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Seasonal Variations of Manning's Roughness Coefficient in a Subtropical Marsh

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ABSTRACT

Manning's roughness coefficient, N, ranged from 0.16 to 0.55 in a subtropical marsh over the flow depth varying between 65 to 40 cm. The N value increased with a decrease in flow depth. The roughness coefficient tripled over a six month period from June to November. The N value in a nonsprayed area was twice of that determined in a chemically defoliated area. The N value and vegetation density were parabolically related. The increase in N value was directly proportional to the 1/2 power of vegetation density and ⅔ power of flow depth in all types of vegetation.

INTRODUCTION

Knowledge of flow resistance, referred to as Manning's roughness coefficient, for different flow conditions helps to develop better water management systems. Specifically, the solutions to water resources related problems such as flood routing, backwater curve computation, channel improvement, marshland flow, and scouring intensity are related to the determination of flow resistance value. However, the resistance value is greatly affected by vegetation. Type of vegetation, its interactions with seasonal variation, vegetation density, and flow depth can retard the flow tremendously, especially in shallow channels and marshland flow.

Unfortunately, little is known about flow resistance patterns in heavily vegetated flow systems except for some grassed water ways. Most previous studies were conducted under simulated conditions. General conclusions for these studies indicate that there is a significant increase in flow resistance due to vegetation.

Bogart (1949) observed that water hyacinth (*Eichhornia crassipes*) in canals in the Everglades area increased the flow resistance value by 2.5 times higher than the original value the canals were designed for. Ree and Palmer (1949) conducted flow studies on trapezoidal and rectangular channels lined with Bermuda grass (*Cynodon dactylon*). The flow resistance value for turbulent flow in these channels was found to be about 0.11. Ree (1958) determined flow resistance values for row crops wheat (*Triticum valgare*) and sorghum (*Sorghum spp.*). He recorded the resistance values for wheat up to 0.17. He noted that height and better growth of wheat had a greater impact than did the row spacing from 18 to 36 cm. The values for tall and short sorghum were 0.15 and 0.11, respectively. Leutheusser and Chisholm (1972) determined the resistance value of about 0.225 in an open channel with steep and heavily vegetated sideslopes in Toronto, Canada. Thompson and Roberson (1976) calculated the conveyance factor as a function of flow depth in simulated vegetated channels. They found that the value of the factor was higher in general for fully submerged vegetation as compared to partially submerged vegetation.

Chen (1976) evaluated the flow resistance value for shallow flows over turf surfaces and found that the resistance value for laminar flow on the turf surface was a few orders of magnitude higher than that on the glued-sand or concrete surface.

Petryk and Bosmajian (1975) introduced the component of vegetation density in their flow resistance model for vegetation. They observed that the resistance value increased in proportion to the ⅔ power of hydraulic radius in heavily treed flood plains. The computed variation in vegetation density was found to be a function of height. Preliminary computation of water surface profiles gave flow resistance values as high as 0.4 in heavily vegetated flood plains.

In the above studies little work was done on the dependence of flow resistance values on vegetation and its density in sluggish water flow systems such as marhsland or slough. Seasonal changes, vegetation density, flow depth, and types of plant community and their growth patterns can give a marked difference in the estimation of flow resistance values. The main objectives of these studies were to investigate: (a) the changes in flow resistance with depth for predominant vegetation groups, (b) the effect of seasonal vegetative growth on flow resistance, (c) the effect of aquatic weed control by defoliant sprays on flow resistance, (d) the dependence of flow resistance on vegetation density, and (e) the quantitative relationships between flow resistance, growth seasons, and vegetation density.

PROCEDURES

Study Area

These studies were conducted in Chandler Slough, which is the largest tributary to the Kissimee River in Florida with a drainage area of about 360 km². The slough marsh with an area of 4.4 km² (about 0.65 km wide and 6.77 km long) presents a diverse wetland system which predominantly includes aquatic broad leaf plants and shrubs. Rainfall is seasonal with about 75 percent of the total precipitation occuring in the wet season between May and October. The slough has a surface flow through the marsh during the wet season and becomes completely dry during the late winter and early spring.

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Contribution from the Florida Agricultural Experiment Stations as Journal Series No. 3309.

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Four sites in the most heavily vegetated plant communities were selected. These combined communities constituted about 90 percent of the total area of the slough. The three of the most predominant vegetation species present were water hyacinth, pickerel weed (*Pontederia lanceolata*), and buttonbush (*Cephalanthus occidentalis*).

Flow Measurements

In each site a number of subsites with uniform vegetative growth of the representative vegetation groups were selected. The selected subsites were staked, and wherever possible, measurements were taken at the same location or in the near vicinity. Flow velocity measurements were made once a month during August through November in 1978 and June and July in 1979. Care was taken to keep disturbance of the site to a minimum. Flow velocity was measured using two techniques:

Water Current Meter: An electromagnetic water current meter (Velmeter)* was used to measure flow velocity profiles along with the flow depth at 10 cm depth intervals at different subsites.

Fluorescein Dye Technique: A fluorescein dye technique was used for flow measurements. Average depth of flow over the dye path was also measured.

Computation of Manning's Roughness Coefficient

The Manning's roughness coefficient (N) was calculated using the modified Manning's flow formula that is applicable to wide channels as:

$$N = \frac{D^{2/3} S^{1/2}}{V} \quad [1]$$

where

V = flow velocity, m/s
D = flow depth, m
S = slope of energy gradient, m/m

The hydraulic radius in the original Manning formula was substituted by flow depth because the wetted perimeter in the marsh flow was very close to the width of flow cross section. A contour map for topography of the marsh area was prepared with 10 cm contour interval. General elevation of the site was computed from contour map by averaging the elevations taken in the flow direction. The flow velocity in the marsh, as reported in earlier study by Shih et al. (1979), ranged between 0.01 and 0.03 m/s. Therefore, the velocity head caused by this small flow velocity was insignificant. Consequently, the slope of ground surface was considered as a slope of energy gradient.

A composite flow velocity was used in computing N values where velocity was determined using flow meter. The composite velocity was calculated by weighting the flow velocity values with depth.

Studies in Sprayed and Nonsprayed Areas

Two independent areas each approximately 200 m wide and 2000 m long with similar type of vegetation and flow depths were selected in one of the sites. One of the areas was sprayed with a chemical defoliant at the end of April 1979. The predominant vegetation species at both locations were pickerel weed and buttonbush; there was very little water hyacinth. Subsequent flow measurements using the dye and flow meter methods were taken in the center (50 × 50 m area) of each designated area in June and July of 1979. The specific locations for flow measurements were selected to provide a straight one-dimensional flow path representing typical conditions of the sprayed and nonsprayed areas. Differences in N values were evaluated in sprayed and nonsprayed areas for the same average flow depth to determine how control of vegetation (aquatic weeds) influenced flow patterns.

Determination of Vegetation Density at Different Depths

Vegetation density at different depths at each location was calculated to evaluate its effect on the flow resistance and to determine if the flow resistance was related to vegetation density. The relationship used to calculate vegetation density is given by Petryk and Bosmajian (1975):

$$X = \frac{Cd \sum_{i=1}^{n} A_i}{AL} = \frac{2gS}{V^2} \quad [2]$$

where

X = vegetation density, $m^2/m/m^2$
Cd = the drag coefficient for vegetation
A_i = the projected area of the ith plant in the direction of flow, m^2
A = cross-sectional area of flow, m^2
n = total number of plants in the flow path
L = length of the channel being considered, m
S = bed slope of the channel, m/m
V = flow velocity, m/s
g = acceleration due to gravity, m/s^2

Vegetation density, calculated as an area occupied by vegetation per unit area of flow per unit length of flow path, was compared for different vegetations.

Manning's Roughness Coefficient Variation with Season and Vegetation Density

These studies were conducted during the wet season because the slough has a surface marsh flow during that season. Aquatic weed growth in the slough starts in late spring and dies back in the late winter. Therefore, the dynamics of plant growth for the wet season are assumed to follow an exponential form, i.e. the plant grows rapidly at the early wet season and slows down near the end of the season. Thus the N value related to the wet season is expressed as:

$$N = ae^{bZ} \quad [3]$$

where

Z = index of growth season starting with June i.e. June = 1, November = 6
e = exponential base
a, b = constants

The values of a and b are estimated from the experimental data using a regression analysis.

Relation between N values and vegetation density was computed as follows: Substitution of equation [2] into equation [1] would give the N value as a function of flow

*Cushing Engineering, Inc., Redwood City, California. The trade name is included for the convenience of the reader, and does not imply any endorsement or preference by the authors.

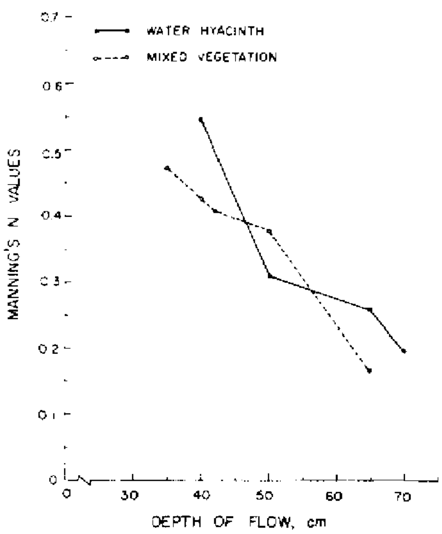

FIG. 1 Relation between depth of flow and Manning's N values for different types of vegetation for September conditions (mature vegetation).

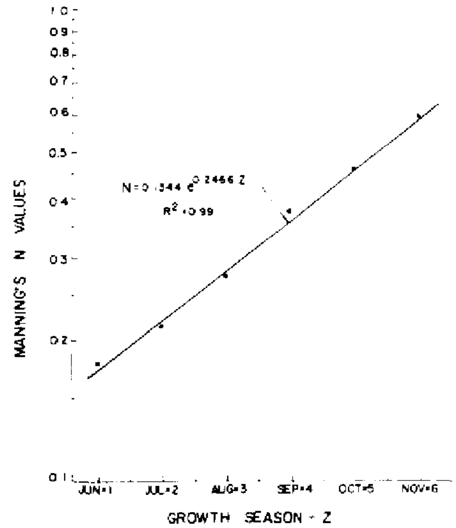

FIG. 2 Effect of time on Manning's N values for water hyacinth with 50 cm of flow depth.

depth and vegetation density, i.e.

$$N = \frac{D^{2/3}\, X^{1/2}}{(2g)^{1/2}} \qquad [4]$$

where

X = vegetation density as defined in equation [2]
D = flow depth, m
g = acceleration due to gravity, m/s^2

RESULTS AND DISCUSSION

Type of vegetation, its growth characteristics, flow depth, fluctuating flow stage, and seasonal variations are among the crucial factors that affect the flow characteristics of a vegetated flow system. This makes it difficult to obtain any meaningful relations of the N values if specific contributory factors are not considered one at a time.

Manning's Roughness Coefficient and Flow Depth Relations

Ten subsites were selected to test difference between the flow velocities measured by the flow meter and fluorescein dye methods. The results showed that the composite velocity computed from the flow meter method gave velocity values similar to those measured using the dye technique. The range of difference was within 10 percent. This indicates that the concept of composite flow velocity is useful in estimating average flow velocity in the marsh area. The N values as related to flow depth are plotted in Fig. 1 for typical marsh vegetation species of water hyacinth and mixed vegetation (pickerel weed, buttonbush and very little water hyacinth). The N values were computed based on the method defined in equation [1] using the flow velocity data collected in September, 1978. This period represented a typical situation in the marsh when the flow was at its peak; the vegetation was in full growth, and the flow stage had not started receding while approaching the dry season. As Fig. 1 shows, the N values increased with a decrease in flow depth, and varied from 0.2 to 0.55 for water hyacinth and from 0.11 to 0.43 for mixed vegetation. The flow depths corresponding to these N values were between 65 and 40 cm. This indicates that the N values increased by approximately 2 to 2½ fold over a flow depth decrease from 65 cm to 40 cm depending on the type of vegetation present. However, N values for maidencane wet prairie (which is comprised of a vast and uniform growth of *Panicum hemitomon*) and aquatic grass (*Panicum spp.*), which were reported in an earlier study by Shih et al. (1979), gave a relatively smaller increase from 0.44 to 0.52 over the same range of flow depth used in this study.

Time Dependence of Manning's Roughness Coefficient

To study the effect of seasons on the N values, flow velocity measurements using dye were made in the same approximate location at each site. The computed data corresponding to the growth period from June through November is given in Fig. 2. The N values increased at all sites with time and varied between 0.18 and 0.59 over the six month period for water hyacinth with 50 cm flow depth. This indicated that the N values became thrice from June to November.

The relationships between the N value and vegetation growth season were developed based on the model defined in equation [3] and the field measurement data. The results for water hyacinth are shown in Fig. 2. The R^2 value was greater than 0.99. This means that the general relationship between the N value and the growth season as defined in equation [3] would give satisfactory results.

Flow Roughness Values in Sprayed and Nonsprayed Areas

Flow velocity measurements made using dye technique and flowmeter were used to compute the N values in the sprayed and nonsprayed areas. The main vegetation consisted of pickerel weed with a small fraction of water hyacinth and dried buttonbush. Pickerel weed and water hyacinth were starting vigorous growth in the month of June whereas buttonbush had become leafless and dry. The calculated N values for both sprayed and nonsprayed areas are given in Table 1. The results indicated that ratio between the N values in nonsprayed

TABLE 1. COMPARISON OF FLOW RESISTANCE VALUES IN SPRAYED AND NONSPRAYED AREAS.

			Nonsprayed area			Sprayed area		
Time of measurement	Type of vegetation	Measurement technique	Location	Flow depth, cm	N value	Location	Flow depth, cm	N value
June 1979	Mostly pickerel weed and dried button bush	Dye	1	16	0.253	1	16	0.116
July 1979	Dense pickerel weed and dried button bush	Dye	1	25	0.510	1	25	0.141
June 1979	Mostly pickerel weed and dried button bush	Flow-meter	1	16	0.251	1	16	0.121
			2	16	0.491	2	16	0.141
			3	16	0.217	3	16	0.107
			Ave		0.320			0.123
July 1979	Dense pickerel weed and dried button bush	Flow-meter`	1	25	0.613	1	25	0.188
			2	25	0.362	2	25	0.188
			3	25	0.344	3	25	0.102
			4	25	0.564	4	25	0.094
			Ave		0.471			0.143

and sprayed areas increased from June to July. This ratio varied from 2.7 to 3.7 indicating that the N values increased in nonsprayed areas due to more profuse vegetative growth. This implies that successful control of vegetation alone could reduce the N values.

Relation Between Manning's Roughness Coefficient and Vegetation Density

Dependence of the N values on vegetation density was studied from the flow measurements made at different flow depths as shown in Fig. 1 for a given type of vegetation. Vegetation density and N values were calculated using equations [2] and [4], respectively. The results of the N values in relation to vegetation density are shown in Fig. 3. As Fig. 3 shows, the relationship between the N values and vegetation density for both water hyacinth and mixed vegetation follows a similar pattern of parabolical form. In other words, irrespective of the type of vegetation grown in the marsh, the increase in flow resistance was directly proportional to the square root of vegetation density and ⅔ power of flow depth. This result also implies that as the vegetation density and/or flow depth increased, the rate of increase in the N values gradually became smaller.

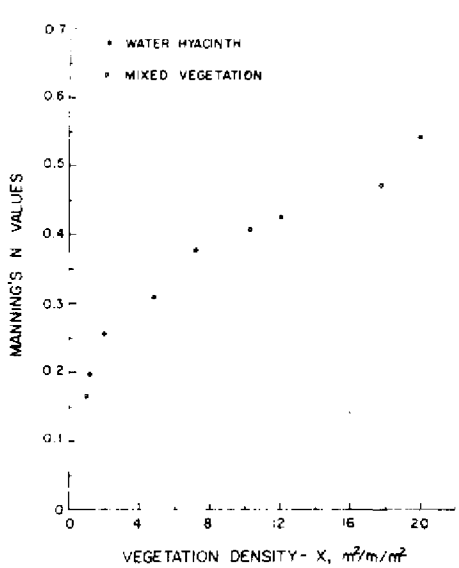

FIG. 3 Relation between Manning's N values and vegetation density.

CONCLUSIONS

Manning's roughness coefficient, N, was studied in relation to flow depth, growth season, vegetation growth control, and vegetation density for predominant vegetation species in a subtropical marsh. From the results of these studies, we concluded that the N values in the marsh land were significantly increased by vegetation.

The N values increased with a decrease in flow depth and varied from 0.26 to 0.55 for water hyacinth and from 0.16 to 0.43 for mixed vegetation with flow depth ranging between 65 to 40 cm.

The N values also increased along with the vegetative growth during the wet season, and it was observed that values could triple in the six-months growing period of water hyacinth. The relationship between the N values and the wet growing season was expressed well by an exponential function.

Chemical defoliants reduced the N value by suppresssing aquatic weed growth. An effective weed control program could reduce N values by as much as one-half.

The N values and vegetation density were parabolically related. The increase in N value was directly proportional to the square root of vegetation density and ⅔ power of flow depth in all types of vegetation.

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