Introduction

The Florida Everglades is a vast, diverse wetland ecosystem characterized by small ground-surface slopes, slowly moving surface waters, and dense aquatic vegetation (both submerged and emergent vegetation are found in sawgrass and cattail marshes (fig. 1), wet prairies, and sloughs. The south Florida ecosystem has been greatly altered during the last 100 years. A complex water-management system that includes levees, canals, pumps, and water-control structures now regulates flooding and provides a steady supply of fresh water to urban areas and agriculture. Drainage projects have diverted much of the water that originally flowed slowly southward from Lake Okeechobee through the Everglades. Restoration and management of the Everglades ecosystem requires understanding and manipulating the amount and timing of water flows throughout the ecosystem.

The spatial and temporal distribution of water and water-borne contaminants in the Everglades must be understood if degradation of the ecosystem is to be halted and reversed. To understand how water moves through the Everglades, it is necessary to quantify the forces affecting the flow. The resistance exerted on the flow by the vegetation through which the water moves is one of the dominant but least understood forces affecting Everglades surface-water flows.

The aquatic vegetation of the Everglades affects both the depth of water and the rate at which it moves. The presence of living and dead plant material in the water column creates drag forces on the moving water. Water flows most slowly and the water-surface slope is largest in areas where vegetation is most dense.

Plan of Study

U.S. Geological Survey (USGS) hydrologists and ecologists are conducting studies to quantify vegetative flow resistance to improve numerical models of surface-water flow. For use in the models, vegetative flow resistance must be expressed in terms of parameters describing the flow and the vegetation. These parameters include the flow velocity through the vegetation, the water depth, the slope of the water surface, and the type, geometric characteristics, and density of the vegetation.

Both indoor flume and field measurements are being conducted to develop methods for evaluating the resistance of relatively uniform stands of vegetation and to identify the most appropriate parameters for representing resistance due to vegetation types typically found in the Everglades. By using computer models, remote-sensing techniques, and geographical-information-system tools, empirical expressions will be developed to define flow resistance in areas of mixed vegetation of variable density. Such expressions will quantify flow resistance at scales appropriate for large-scale hydrodynamic models or regional hydrologic models. These expressions for flow resistance will be tested by comparing results from computer flow models with measurements in selected areas of the Everglades.

Indoor Flume Experiments

The USGS tilting flume at Stennis Space Center, Mississippi, is being used to determine the flow resistance of uniform stands of sawgrass (Cladium jamaicenscens) and cattail (Typha domingensis). For the initial study, uniform, dense stands of sawgrass were grown in pans that were fit snugly into the flume to form a 200-foot-long, 6-foot-wide artificial sawgrass ecosystem. The depth of water in the flume is controlled by adding or removing metal plates (stop logs) at the downstream end. Experiments are being conducted for five flow depths between 6 inches and 2 feet, for mean cross-sectional velocities between 0.001 and 0.15 foot per second, and for three plant densities. For each experiment, the flow rate, flow depths, and water-surface elevations (fig. 2) are measured. The water-surface slope (equivalent to the energy loss per unit length of channel) is calculated from the water-surface elevations, and vegetative resistance is computed from the flow rate, mean depth, and slope.

During each experimental series, the vegetation in the flume is sampled to determine, as a function of distance from the bed, biomass per unit area, the number of stems and leaves per unit area, and leaf and stem width. The number of culms (basal stems composed of many closely packed leaves) and leaves per square foot are shown for each of four horizontal lay-
Vegetation is sampled at sites where hydraulic measurements are made to explore the dependence of flow resistance on vegetation characteristics. In contrast to this direct technique for sampling vegetation, another USGS project is using indirect methods, including videography, to determine whether vegetation can be sufficiently characterized by remote-sensing techniques to estimate flow resistance.

Anticipated Schedule

- 1999: Complete modeling.

Initial Results

Manning’s $n$, an empirical coefficient commonly used to express flow resistance in open channels, is plotted as a function of velocity for the flume measurements of January 1996 in figure 4. The plot shows that for a uniform stand of sawgrass with no litter layer, the value of $n$ increases with flow depth. At a fixed depth, Manning’s $n$ is relatively constant for velocities between 0.05 and 0.15 foot per second but increases as the flow velocity approaches zero.

Results of field efforts are not yet available. However, the first field measurements have shown that instruments are available with the capabilities needed to determine flow resistance for small, relatively uniform stands of vegetation in the field.

USGS Role in Restoration of the South Florida Ecosystem

Quantifying the effects of vegetation on the movement of surface water in the Everglades is necessary for the development of accurate numerical flow and water-quality models that can be used to evaluate restoration alternatives. In undertaking laboratory, field, and theoretical studies to define the flow-resistance characteristics of Everglades vegetation, the USGS is playing a key role in providing reliable model parameters to Federal and State agencies involved in managing the Everglades ecosystem.

For More Information

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