1 Introduction

Background

The Upper Mississippi River (UMR) is unique among inland freshwater waterways in the United States in that it is an impounded floodplain river, is a Federal inland waterway, and has a Federal fish and wildlife refuge along much of its length. The UMR has been altered for navigation and flood-control purposes over the years, with most extensive changes resulting from construction of a series of 29 lock and dam structures that maintain a 2.75-m navigation channel between St. Louis, MO, and Minneapolis, MN. Impoundment and river regulation has modified the river into a series of navigation pools, with most pools having three distinct zones: (1) the extensively braided tailwater area, (2) the mid-pool marsh area, and (3) the main-pool lentic area (Fremling and Claflin 1984).

Following the 1930s completion of the UMR lock and dam system, aquatic macrophytes began to colonize the newly created shallow-water areas. Emergent plant communities, which were previously widely distributed within the preimpoundment floodplain, quickly colonized the new habitat (Peck and Smart 1986). For submersed species, however, the stable water levels provided by the impoundments created vast new areas suitable for establishment. For these new habitats, water smartweed (*Polygonum amphibium* L.) was often the pioneer colonizer. Records indicate that by the 1960s, submersed communities dominated by pondweeds and vallisneria (*Vallisneria americana* Michx.) had become established (Rogers 1994) reaching peak levels by the early 1980s. Coinciding with multiple years of drought conditions, significant declines in submersed aquatic plants occurred during the late 1980s. The only submersed species not showing significant widespread declines during this period has been Eurasian watermilfoil (also referred to herein as milfoil) (*Myriophyllum spicatum* L.), an exotic species which appears to be forming widespread colonies in areas previously occupied by vallisneria (Rogers 1994).

Reductions in submersed aquatic plants in the UMR are considered significant since they are regarded as a critical component for proper functioning of this multi-use resource. Where established, aquatic macrophyte beds help maintain the integrity of the waterway by reducing shoreline erosion. Emergent and submersed macrophytes also function to improve water quality by reducing suspended solids (Carpenter and Lodge 1986) and nutrients from the water (Kufel and Ozimek 1994). Further, many of the other biological components (e.g., periphyton, arthropods, fish, waterfowl, mammals) utilize aquatic macrophytes for habitat and food (Engel 1985; French 1988; and Killgore, Morgan, and Rybicki 1989).

Given that aquatic macrophytes are a critical component of the UMR system, the Mississippi River - Illinois Waterway Navigation Study has included a series of task areas to determine the potential impacts of navigation traffic on both the integrity of existing plant beds and on the ability of plant species to recolonize previously occupied areas (National Biological Service 1995). These studies were deemed necessary because forces (e.g., waves and currents) generated by navigation traffic are assumed to be of sufficient magnitude and frequency to have both direct and indirect effects on aquatic plants (Kimber and Barko 1994). Direct impacts of navigation traffic are caused directly by hydraulic disturbances produced by passing vessels. Navigation traffic on the UMR system includes commercial towboats and their barges as well as recreational boats. Direct impacts include plant breakage and uprooting caused by waves or altered currents. Direct impacts, for the most part, are likely to be restricted to plant communities within the main channel border. Indirect impacts are defined as those that affect the growth and distribution of the plant communities by impacting their environment. An example of an indirect impact is reduction in photosynthesis rates due to increased water column turbidity levels or to settling out of suspended particles onto photosynthetic surfaces.

Hydraulic Disturbances Generated by Navigation Traffic

As a vessel navigates through a waterway it generates hydraulic disturbances in the form of waves and currents. The dominant hydraulic disturbance features associated with a moving tow are the drawdown, return current, propeller jets, and secondary waves. The size of the vessel with respect to the waterway along with its speed dictate the magnitude of these forces and their effects on the environment (Bhomik, Demissie, and Osakada 1981, Bhomik and Mazumber 1990).

As the vessel displaces water during its forward motion, it causes a drop in the water level alongside the barges known as the drawdown (Figure 1). Drawdown begins near the bow and rebounds near the stern producing a single wave with a duration on the order of 40 to 120 sec, depending on vessel length. Drawdown can cause dewatering of shallow areas along the shoreline during vessel passage, as well as effectively cause a pumping action at the mouth of narrow off-channel inlets to backwaters and side channels. Nearshore dewatering imposed by these drawdowns normally does not extend to depths greater than 0.3 m, and most often is restricted to depths of 0.1 m or less.

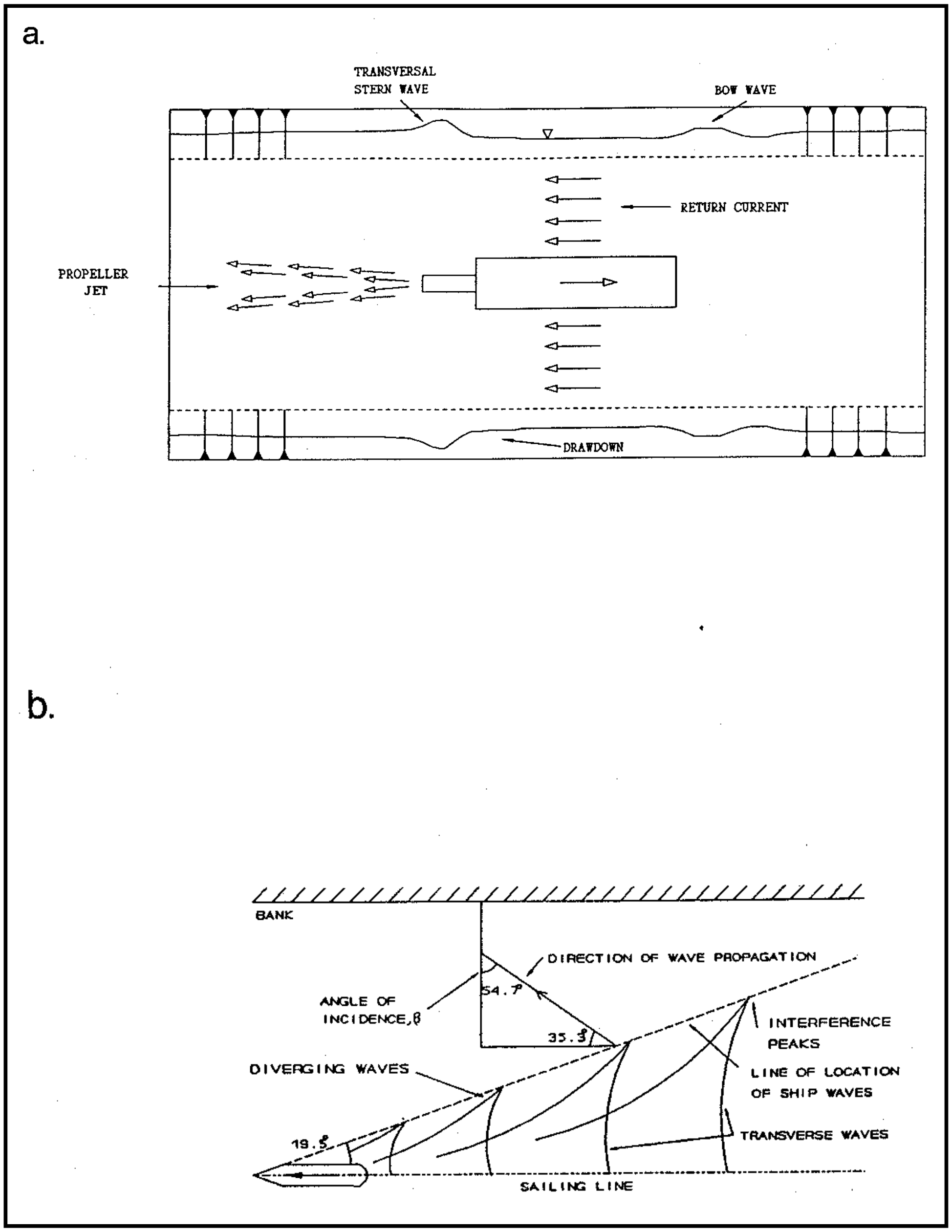

Figure 1. Type of waves and currents generated by commercial navigation traffic: (a) general definition sketch of navigation effects terms, (b) ship wave angles and definition sketch

flow toward the stern parallel to the tow. The maximum return current is produced adjacent to the barges and typically closer to the stern. As vessels move upstream, return currents cause a temporary increase in ambient current velocities. In a tow moving downstream, the return current causes a decrease in ambient current velocities and under certain low flow conditions can create temporary ambient flow reversals.

Currents associated with the propeller jets are highly three-dimensional and cause localized disturbances to the flow. The characteristics of these jets are a function of the hull shape, propeller type and size, and horsepower of the vessel. The thrust, alignment to the bank, and the rudder angles affect the potential flow impingement on the bed or banks. Under normal underway operations, propeller jet effects are limited to the area behind the tow in the navigation lane.

Beginning at the corners of the lead barges, waves diverge from the sides of the tow. As transverse stern waves intersect with this diverging wave, secondary waves are formed which propagate away from the tow at an angle toward the shoreline (Figure 1). These waves are rather consistent in amplitude and have short periods (1 to 5 sec). For high-speed commercial vessels, and particularly for recreational craft, these waves can have significant wave heights and often dominate the hydraulic disturbances produced by the vessel. Transverse waves diminish in magnitude with distance from the stern and have wave periods on the order of 2 to 5 sec.

On the UMR, commercial traffic is characterized by vessels having multiple barge units pushed by towboats with 100 to 7,000 hp and twin screws. The standard barge-tow configuration is made of 9 to 15 jumbo barges (each barge 59.4-m long by 10.7-m wide) configured three barges wide and four or five barges long. The maximum or loaded draft of the tow unit is 2.7 m. Bhomik, Demissie, and Guo (1982) have reported that navigation-generated wave heights of secondary waves are generally less than 0.3 m with a wave period of 1 to 5 sec. Though waves generated by a passing vessel generally last only a few minutes at any one location, the frequency of navigation traffic on the UMR can result in daily cumulative exposures of 30 to 75 min.

Study Objectives and Scope

The primary objective of this study was to investigate the direct damage caused to submersed aquatic plants by different combinations of waves and currents likely to be generated by UMR system navigation traffic. The focus of these tests was restricted to direct effects of navigation-generated secondary waves on aquatic plants along the main channel border. All tests reported herein were conducted in a two-dimensional (2-D) flume facility at the Waterways Experiment Station (WES), Vicksburg, MS. The 2-D system allowed tests to be run for different combinations of current velocities, wave periods, and wave heights, but required that all waves be propagated in the same direction as the ambient current. Further, all tests were performed using plants reared under greenhouse conditions with no ambient current or waves. Therefore, a secondary objective was to compare the tensile strengths of test plants with field-collected plants from the UMR system.