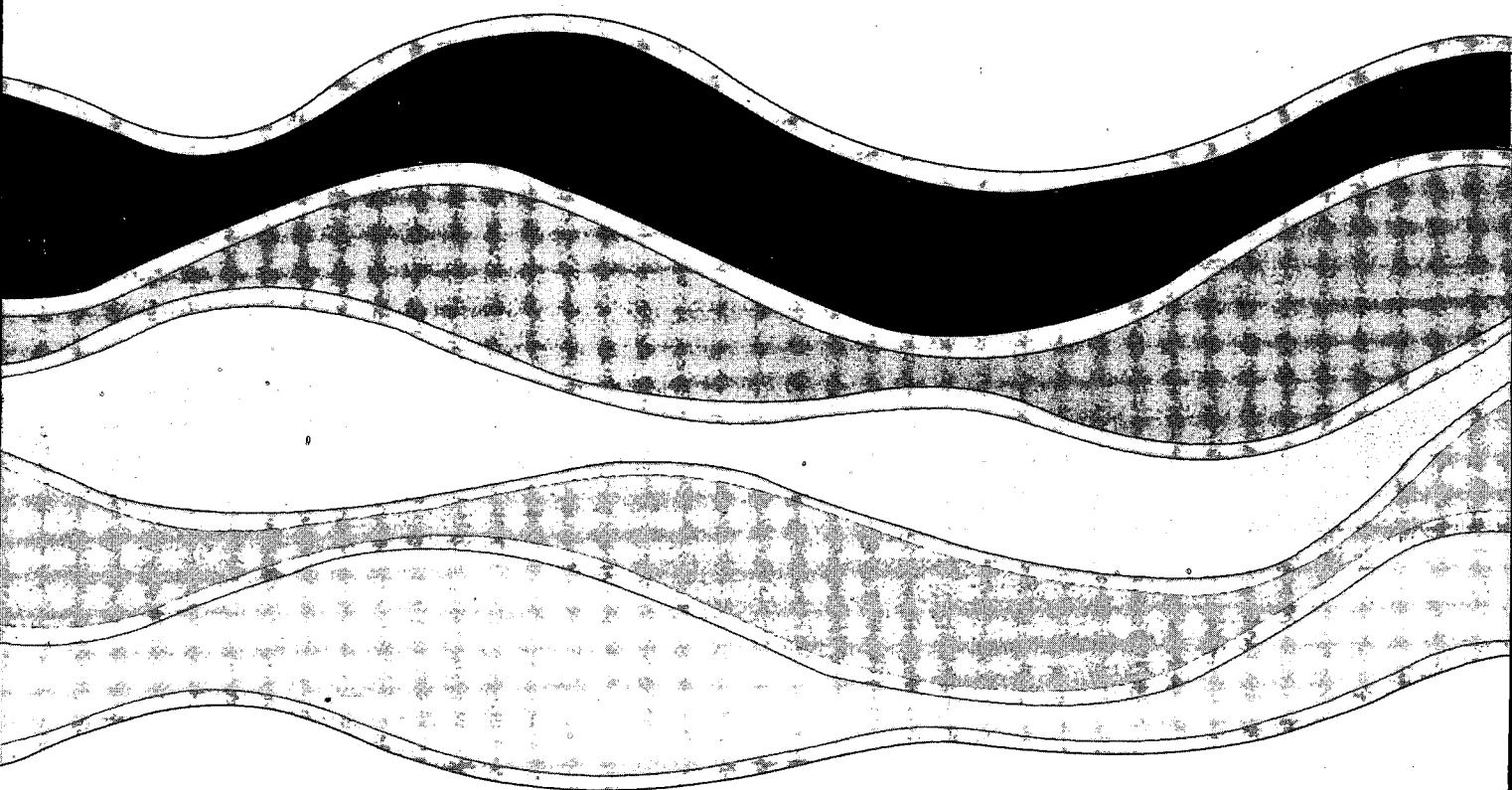NATIONAL WATER RESEARCH INSTITUTE

INSTITUT NATIONAL de RECHERCHE sur les EAUX

ESTABLISHING HABITAT GOALS AND RESPONSE
IN AN AREA OF CONCERN USING A
GEOGRAPHIC INFORMATION SYSTEM

D.S. Painter

NWRI Contribution No. 90-20

ESTABLISHING HABITAT GOALS AND RESPONSE
IN AN AREA OF CONCERN USING A
GEOGRAPHIC INFORMATION SYSTEM

D.S. Painter

Lakes Research Branch
National Water Research Institute
867 Lakeshore Road, P.O. Box 5050
Burlington, Ontario L7R 4A6

Management Perspective

The Great Lakes Water Quality Agreement lists 14 possible impaired uses of an Area of Concern (AOC) that the Remedial Action Plan (RAP) must examine (Stage 1) and if impairment is observed then remedial actions should be determined (Stage 2). One of the 14 impairments is the loss of fish habitat. The listing/delisting criteria for an AOC stipulate that the loss of fish habitat must be due to water quality. The magnitude of fish habitat loss in the Great Lakes is large but how much of that loss is due to water quality is unknown. If the loss in habitat due to water quality could be quantified, then establishing habitat targets and water quality goals are also possible (Stage 2). One aspect of fish habitat that is affected by water quality is the extent of aquatic plants in the littoral zone. An approach, using a Geographical Information System (GIS), has been developed in the Hamilton Harbour AOC which can determine if aquatic plants are limited by water clarity, thereby fulfilling the Stage 1 requirement. Habitat targets can be established by determining aquatic plant productivity and distribution when water clarity is assumed to meet the provincial water quality objective (within 10% of background when background is assumed to be early winter water clarity least affected by algal chlorophyll). Improvements in water clarity can be evaluated for their effect on aquatic plant productivity and distribution. Options can be compared and chosen (Stage 2).

Water clarity in the Hamilton Harbour RAP area is definitely affecting the quantity and productivity of submergent plants. The analysis predicts a 1988 total submergent plant area of 133.5 - 139.5 ha. The provincial water quality objective for water clarity would result in 432 - 513 ha of submergent plant area. The increase is approximately 300 - 380 ha more than is presently occurring in the Hamilton Harbour RAP area. Therefore, the Stage 1 RAP requirement that the loss of fish habitat be due to water quality has been confirmed and targets, which is a Stage 2 requirement, have been established.

Very optimistic water clarity improvements as a result of remedial options under discussion could increase the present total area to 210 - 220 ha, an increase of approximately 70 - 80 ha. The remedial options under discussion should be implemented and water clarity improvements and habitat response assessed. The habitat targets for submergent aquatic plants will not be achieved by the present suite of remedial options and further water clarity improvements through phosphorus and suspended solids loading reductions will likely be necessary.

On trouve dans l'Accord relatif à la qualité de l'eau dans les Grands Lacs, 14 aspects potentiellement endommagés d'un secteur préoccupant sur lesquels le Plan de mesures correctives doit se pencher (étape 1); si on observe des dommages, alors il faut déterminer les mesures correctives à apporter (étape 2). L'un de ces 14 aspects touche la perte de l'habitat des poissons. D'après les critères d'inclusion sur la liste des dommages, ou d'exclusion de celle-ci, pour un secteur préoccupant, la perte de l'habitat des poissons doit être liée à un problème de qualité de l'eau pour y être inscrite. L'ampleur de la perte des habitats de poissons dans les Grands Lacs est considérable, mais on ne connaît pas la part de cette perte qui est liée à des problèmes de qualité de l'eau. Si cette part pouvait être quantifiée, alors il serait possible de déterminer des objectifs de qualité d'eau et des cibles en matière d'habitat (étape 2). L'un des aspects de l'habitat des poissons touché par la qualité de l'eau : la superficie occupée par l'herbier dans la zone littorale. On a mis au point une méthode pour le secteur préoccupant du port d'Hamilton qui, à l'aide d'un Système d'information géographique (SIG), permet de déterminer si les plantes aquatiques sont limitées par la transparence de l'eau, ce qui répond aux exigences de l'étape 1. On peut déterminer des cibles pour les habitats en évaluant la distribution et la productivité des plantes aquatiques si l'on suppose que la transparence de l'eau répond aux objectifs provinciaux de qualité des eaux (à moins de 10 % de la transparence naturelle, quand on suppose que celle-ci correspond à la transparence du début de l'hiver la moins touchée par les algues chlorophylliennes). Les améliorations de la transparence de l'eau peuvent être évaluées en terme de leurs effets sur la distribution et la productivité des plantes aquatiques. On peut comparer les options et en retenir certaines (étape 2).

La transparence de l'eau dans le secteur préoccupant du port d'Hamilton a de toute évidence un effet néfaste sur la quantité et la productivité des plantes submergées. D'après l'analyse, la superficie totale des plantes submergées serait de 133,5-139,5 ha en 1988. Si on respectait l'objectif provincial de la qualité de l'eau, en ce qui a trait à la transparence, la superficie passerait à 432-513 ha. La superficie réelle dans le secteur préoccupant du port d'Hamilton est à l'heure actuelle de 300-380 ha inférieure à cela. L'exigence de l'étape 1 du Plan de mesures correctives voulant que la perte de l'habitat de poissons soit due à la qualité de l'eau a donc été confirmée et les cibles, exigence de l'étape 2, ont été établies.

Des améliorations très considérables de la transparence de l'eau, suite aux mesures correctives à l'étude, pourraient faire augmenter la superficie totale actuelle à 210-220 ha, une augmentation d'environ 70-80 ha. Les mesures correctives à l'étude devraient être mises en application et les améliorations à la transparence de l'eau et à l'habitat devraient être évaluées. L'application de la présente série de mesures correctives ne permettra pas d'atteindre les cibles en matière d'habitat pour les plantes aquatiques submergées; il faudra probablement améliorer encore plus la transparence de l'eau par des réductions de la charge en phosphore et en matières solides en suspension.

Establishing Habitat Goals and Response in an Area of Concern using a Geographic Information System

Scott Painter
Lakes Research Branch
National Water Research Institute

INTRODUCTION

The Great Lakes Water Quality Agreement lists 14 possible impaired uses of an Area of Concern (AOC) that the Remedial Action Plan (RAP) must examine (Stage 1) and if impairment is observed then remedial actions should be determined (Stage 2). One of the 14 impairments is the loss of fish habitat. The listing/delisting criteria for an AOC stipulate that the loss of fish habitat must be due to water quality. Loss of fish habitat in the Great Lakes is a serious concern due to the magnitude of the loss, however how much of that loss is due to water quality is unknown. If the loss in habitat due to water quality could be quantified, then establishing habitat targets and water quality goals are also possible (Stage 2). An approach, using a Geographical Information System (GIS), has been developed in the Hamilton Harbour AOC which can determine if aquatic plants (fish habitat) are limited by water clarity, thereby fulfilling the Stage 1 requirement. Habitat targets can be established by determining aquatic plant productivity and distribution when water clarity is assumed to meet the provincial and IJC water quality objective (within 10% of background when background is assumed to be early winter water clarity least affected by algal chlorophyll). Improvements in water clarity can be evaluated for their effect on aquatic plant productivity and distribution. Options can be compared and chosen (Stage 2).

METHODS

The GIS analysis requires detailed information on bathymetry and spatial water clarity for the areas involved. Aquatic plant response to water clarity can be determined in two ways. Several studies have reported an empirical relationship between the maximum depth of colonization (Z_c) and Secchi depth. The spatial Secchi depths can be converted into a Z_c using the empirical relationship. If the bathymetric map shows that the area in question is shallower than the Z_c then aquatic plants will be present but if the area is deeper than the Z_c then aquatic plants will be absent. Using a GIS to perform the analysis, a map would be derived that would illustrate presence or absence of aquatic vegetation from the spatial maps of Secchi depth and depth contours.

The second approach would rely on photosynthetic response curves which are well understood and reported for several species of aquatic plants in the literature. The spatial Secchi depths can be converted into extinction coefficients. The extinction coefficient, seasonal average daylight incident light intensity and depth map can calculate an average daily light intensity at the sediment surface. The light intensity can then be converted into a relative productivity rate (V/V_{max}) for single species or groups of aquatic plants. The advantage of the relative productivity analysis is that the results can be classified into sparse, low, moderate, and high productivity classes thereby yielding more information than the Z_c analysis.

1

The two approaches can be used to confirm the results of each analysis. The total area of aquatic plants predicted by both methods should be similar since the empirical Z_c analysis is based upon the photosynthetic capacity of aquatic plants.

Sediment Elevation Maps

Sediment elevation contour maps were derived for Grindstone Creek Delta, Sunfish Pond, the Elbow, Cootes Paradise, Westdale Cut, and Hamilton Harbour (Figure 1). The depth contour intervals chosen were 10 cm for the Grindstone Creek areas and Westdale Cut, 15 cm for Cootes Paradise, and 30 cm for Hamilton Harbour. The contour intervals were chosen to provide less than 10% error in the estimate of aquatic plant response as described later. The navigational chart for Hamilton Harbour was adequate for deriving vectors for the depth classes chosen. The remaining areas had to be visited and echosounded to determine precise depth contours. The depth contours were digitized as arcs and nodes using TYDIG and exported into SPANS, a GIS software package from TYDAC.

Water level fluctuations influence aquatic plant distribution patterns and result in emergent and submergent vegetation occupying specific depth ranges. Emergent plants were confined to sediment elevations of 74.7 m and higher which is the late July Lake Ontario average water level. Submergent plants were confined to elevations of 74.4 m and lower. The 74.4 m elevation is the November – February average water level in Lake Ontario. Mudflats occupy the intermediate elevations (74.7 – 74.4 m). A more detailed discussion of the effects of seasonal water level fluctuation and the rationale for the above elevation restrictions is included in Painter et al. (1989) but basically the elevations chosen are based on existing knowledge of emergent plant response to summer and/or winter flooding, and submergent plant response to ice scouring, wave action and late summer drawdown.

Secchi Depth Maps

Secchi depth maps were developed from 1988 spatial surveys of Grindstone Creek Delta, Cootes Paradise and Hamilton Harbour. Westdale Cut, Sunfish Pond and the Elbow did not require a spatially variable Secchi depth map because the 1988 survey did not observe spatially variable water clarity in these three areas probably because of their small size. Simulated Secchi depths depicting improved water clarity were generated by examining the 1987-89 data. The Z_c and productivity analyses were performed on at least five Secchi depth scenarios. The 1988 Secchi depth spatial pattern was used for the first analysis; the 90% of background Secchi depth as determined by late winter values or upstream values in the case of the stream sites was used in the last analysis. The other analyses were performed at intermediate Secchi depths scenarios and were again based on observed spatial patterns of Secchi depth. The last scenario, using a uniform background Secchi depth, was used to derive the habitat targets for each area.

Maximum Depth of Colonization (Z_c)

In order to predict the maximum depth of colonization of aquatic plants, the equations of Chambers and Kalff (1985), Canfield et al. (1985), Spence (1976), and Chambers and Prepas (1988) were compared (Figure 2). The raw data from over 200 lakes was examined in the 0 - 4 m Secchi depth range to determine the suitability of the various equations in predicting Z_c. The chosen equation had to work well in this Secchi depth range because aquatic plant response was to be predicted in turbid water bodies. The equation of Chambers and Kalff ($r = 0.76$, $Z_c = (1.33 * \log(secchi) + 1.40)^2$ was determined to be the best predictor of Z_c.

The empirical relationship could also be used to determine the intervals required for the depth contours to detect an aquatic plant response to increasing water clarity. For example, for an allowable error of only 10%, if the Secchi depth was 2 m, the Z_c would be 3.5 m and the depth contour interval would have to be at least 35 cm (Figure 3). If the Secchi depth was 1 m, the Z_c would be 2 m and the depth contour interval would have to be at least 20 cm. As water clarity improves, the necessary depth contour interval increases. A very turbid water body would require very small depth contour intervals in order to predict an aquatic plant response with only 10% error.

Relative Productivity Analysis

Relative productivity response to light, half-saturation coefficients and light compensation constants are available for a number of common aquatic plant species. Figure 4 illustrates the relative productivity response of Myriophyllum spicatum and Hydrilla verticillata as reported by Van et al. (1976) and the Monod-Droop equation to fit the data. Figure 4 also illustrates a generic plant response to light which is intermediate between the two species. The Monod-Droop equation for productivity is as follows:

$$Pmax = (I/(I + k_m)) * (1 - (LC/I))$$

where

P_{max} = Relative productivity
I = light intensity ($\mu E\ m^{-2}\ sec^{-1}$)
k_m = operationally defined to ensure $\frac{1}{2}\ V_{max}$ equal to reported value
LC = light compensation constant
($\frac{1}{2}\ V_{max}$ and LC are specific for each plant species)

Table 1 shows the k_m and LC values for Myriophyllum spicatum and Hydrilla verticillata and the generic plant.

Table 1: Selected LC, k_m and $\frac{1}{2} V_{max}$ values used in Productivity Equation

	LC	$\frac{1}{2} V_{max}$	k_m
Myriophyllum spicatum	35	120	50
Hydrilla verticillata	15	80	50
Generic	25	100	50

Light intensity at the sediment depth was calculated using the following equation:

$$I_{bottom} = e^{\ln(PAR)-(extinction\ coefficient\ *\ depth)}$$

where PAR = photosynthetically available radiation
at the water's subsurface ($\mu E\ m^{-2}\ sec^{-1}$)

The surface PAR was determined using daily averages of hourly recordings between June 1st and August 31st, from data collected over a nine-year period (1977–1985). The average daily light intensity determined from the nine years of data was 700 $\mu E\ m^{-2}\ sec^{-1}$. Subsurface PAR was determined by deducting 10% from the surface PAR. The extinction coefficient was calculated using the following regression equation:

Extinction Coefficient = (1.63/Secchi depth); $r^2=0.90$.

This regression equation was derived from three years of observations in Hamilton Harbour and Cootes Paradise and suggests that Secchi depth occurs at a depth that receives 19.5% of the incident photosynthetically available radiation. Secchi depth has been observed to occur between 15 and 20% of incident radiation (Vollenweider, 1969).

The relative productivity response was classified into 25% productivity classes (sparse, low, moderate, or high) which provided another series of maps predicting relative plant productivity at observed and simulated Secchi depths. An area analysis of the relative productivity maps provided the individual productivity class areas as well as the total aquatic plant area. The total areas for the Z_c and relative productivity analyses were compared to confirm the analyses.

RESULTS AND DISCUSSION

The two methods of predicting aquatic plant response to improved water clarity were comparable ($r^2=0.98$), yielding similar total aquatic plant areas (Table 2). The relative productivity analysis is the preferred method because of the increased amount of information provided (Figure 5). The productivity classes could be used in fish habitat suitability analyses. The sparse productivity vegetation is of little value to pike for example and the high productivity areas may be of little value if it occurred in shallow water.

The emergent plant area is not affected by water clarity but is affected by bathymetry. The present bathymetry and water level fluctuation in Lake Ontario restricts the amount of emergent plant area to only the present small area. Restoration of emergent vegetation will not occur due to improvements in water quality.

Water clarity in the Hamilton Harbour RAP area is definitely affecting the quantity and productivity of submergent plants. The analysis predicts a 1988 total submergent plant area of 133.5 - 139.5 ha. The provincial water quality objective for water clarity would result in 432 - 513 ha of submergent plant area. The increase is approximately 300 - 380 ha more than is presently occurring in the Hamilton Harbour RAP area. Therefore, the Stage 1 RAP requirement that the loss of fish habitat be due to water quality has been confirmed and targets, which is a Stage 2 requirement, have been established.

Very optimistic water clarity improvements as a result of remedial options under discussion could increase the present total area to 210 - 220 ha, an increase of approximately 70 - 80 ha. The remedial options under discussion should be implemented and water clarity improvements and habitat response assessed. The habitat targets for submergent aquatic plants will not be achieved by the present suite of remedial options and further water clarity improvements through loading reductions will likely be necessary.

Table 2: Area Analyses of Study Areas

Secchi (cm)	Emergents	Mud-flats	Submergents Productivity						Total Area (ha)
			Z_c	S	L	M	H	Total	

Hamilton Harbour

Secchi (cm)	Emergents	Mud-flats	Z_c	S	L	M	H	Total	Total Area (ha)
157	0	1	120	36.6	24.9	46.6	17.2	125.3	2032
200	0	1	149	37.0	31.7	50.6	33.5	152.8	2032
225	0	1	155	24.9	52.8	53.2	36.2	167.0	2032
250	0	1	164	24.3	42.4	64.1	43.6	174.4	2032
300	0	1	207	80.6	38.6	97.5	71.3	287.9	2032

Cootes Paradise

Secchi (cm)	Emergents	Mud-flats	Z_c	S	L	M	H	Total	Total Area (ha)
24	6	34	0	0.03	0	0	0	0.03	217
35	6	34	0.03	0.06	0	0	0	0.06	217
40	6	34	9.4	9.3	0	0	0	9.3	217
50	6	34	13.3	9.7	0.3	0	0	10.0	217
100	6	34	177.3	0	27.1	116.5	33.7	177.3	217

Westdale Cut

Secchi (cm)	Emergents	Mud-flats	Z_c	S	L	M	H	Total	Total Area (ha)
25	0.2	2	0	0	0	0	0	0	5.1
30	0.2	2	0.4	0.4	0	0	0	0.4	5.1
35	0.2	2	0.7	0.36	0.39	0	0	0.75	5.1
40	0.2	2	1.3	0.26	0.74	0	0	1.0	5.1
45	0.2	2	1.9	0.56	0.74	0	0	1.3	5.1
50	0.2	2	2.3	0.85	0.62	0.39	0	1.86	5.1
55	0.2	2	2.7						5.1
60	0.2	2	2.9	0.86	1.11	0.74	0	2.71	5.1
100	0.2	2	2.9	0	0.57	1.92	0.39	2.88	5.1

Grindstone Delta

Secchi (cm)	Emergents	Mud-flats	Z_c	S	L	M	H	Total	Total Area (ha)
28	0	0.8	13.45	10.67	3.43	0.03	0	14.14	40.9
33	0	0.8	19.09	12.13	4.64	0.09	0	17.0	40.9
38	0	0.8	22.21	16.39	7.11	0.32	0	23.83	40.9
45	0	0.8	22.62	17.88	8.72	1.90	0	28.52	40.9
100	0	0.8	38.8	5.9	15.36	14.84	2.67	38.80	40.9

Sunfish Pond

Secchi (cm)	Emergents	Mud-flats	Z_c	S	L	M	H	Total	Total Area (ha)
25	0	0.2	0	0	0	0	0	0	2.8
30	0	0.2	0.66	0.67	0	0	0	0.67	2.8
35	0	0.2	1.13	0.47	0.66	0	0	1.13	2.8
40	0	0.2	2.27	0.69	1.13	0	0	1.82	2.8
45	0	0.2	2.42	1.15	1.13	0	0	2.27	2.8
50	0	0.2		0.6	1.16	0.66	0	2.43	2.8
60	0	0.2		0.07	1.29	1.28	0	2.49	2.8
100	0	0.2	2.55	0	0.09	1.8	0.66	2.55	2.8

Grindstone Elbow

Secchi (cm)	Emergents	Mud-flats	Z_c	S	L	M	H	Total	Total Area (ha)
25	0	3.25	0	0	0	0	0	0	7.2
30	0	3.25	1.24	1.23	0	0	0	1.23	7.2
35	0	3.25	2.10	0.87	1.23	0	0	2.1	7.2
40	0	3.25	3.38	0.63	2.1	0	0	2.73	7.2
45	0	3.25	3.86	1.28	2.1	0	0	3.38	7.2
50	0	3.25	3.98	1.13	1.5	1.24	0	3.87	7.2
60	0	3.25		0.12	1.75	2.1	0	3.97	7.2
100	0	3.25	3.98	0	0	2.74	1.24	3.98	7.2

			Z_c	S	L	M	H	Total	Total Area (ha)
1988 =	6.4	41.2	133.45	47.3	28.3	46.6	17.2	139.5	2305
Target=	6.4	41.2	432.22	86.5	81.7	235.3	110	513.4	2305

REFERENCES

Canfield, D.E., K.A. Langeland, S.B. Linda, and W.T. Haller. 1985. Relations between water transparency and maximum depth of macrophyte colonization in lakes. J. Aquatic Plant Manage. 23:25-28.

Chambers, P.A. and J. Kalff. 1985. Depth distribution and biomass of submersed aquatic macrophyte communities in relation to Secchi depth. Can. J. Fish. Aquat. Sci. 42:701-709.

Chambers, P.A. and E.E. Prepas. 1988. Underwater spectral attenuation and its effect of the maximum depth of angiosperm colonization. Can. J. Fish Aquat. Sci. 45:1010-1017.

Painter, D.S., K.J. McCabe, and W.L. Simser. 1989. Past and Present Limnologial Conditions in Cootes Paradise affecting Aquatic Vegetation. Royal Botanical Gardens Tech. Bulletin #13. Hamilton Ontario. Canada. L8N 3H8.

Spence, D.H.N. 1976. Light and plant response in fresh water. In G.C. Evans, R. Bainbridge and O. Rackman, eds. Light as an Ecological Factor: II. Blackwell Scientific Publications, Oxford, England.

Van, T.K., W.T. Haller, and G. Bowes. 1976. Comparison of the Photosynthetic Characteristics of Three Submersed Aquatic Plants. Plant Physiol. 58: 761-768.

Vollenweider, R.A. 1969. Möglichkeiten und Grenzen elementarer Modelle der Stoffbilanz von Seen. Arch. Hydrobiol. 66(1):1-36.

Figure 1 Study areas for habitat response analysis
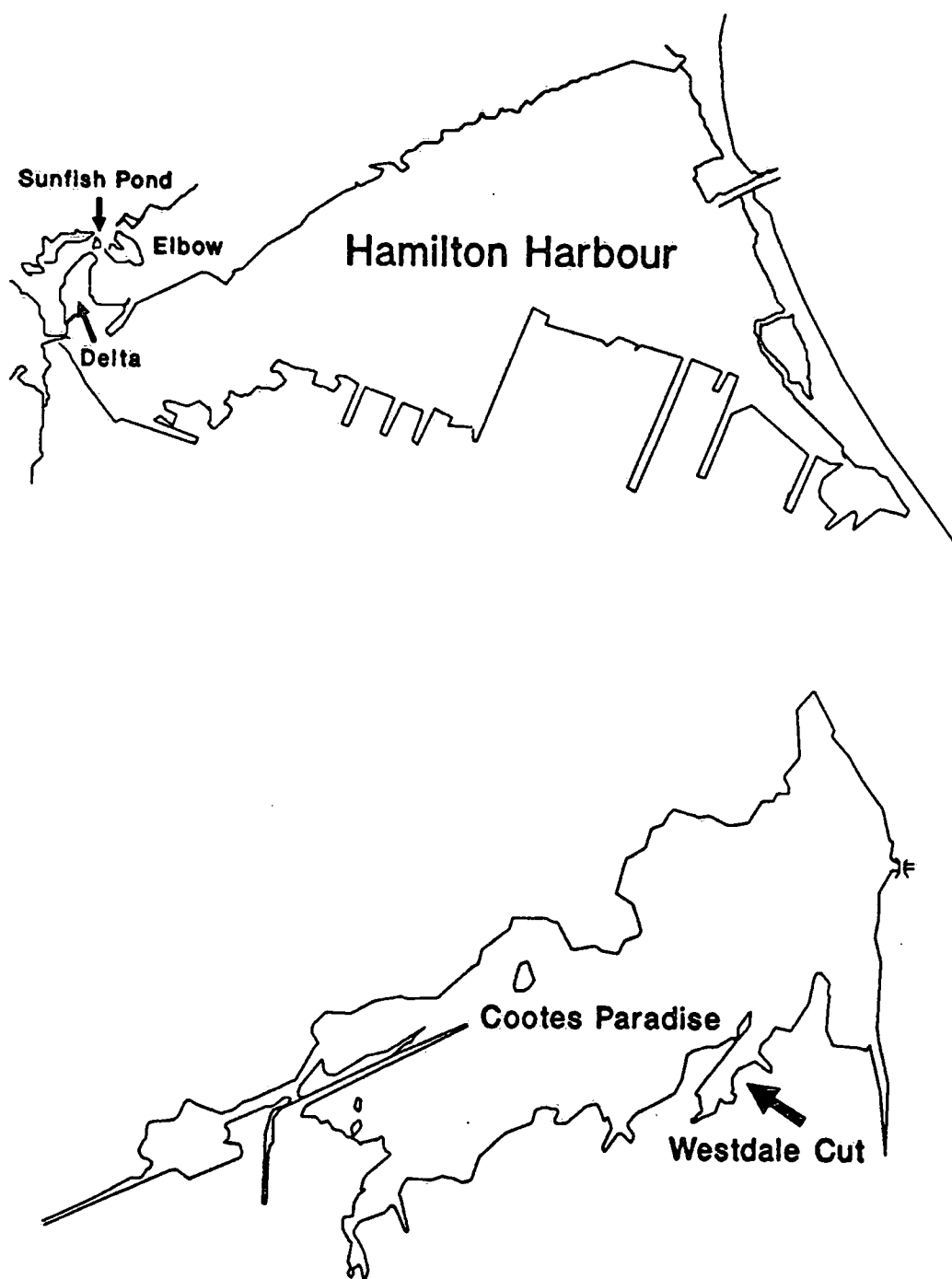
Secchi VS Maximum Depth of Colonization

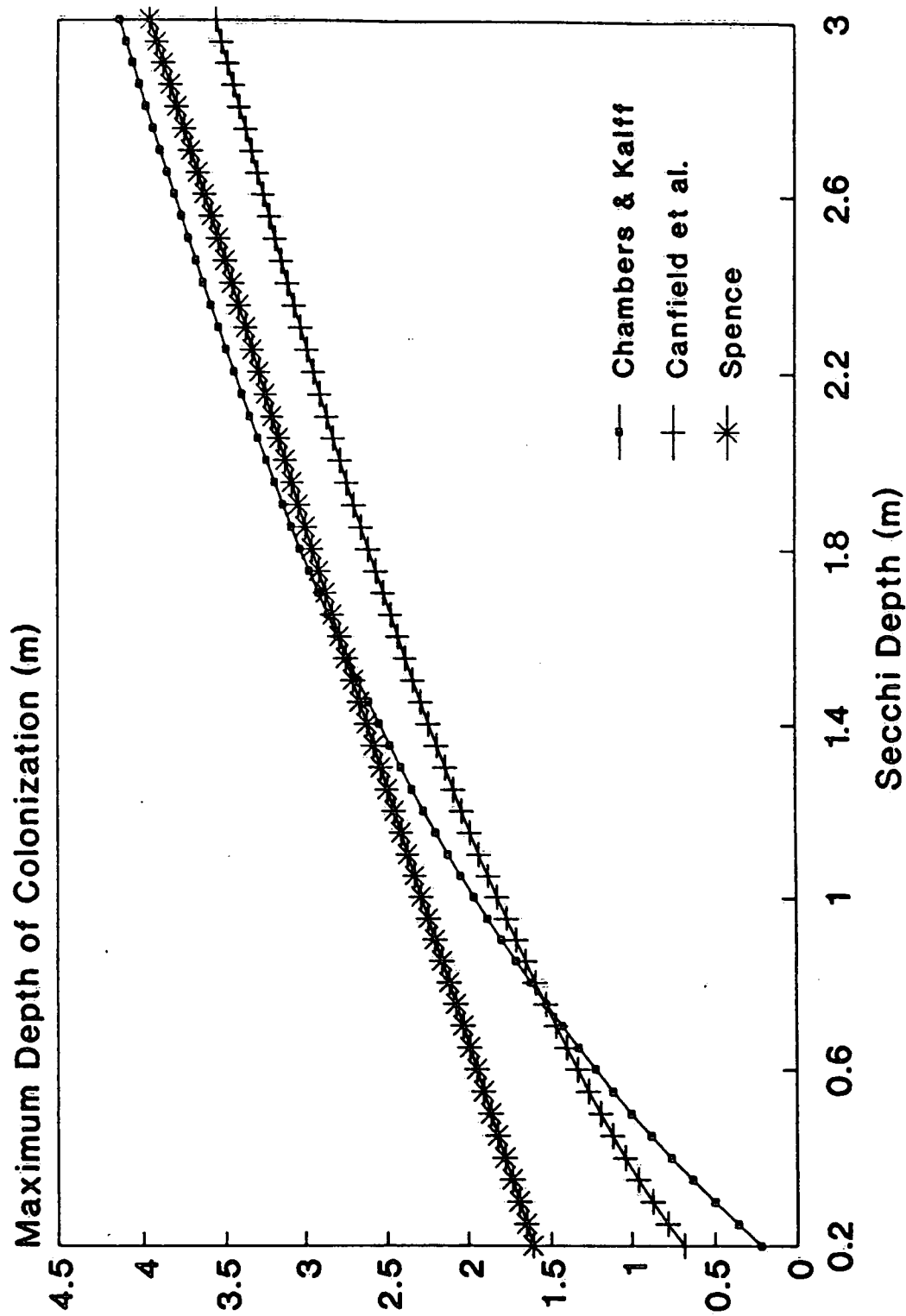**Maximum Depth of Colonization (m)**

Figure 2   Reported relationships between Secchi depth and maximum depth of colonization

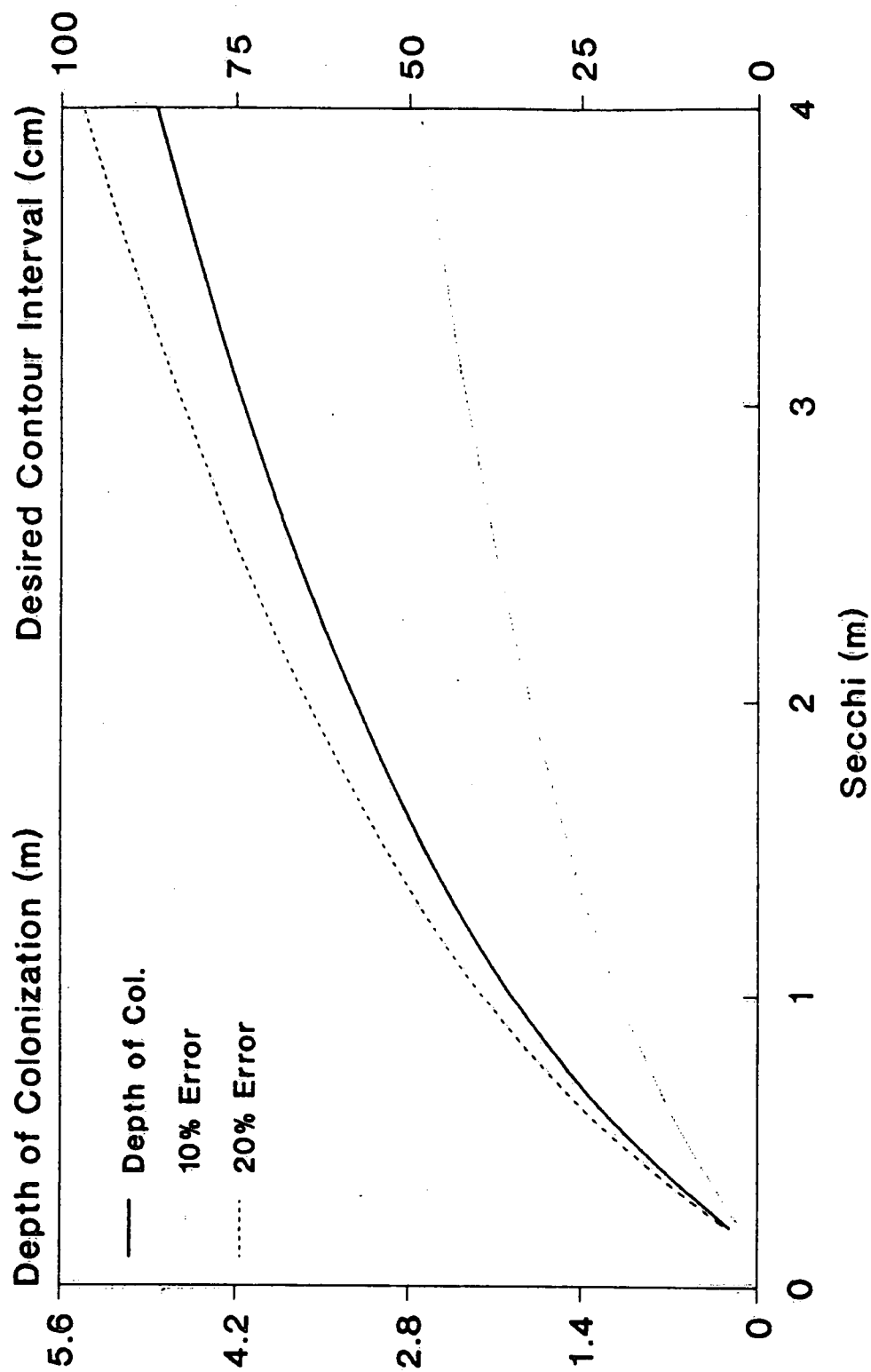# Aquatic Plant Depth of Colonization and Error Estimates of Contour Interval

Figure 3 Desired depth contour interval for 10% and 20% error in estimating plant response to water clarity
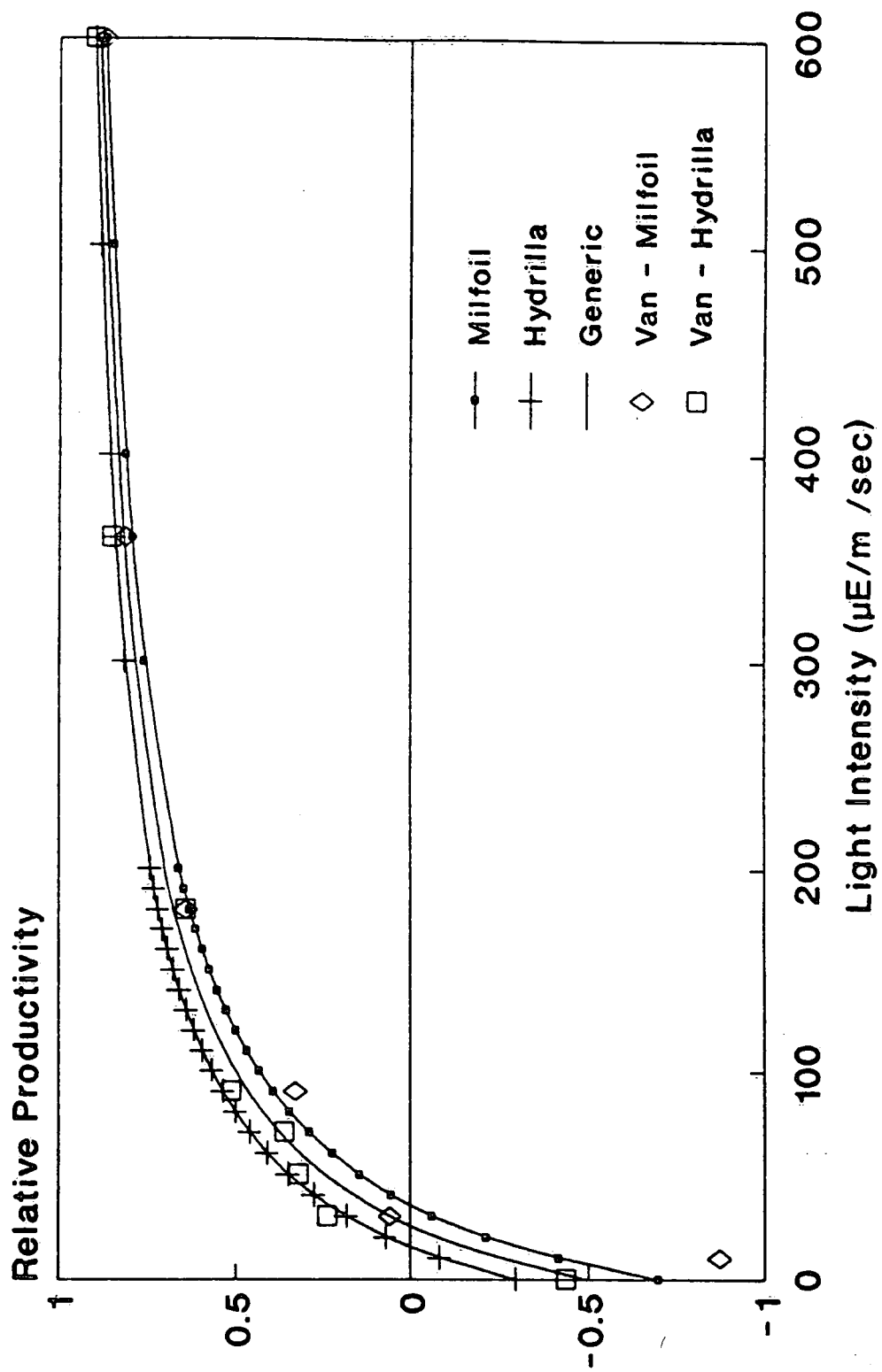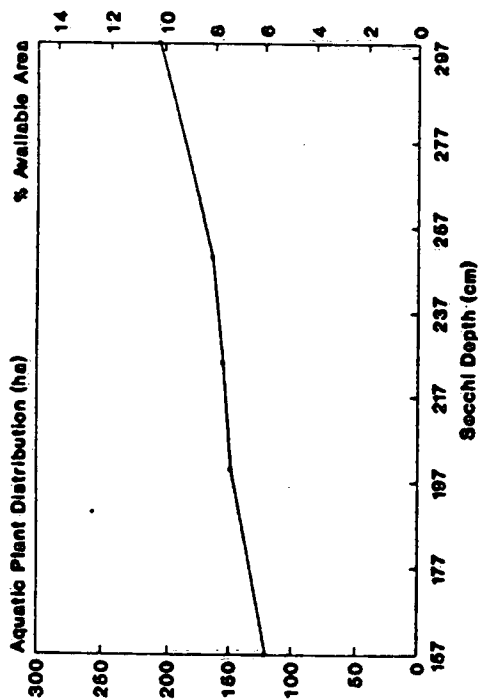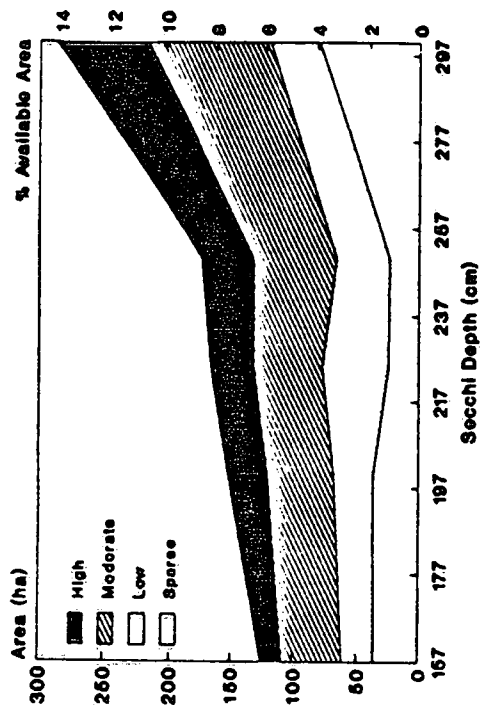
Productivity VS Light Intensity
M. spicatum, H. verticillata, & Generic

Relative Productivity

Milfoil
Hydrilla
Generic
Van – Milfoil
Van – Hydrilla

Light Intensity (µE/m /sec)

Figure 4   Relative productivity of two aquatic plants and our generic plant vs light intensity (µE/m²/sec)
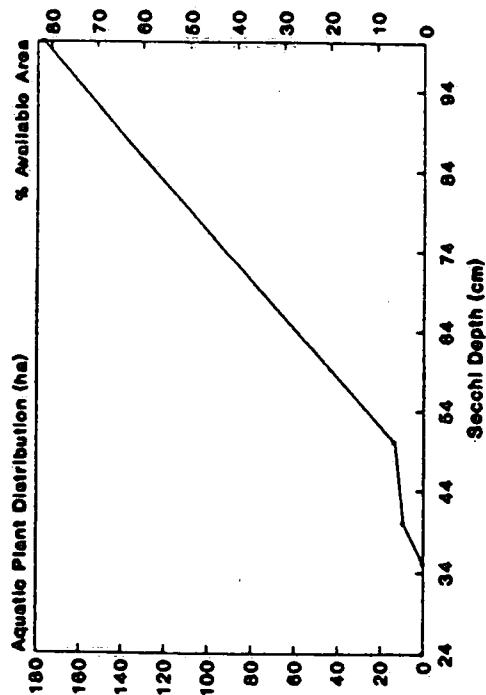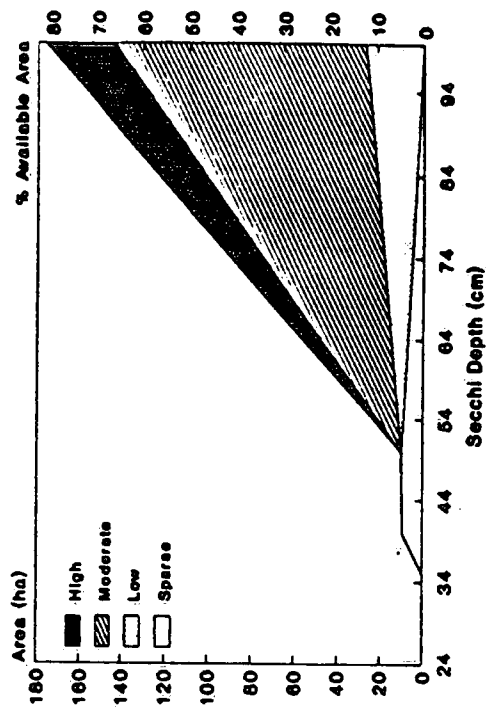
Figure 5   Comparison of aquatic plant Z_c and productivity responses for two study areas at the simulated Secchi depths

NATIONAL WATER RESEARCH INSTITUTE
P.O. BOX 5050, BURLINGTON, ONTARIO L7R 4A6

Environment Environnement
Canada   Canada

Canada

INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX
C.P. 5050, BURLINGTON (ONTARIO) L7R 4A6

Think Recycling!

Pensez à recycler !