Gamma	0.942	0.075	0.758	0.027	0.948	0.948
Kendall's Tau-a	0.467	0.031	0.378	0.009	0.474	0.474
c	0.966	0.531	0.878	0.509	0.974	0.974

The coefficients derived for the model in equation (3) were applied to the GIS database of Par Pond at full pool level to produce a probability surface of the lake, with values ranging from 0-percent to 100-percent. There are several areas in Par Pond which have a very low probability of harboring aquatic macrophyte growth, and it is becomes necessary to delineate a cut-off point in the probability surface where aquatic macrophytes would have the greatest likelihood of occurring. This was performed by overlaying the 1989 remote sensing derived classification map on the percent probability surface. Nearly 88% of the total area (268.11 ha out of 305.58 ha) of aquatic macrophytes was in regions of greater than 85% probability. This value can, therefore, be used as the cut-off probability to model aquatic macrophytes at the six additional levels of Par Pond.

Remote sensing derived classifications for 1988 - 1990 showed that the average area of aquatic macrophytes was 323.67 ha (1988=342 ha; 1989=305 ha; and 1990=324 ha). The total area of aquatic macrophytes as predicted by the logistic model for areas with >85% probability was 311.38 ha. This demonstrates that the model was accurate to within 4% and can be used as an effective predictive tool.

The final step in the model development process is the cartographic representation of the probability surface. It should be noted that the information derived from the model will be used in an environmental decision making process. According to Jensen and Narumalani (1992), remote sensing and GIS products should follow basic cartographic principles to facilitate decision making by the end user. Therefore, the >85% probability surface can be divided into four distinct classes (i.e., 99%-100%, 96%-98%, 91%-95%, and 86%-90%) The 99% - 100% class was selected since it represents the highest probability where aquatic macrophyte growth may occur. Due to the dynamic nature of the variables being studied in environmental science, a >95% level of confidence is often considered acceptable. Hence, the selection of the second class interval of 96% - 98%. The final two classes (91%-95% and 86%-90%) were equal sized classes. Data presented in this spatial context is easily interpreted by users (Figure 6).

Application of Logistic Model to Par Pond (6 levels) and: The main function of any model is its application toward providing a realistic representation of the unknown based on a given set of known circumstances. Information provided by such models is often used at management levels for decision making processes. In this research the LMR model developed in the preceding section was applied for predicting the future growth of aquatic macrophytes in Par Pond for the six pre-selected water levels. The data derived from this model can provide environmental scientists at the SRS with a statistical as well as a spatial representation to be used for selecting the most appropriate water level at which to maintain Par Pond. In addition, knowledge of the future spatial distribution of aquatic macrophytes can be used to direct the wetland management efforts that are currently underway at the site.

An assessment of change in the potential growth and distribution of aquatic macrophytes at Par Pond for the six water levels shows that there is a steady decline in the total area where the potential growth could occur. When the >85% probability constraint is considered, the potential areas of aquatic macrophytes demonstrate a similar decline (Table 3). However, a small increase of approximately 3 ha is detected at the 184-foot contour. Figure 7 a-f shows the predicted areas of aquatic macrophyte growth with >85% probability of occurrence.

The analysis of percent change in areas of $\leq$85% versus those with >85% probability shows that the rate of decline is greater in areas which are more likely to have aquatic macrophvtes growing (Table 3). There are two possible explanations for these observations. First, the total area of the lake is shrinking and, therefore, inevitably the area of potential aquatic macrophytes growth will decline. Second, the movement toward the middle of the lake may reduce the ideal areas to which the wetland may expand. This would be especially true in the case of variables such as water depth and percent slope, which are greater in some of the areas of Par Pond.

Similar to evaluating the changes that potentially could occur on a broad scale (i.e., 1% - 100% probabilities), it is also important to examine the changes within the areas of >85% probability (Table 4). The probability surface within the >85% range was divided into four classes so as to represent the changes that could occur within the 85% - 100% range. It was interesting to note that unlike the decline noted when considering overall groups (i.e., >85%; $\leq$85%; and total area), the predicted area within the >85% probability fluctuated considerably. In evaluating this change it was noted that the 190-foot contour showed substantial variations between the four classes. The total predicted change in the potential area of aquatic macrophytes between the 194- and 190-foot contours was only -11.86 ha or -5-1%. However, the within group variance was significant. Areas with probability of 86% - 90% showed a gain of 16%, while areas between 91% - 95% declined by 19%. A large loss (-35.5%) was detected in areas of 96% - 98% probability, while those with 99% - 100% gained 27.4%. Therefore, it appears that most of the gains of class are offset by the losses of another class at the 190-foot contour. The extent of gains and losses is not observed at any other water level.

Table 3. Change in Spatial Distribution of Aquatic Macrophytes
at Par Pond (7 levels)

Contour	Area >85%	in ≤85%	hectares Total	>85%	% change ≤85%	Total
200′	311.38	321.73	633.11	0	0	0
197′	265.35	289.87	555.22	-14.8	-9.9	-12.3
194′	232.92	274.59	507.51	-12.2	5.5	-8.6
190′	221.06	262.73	483.79	-5.1	-4.3	-4.7
187′	198.62	244.12	442.74	-10.2	-7.1	-8.5
184′	201.77	213.97	415.74	+1.6	-12.4	-6.1
181′	197.54	198.66	396.20	-2.1	-7.2	-4.7

CONCLUSION

The GIS modeling techniques described here can be of value when predicting where freshwater aquatic macrophytes could occur in the future. Additional data on the physical and chemical processes can be included to refine the LMR predictive model. For example, this study did not consider light penetration as a variable affecting aquatic macrophyte growth. Harvey *et al.* (1987) found that among the environmental variables influencing aquatic macrophytes, light penetration is important in limiting their depth distribution. Canfield *et al.* (1985) and Chambers and Kalff (1985) also found a significant correlation between aquatic macrophyte depth colonization and the depth to which light penetration occurred. However, both studies showed a low predictive power in their equations and attributed some of the scatter to differing light requirements of various macrophyte species and the error associated with the type of sampling methods used to collect the data.

Turbidity is another factor that should be considered. Turbid waters directly affect the amount of light that is available for the photosynthesis processes of aquatic plants (Sculthorpe, 1967). Moran (1981) has also established that turbidity can have a great influence upon the occurrence and development of aquatic vegetation. Given the importance of turbidity, it can be concluded that even if a lake or reservoir is shallow, the turbid waters may make it unlikely for an aquatic macrophyte community to flourish.

The chemical composition of a water body also influences the growth and distribution of aquatic macrophytes. Nutrient loadings such as phosphorus, dissolved nitrogen, oxygen and carbon dioxide have been recognized to have a significant impact on aquatic macrophytes (Swindale and Curtis, 1957; Seddon, 1965). Several studies have illustrated that the chemical composition as determined by the nutrients present can influence species composition of aquatic macrophytes (Spence, 1967; Raitala and Lampinen, 1985). Non-point sources such as run-off from agricultural fields or from development areas around the lake can severely affect its nutrient content, which in turn would contribute toward determining where the aquatic macrophytes would grow and what their species composition would be. In addition, the nutrients balance can lead to enriched systems where phytoplankton and algae blooms would reduce the light penetration and limit the growth of aquatic macrophytes (Jupp and Spence, 1977). The inclusion of data on the variables discussed above, such as light availability, turbidity and water chemistry into the GIS will serve to strengthen the model. Consequently, the predicted probability distribution of aquatic macrophytes at Par Pond would change and the spatial distribution maps modified accordingly. In addition, the incorporation of these data may explain why aquatic macrophytes are growing in some areas which have been predicted as having a low probability of growth (e.g., 52% - 85%).

Table 4. Predicted Logistic Regression of Total Area of Aquatic Macrophytes at >85% Probability in Par Pond

Contour	86%-90%	91%-95%	96%-98%	99%-100%	Total	86%-90%	91%-95%	96%-98%	99%-100%
200'	31.97	51.24	84.98	143.25	311.38	0	0	0	0
197'	26.90	54.34	79.15	104.96	265.35	-15.8	+6.0	-6.9	-26.7
194'	19.77	45.16	83.51	84.48	232.92	-26.5	-16.9	+5.5	-19.5
190'	22.93	36.57	53.90	107.66	221.06	+16.0	-19.0	-35.5	+27.4
187'	20.48	39.42	62.20	76.52	198.62	-10.7	+7.8	-15.4	-28.9
184'	22.24	38.67	60.53	80.33	201.77	+8.6	-1.9	-2.7	+5.0
181'	17.93	29.04	64.87	85.70	197.54	-19.4	-24.9	+7.2	+6.7

With reference to the LMR model, it was noted that the soils variable was not considered ($P_r >$ Chi-Square) at the 0.05 level of significance. In fact, the stepwise LMR eliminated soils from any further analysis. This may be directly related to the methodology with which soils were derived for Par Pond. The technique used, while logical and reasonable, given the data sources available, did not consider the quality of the soils based on their actual sand, silt and clay content. It was based primarily on the moisture content as derived from the gray-level texture interpretation of large scale black and white aerial photography, and could have resulted in soils being reduced in importance.

The database can be refined by delineating those soils found along the edge of the reservoirs. This operation can be implemented by applying an 'environmental constraint criteria' on the depth variable (Jensen *et al.*, 1992). For example, soils up to a depth of 4 meters (limit of waterlilies growth) should be only considered, while those beyond the specified depth masked out. The depth constraint would be based on the species present in the water body. By considering the distribution of soils up to certain suitable depths, their classification into the five categories (ranging from worst to best) would be modified. Data from the application of this technique may provide a more robust measurement on the quality of the soils used in the predictive model.

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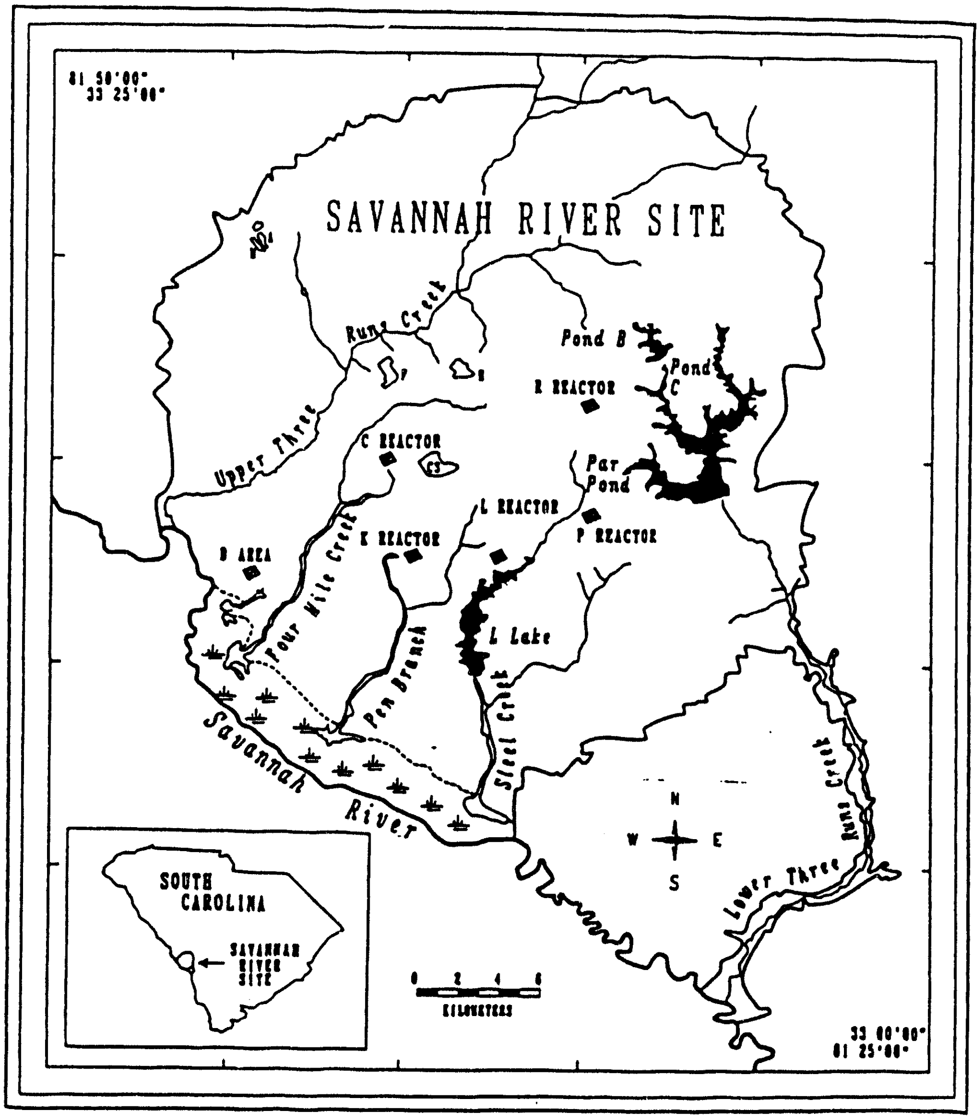

Figure 1 . Location of Par Pond and L Lake at the Savannah River Site in South Carolina.

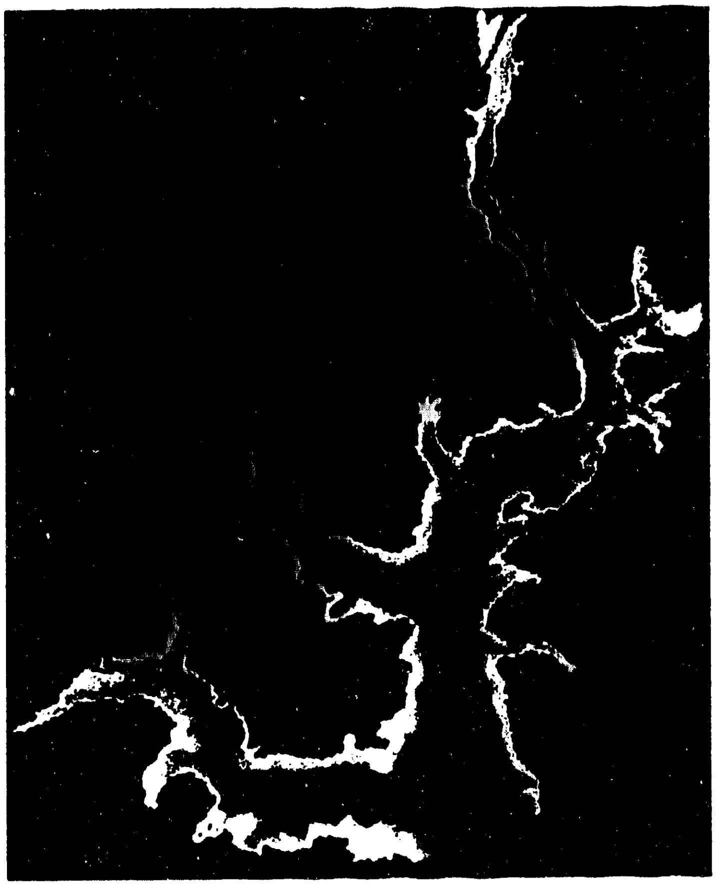

Figure 2 . Digital elevation model of Par Pond.

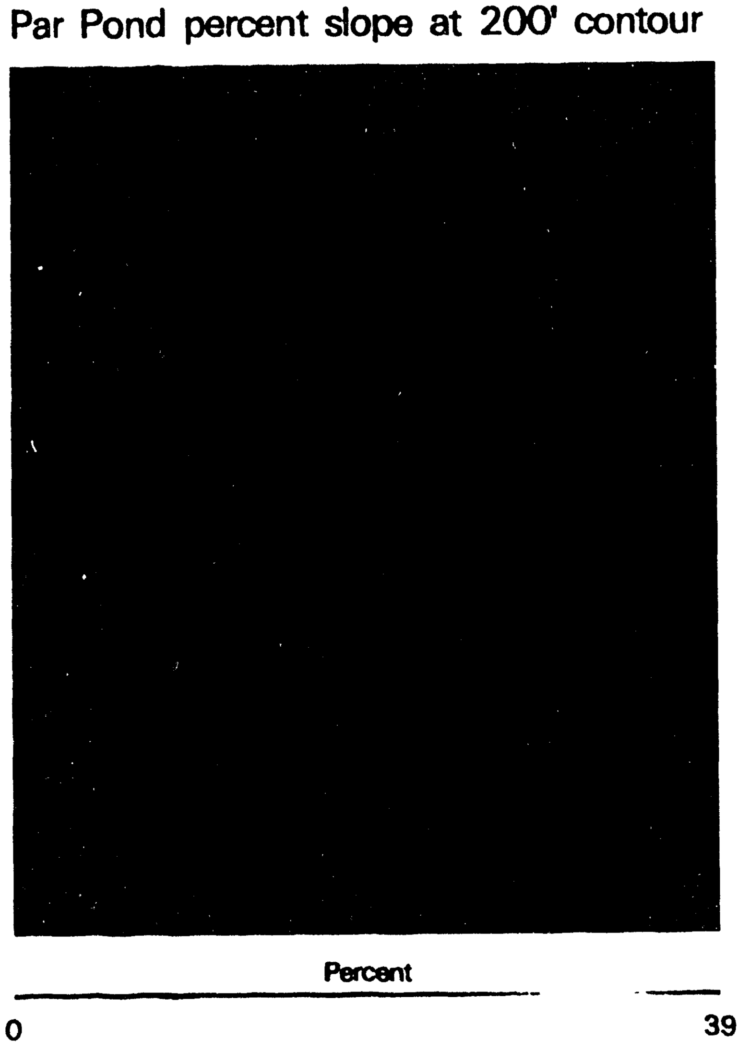

Figure 3 Percent slope distribution map of Par Pond at the 200' contour.

Par Pond fetch at 200' contour

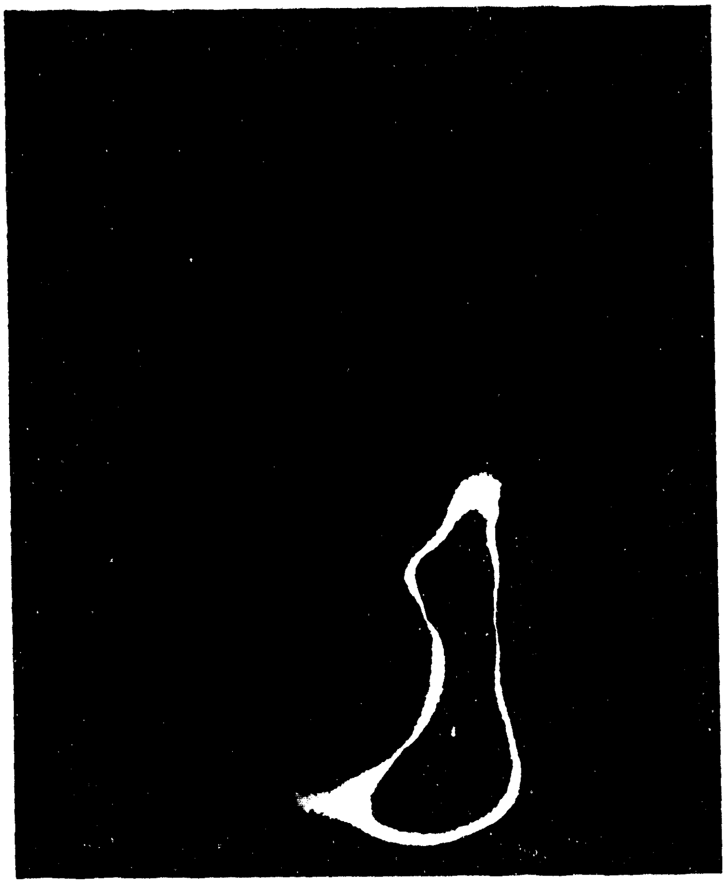

Figure 4. A map of fetch in Par Pond computed for each pixel in 360 directions. The range of fetch was 0 - 1,100 m.

Figure 5 The final soils map of Par Pond as derived from aerial photo interpretation.

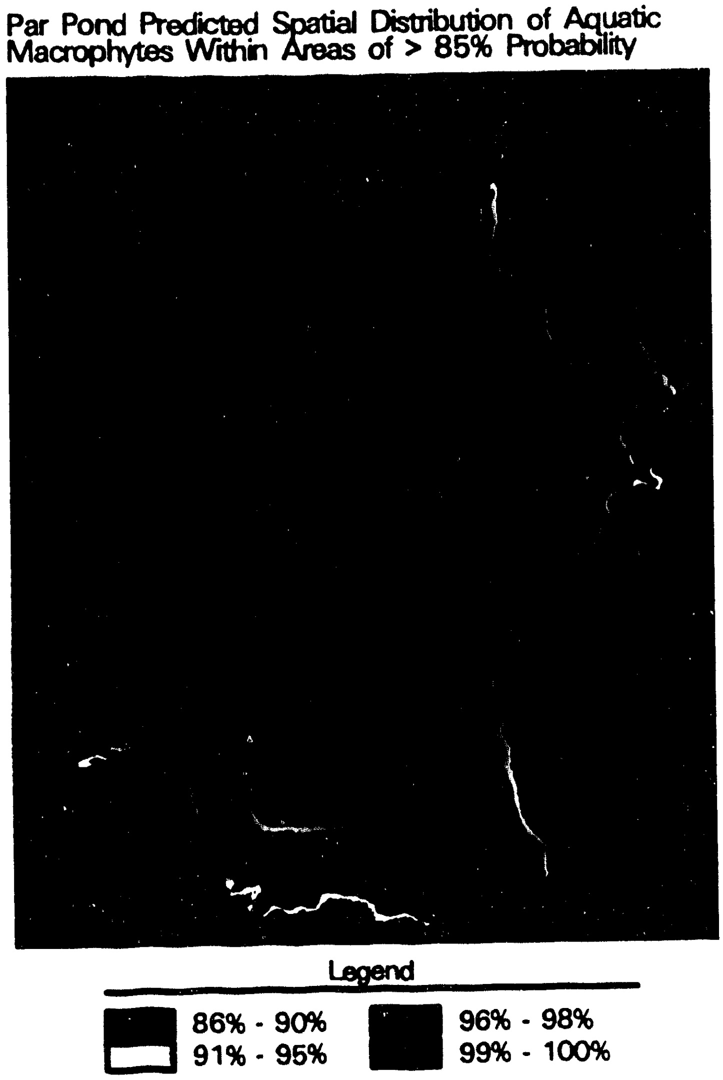

Figure 6 Predicted spatial distribution of aquatic macrophytes at Par Pond full pool level using the >85% probability constraint.

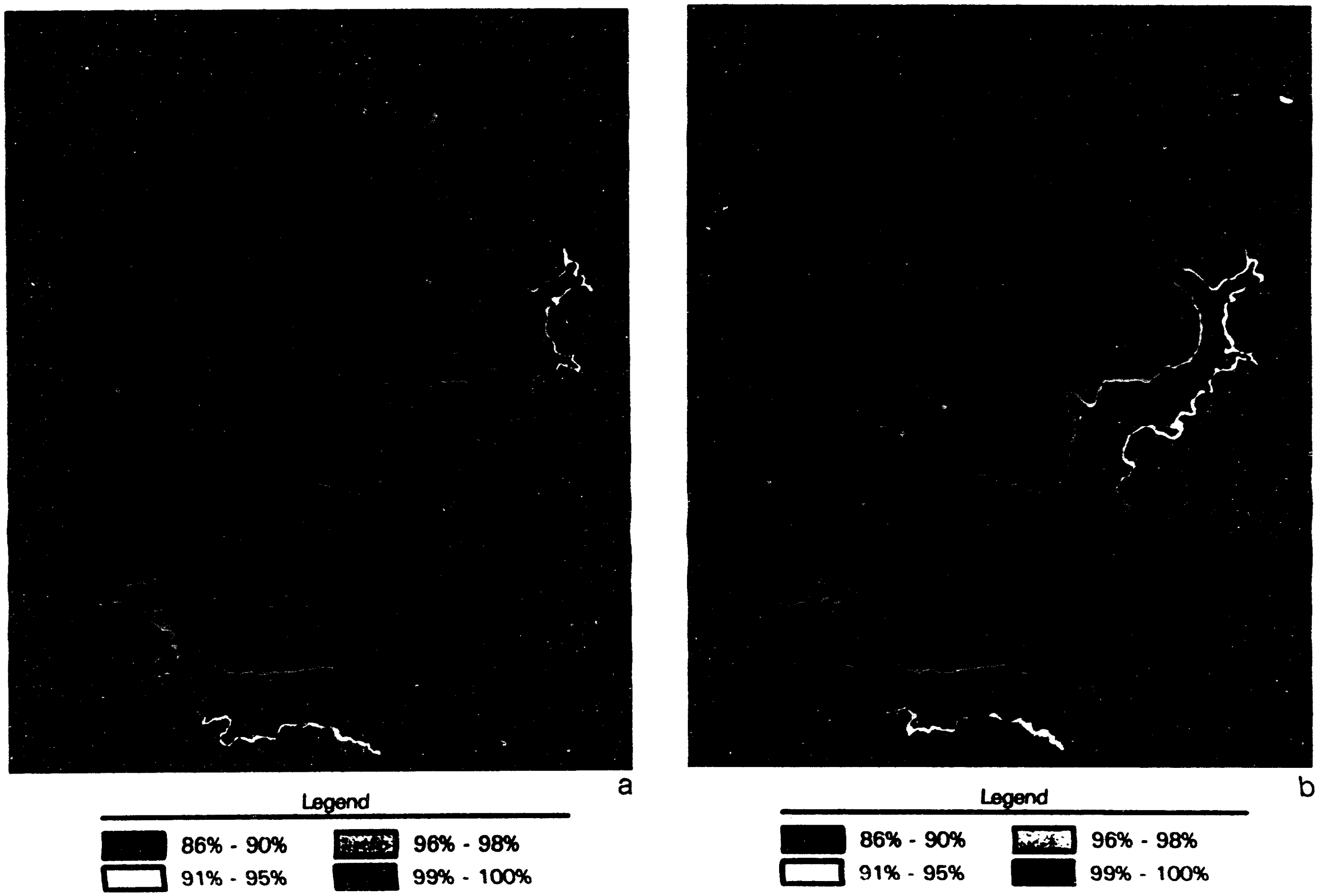

Figure 7 Predicted spatial distribution of aquatic macrophytes in Par Pond using the >85% constraint at the (a) 197' contour and (b) 194' contour.

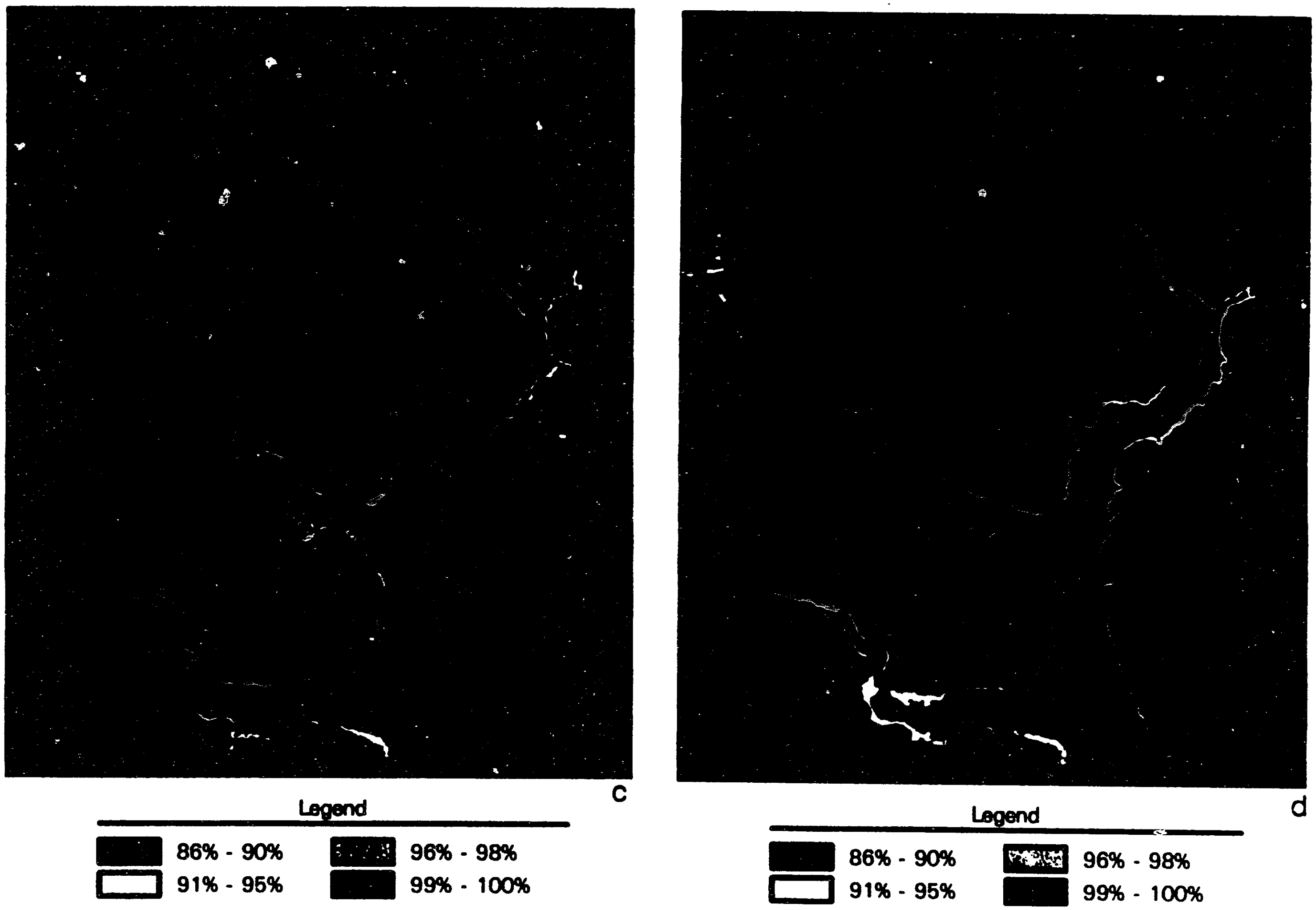

Figure 7 Predicted spatial distribution of aquatic macrophytes in Par Pond using the >85% probability constraint at the (c) 190' contour and (d) 187' contour.

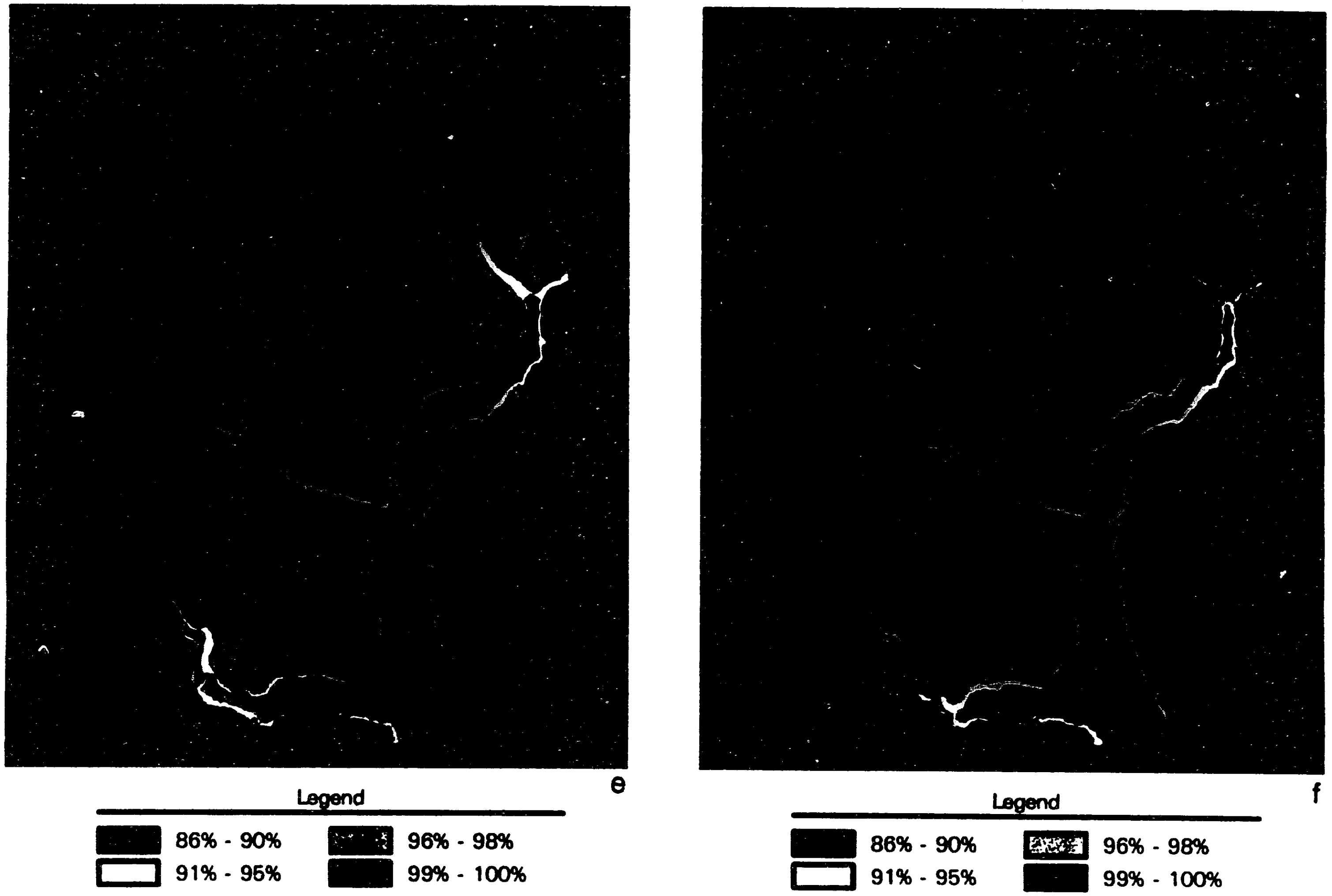

Figure 7 . Predicted spatial distribution of aquatic macrophytes in Par Pond using the >85% probability constraint at the (e) 184' contour and (f) 181' contour.

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