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Reconnaissance study of fish passage impacts resulting from structures in the MRGO, IHNC and GIWW – Letter report

David L. Smith

May 2008

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Reconnaissance study of fish passage impacts resulting from structures in the MRGO, IHNC and GIWW – Letter report

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Technical report

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Prepared for U.S. Army Corps of Engineers, New Orleans District, Hurricane Protection Office

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Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
fathoms	1.8288	meters
feet	0.3048	meters
foot-pounds force	1.355818	joules
inches	0.0254	meters
inch-pounds (force)	0.1129848	newton meters
knots	0.5144444	meters per second
microns	1.0 E-06	meters
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
slugs	14.59390	kilograms
square feet	0.09290304	square meters
square yards	0.8361274	square meters
yards	0.9144	meters

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1 Introduction

Project description and fish passage guidelines

The New Orleans District, US Army Corps of Engineers (CEMVN) proposes to provide structural barriers to prevent damaging storm surges from entering the Inner Harbor Navigation Canal (IHNC) from Lake Pontchartrain and/or the Gulf Intracoastal Waterway (GIWW)-Mississippi River Gulf Outlet (MRGO)-Lake Borgne complex (Figure 1-1 and 1-2). Design commitments[1] pertaining to fish passage include minimizing adverse impacts to fisheries and not exceeding a water velocity of 2.6 ft/s during peak flood or ebb tides. In addition, the National Marine Fisheries Service (NMFS) Baton Rouge Field Office provided recommendations for engineering of structures that minimize adverse impacts on fisheries[2]. These include:

- Flood protection water control structures in any watercourse should maintain pre-project cross section in width and depth to the maximum extent practicable, especially structures located in tidal passes.

- Any flood protection water control structure sited in canals, bayous, or navigation channels that does not maintain the pre-project cross section should be designed and operated with multiple openings within the structure. This should include openings near both sides of the channel as well as an opening in the center of the channel that extends to the bottom.

- Structures should include shoreline baffles and/or ramps (e.g., rock rubble, articulated concrete mat) that slope up to the structure invert to enhance organism passage. Various ramp designs should be considered.

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[1] Record of Decision dated 3/14/08 transmitting "Individual environmental report #11 improved protection on the iner harbor navigation canal Orleans and St. Bernard Parishes, Loisiana

[2] Appendix B of "Draft Fish and Wildlife Coordination Act Report for the Individual Environmental Reports (IER)" November 2007 transmitted to Col. Alvin Lee, USACE-New Orleans District, November 26th, 2007 from James E. Boggs, Acting Director Louisiana Filed Office of US Fish and Wildlife Service

- To the maximum extent practicable, structures should be designed and/or culverts selected such that average flow velocities during peak flood or ebb tides do not exceed 2.6 feet/second. This may not necessarily be applicable to tidal passes or other similar major exchange points.

Primary species that could be impacted from project actions include brown shrimp, white shrimp, blue crab, red drum, black drum, spotted seatrout, sand seatrout, southern flounder, and Gulf menhaden[2]. This letter report will focus on spotted seatrout (*Cynoscion nebulosus*), red drum (*Sciaenops ocellatus)* and brown shrimp (*Farfantepenaeus aztecus*) as reference species for evaluating fish passage (New Orleans District, personal communication).

Fish passage concerns associated with USACE structures is a long standing design issue across the United States. The purpose of this study is to assess if planned water control structures will pose a likely fish passage barrier under conditions when peak velocities are expected. Velocity information is provided by a model (TABS-MDS-3-D) documented in Martin and McAlpin (2008). The model solves the three-dimensional form of the Navier-Stokes equations. The model includes the nonlinear terms; advection, bottom friction, wind stress, and Coriolis forces. Turbulent mixing effects are handled with an eddy viscosity formulation, with several options for the computation of the coefficients, including the Smagorinsky large eddy simulation method and a Peclet number specification. Vertical turbulence is estimated by a Mellor-Yamada 2 1/2 – order algebraic closure scheme. The model uses the hydrostatic assumption and the vertical velocities are computed from the local continuity equation

For this study, three reference species were considered: spotted seatrout, red drum, and brown shrimp. Our objective is to broadly assess if anticipated velocities resulting from implementing new water management strategies will reduce water movement at Seabrook, Bayou Bievenue, GIWW at Paris Road, and GIWW at Michoud.

There are many species of fishes and invertebrates that may be impacted. Species specific responses to hydrodynamic changes induced from new water control structures are not known. In addition, information about the swimming capacities of individual species is limited.

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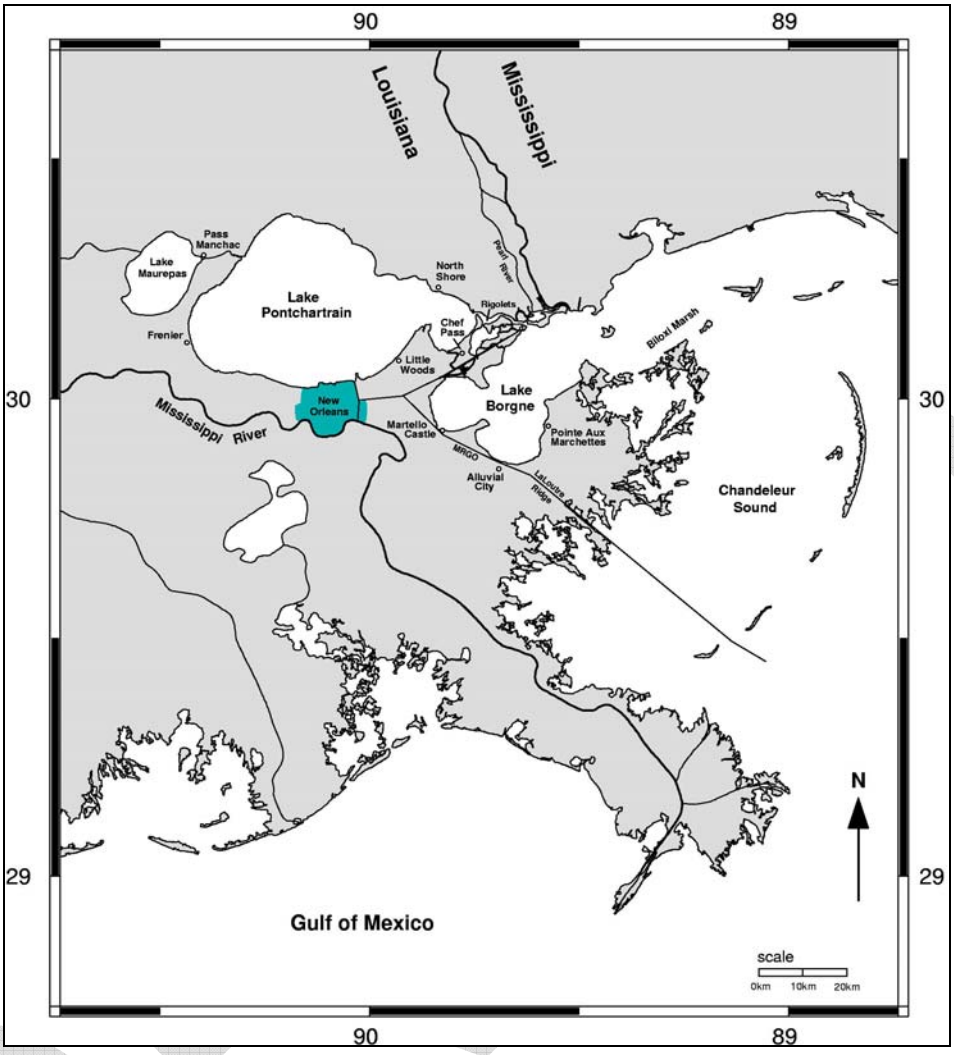

Figure 1-1. Vicinity Map

Swimming Performance

Swimming performance is a key aspect of survival for all aquatic animals as it impacts food acquisition, habitat occupancy and susceptibility to predation (Reidy et al., 2000). Fish swimming performance is related to swimming speed and endurance. Webb (1975a) classified three categories of swimming performance. Sustained swimming is classified as swimming for more than 200 minutes without fatigue. Prolonged swimming can be maintained from 20 s to 200 min and ends in fatigue. Burst speed is the highest swimming speed and can be maintained for less than 20 s. In contrast to sustained or prolong swimming, burst speed is anaerobic. The

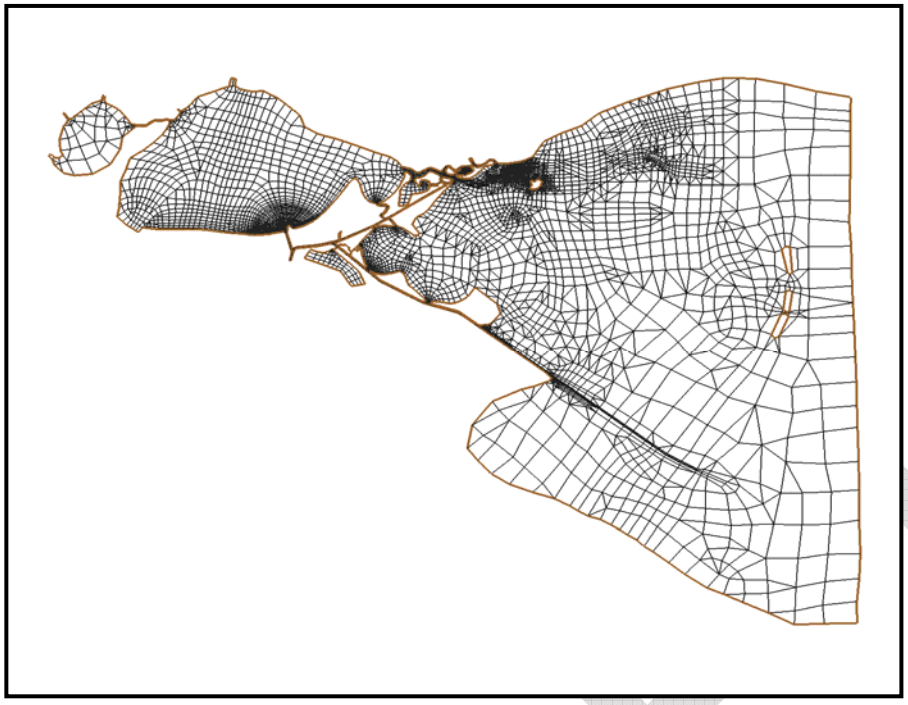

Figure 1-2. An example of the hydrodynamic grid and corresponding spatial domain.

faster burst speed is characterized as fast-start swim speed which is a burst of less than 1 or 2 s (Reidy et al. 2000). Fast-start swimming is usually related to prey capture or predator avoidance.

Fish swimming performance is related to body shape (Vogel 1994), fin type (Videlar 1993) , muscle function (Kieffer, 2000) , and swimming mode (Müller et al., 2001). Swimming velocity is positively correlated with body size such that large fish swim faster than small fish (Webb, 1976). In addition, temperature changes swimming performance with low and high temperatures relative to species physiological requirements reducing swimming capabilities. (Brett and Glass, 1973). For larval fish water viscosity can be a factor in swimming performance (Vogel 1994; Müller et al., 2000). Other non- hydraulic factors including pH (Butler and Day, 1993), dissolved oxygen (Reidy et al., 2000), photoperiod (Kolok, 1991), salinity (Randall and Brauner, 1991), and various pollutants (Hammer, 1995) influence swimming capacities.

Fish swimming performances is quantified through swimming speed. However, fishes by virtue of their lateral line system can also detect velocity gradients. Goodwin et al. (2006) and Nestler et al. (2008) noted that this ability is critical to understanding fish movement. In effect, fishes are using the flow pattern to form a hydrodynamic image of their surround-

ings. Engineering works (such as weirs, dams, levees) may alter the flow pattern in ways that fishes are unable to interpret over short (seconds to minutes) timescales. This, in turn, results in movement that may not result in passage even if velocities within the structure are lower than the fishes swimming capabilities.

In general, swimming speeds of teleost fishes suggest that although individuals 5 and 15 cm long may be expected to have burst speeds of 0.5 m/s and 1.5 m/s over very short periods, their normal maximum swimming performance (or maximum cruising speed, Wardle, 1983) would be much less (Bainbridge, 1958; Wardle, 1975, 1983; Beamish, 1978).

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2 Passage Evaluation

Design Alternatives

Base

The base condition represents hydraulic conditions under current conditions (i.e., no project structures and with the planned closure at La Loutré).

System A

a) 150 foot by 16 foot (sill) sail thru structure on GIWW near located near Michoud.

b) 56 foot by 8 foot (sill) structure on Bayou Bievenue

c) MRGO closure just south of Bayou Bienvenue

d) La Loutré closure and Seabrook structure

System C

a) 350 foot by 40 foot (sill) on way sail thru structure on MRGO/GIWW with spillways (if required) located at Paris Road 30'10.94"N, 89°56'30.03"W

b) La Loutré closure and Seabrook structure

Passage evaluation

Velocities at the surface and at the bottom were obtained from the hydrodynamic model (TABS-MDS-3-D) documented in Martin and McAlpin (2008). The model domain is shown in Figure 2-1 and Figure 2-2. Model information was extracted from lateral transects located at sites were project structures will be placed under System A and System C. Extracted velocities were from March when hydraulic energy is expected to at its peak with maximum rainfall and tidal stage. The amount of information extracted from the hydraulic model was dependent on the number of model

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nodes in project locations and ranged from 2 to 10 locations (Table 2-1). The time series with the maximum velocity was used to represent the "worst case" passage condition for the surface and bottom velocity data.

In order to visualize the impacts of structure placement on velocities, plots of the time series with the maximum velocity for each location in the base with La Loutré , System A and System C design alternatives were made. The maximum velocities were then compared to the swimming capacities of the reference species.

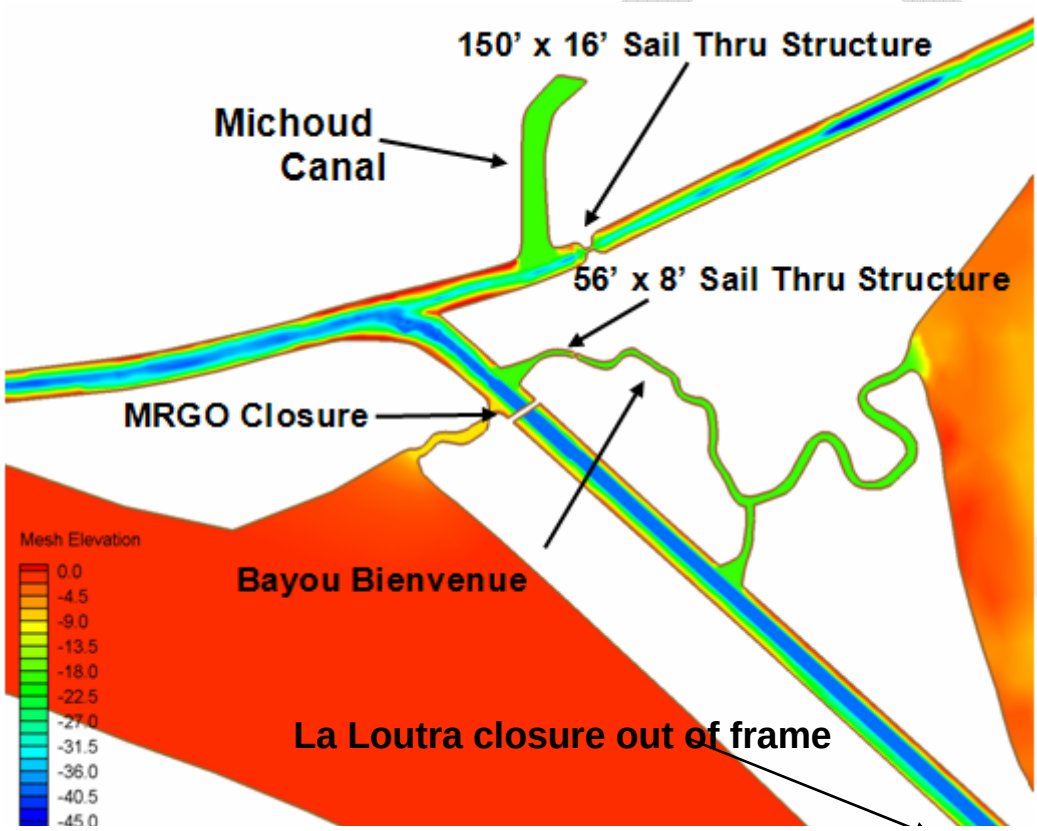

Figure 2-1. Proposed configuration for System A.

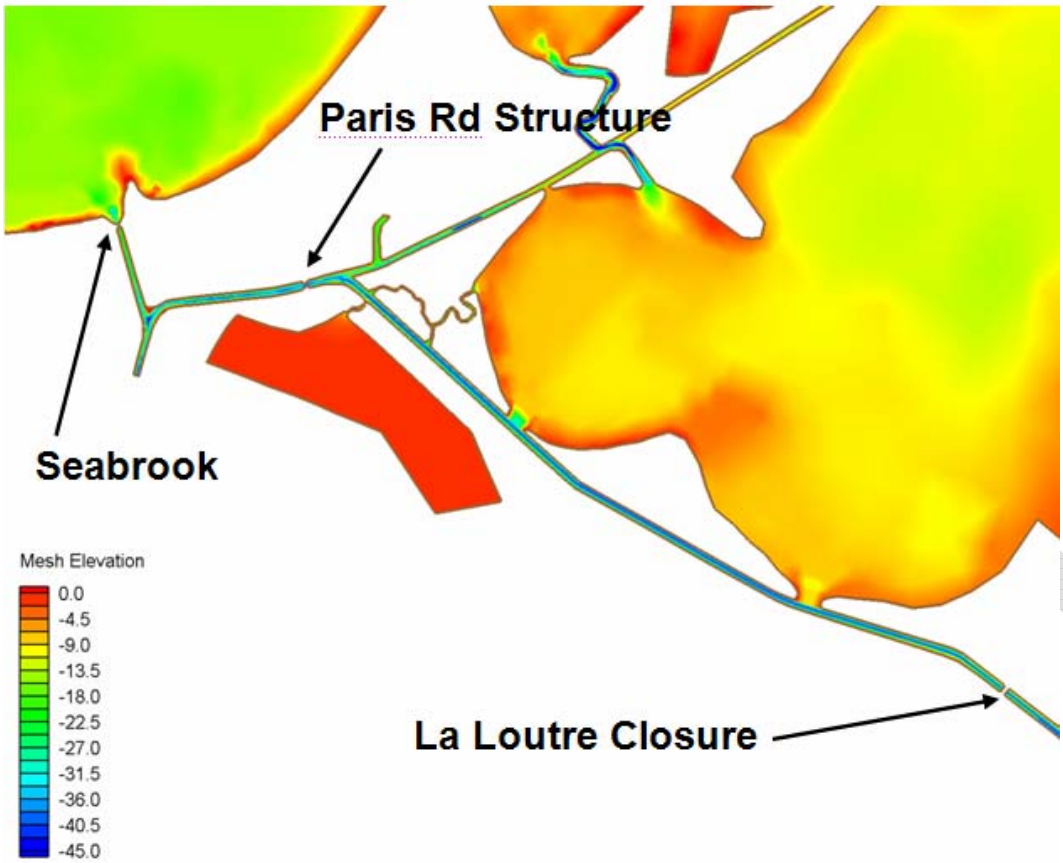

Figure 2-2. Proposed configuration for System C.

Movement of Reference Species

Red drum

Red drum occur in both offshore and inshore locations. Spawning and larval development are thought to occur offshore (Pearson 1929). Post-larvae migrate inshore to grow and mature (Loman 1978). Young fish are associated with quiet shallow water with little tidal influence. As the fish grow to 50 to 150 mm they move to deeper waters (Breuer 1962). Water temperature dictates broad movement patterns. As inshore waters cool, young redfish move toward offshore areas and as spring warming occurs there is a pronounced movement back to inshore waters (Perret et al. 1980). Juvenile red drum are typically 8 to 183 mm in length and adult red drum range from 100 to 300 mm.

Spotted seatrout

Spotted seatrout spend their life within coastal bays and adults spawn in sward entrance channels. Larval seatrout drift with tidal currents and settle on nearshore sea grass beds and silt clay substrates. Juveniles remain in nearshore areas for several months and gradually move to vegetated bottoms as their grow. Seatrout reach maturity around 380 mm (Ault et al. 2003).

There is no consensus on the spawning location (inshore or offshore) for spotted seatrout. Newly emerged fish (1.3 up to 15 mm) are difficult to collect but have been noted in large numbers in an inlet linking the Gulf of Mexico with inshore areas (Jannke 1971). As the fish reach 10 to 15 mm, young fish are located in inshore areas. At 20 to 50 mm the fish begin active schooling. Cooling water temperatures may move fish to deeper water (Perret et al. 1980).

Small seatrout (20-50mm) are planktivorous and feed primarily on copepods (Moody 1950; Tabb 1961; Adams et al. 1973; Rutherford et al. 1982; McMichael and Peters 1989). Larger seatrout, to 70 mm (2.8 inches) in length feed primarily on benthic invertebrates, especially mysids (Moody 1950, Darnell 1958; McMichael and Peters 1989). A dietary shift occurs once seatrout reach approximately 40 – 150 mm and begin to feed more on penaeid shrimps and small fishes (Moody 1950; McMichael and Peters 1989). Spotted seatrout spend their life within coastal bays and adults spawn in sward entrance channels. Larval seatrout drift with tidal currents and settle on nearshore sea grass beds and silt clay substrates. Juveniles remain in nearshore areas for several months and gradually move to vegetated bottoms as they grow. Seatrout reach maturity around 380 mm (Ault et al. 2003).

Brown shrimp

Large specimens of brown shrimp males attain an adult size of approximately 195 mm length, while large female specimens may reach 236 mm in length (Williams 1955). Brown shrimp are commonly found in estuaries and littoral zones along coasts. Primary habitats for these shrimp are muddy bottom areas from the intertidal zone to approximately 110 m. The greatest density of brown shrimp occurs at depths between 27 – 55 m. This species is rarely observed at depths exceeding 165 m (Williams 1984).

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Shrimp, which are negatively buoyant, have to swim actively to maintain their position in the water column. Their displacement is carried out with 3 types of appendages: pereiopods, pleopods and uropods. Pereiopods (4 to 5) are also used to walk. Hill (1985) reported a walking speed of 4 to 6 cm/s for *Penaeus eculentus* (brown tiger prawn). Pleopods are used for swimming; some penaeids are active swimmers and migrating adults can travel tens of nautical miles during the autumn season (Kim 1973, Ruello 1975, Glaister et al. 1987). When alarmed, a penaeid will characteristically give several rapid, powerful strokes with the uropods while flexing the abdomen, driving the shrimp swiftly backwards. (Ibarra and Rodriguez 1994)

Juvenile shrimp habitually orientate into and actively swim against a current. Changes in salinity can reverse the movement direction causing them to turn about and swim downstream. The downstream swimming often gave way to passive drifting with the current which could continue for four to five hours. Upstream and downstream swimming differs in a manner which is certainly highly adaptive. Upstream swimming occurred as a series of short hops along the substrate with constant maintenance of orientation by returning to the substrate, whereas downstream swimming occurred at varying depths in the water column and without constant reference to the substrate. In the experimental situation the proximity of the walls, the substrate, and the movement of the paddles could provide reference points outside the current enabling downstream orientation. But in nature, with greater depths, current speed and turbulence, the shrimp, having lost contact with the substrate would not be able to orientate at night, but would be passively displaced by the prevailing ebb tide (Hughes 1969). Surface ocean currents transport post larvae to coastal areas during late winter and spring (Whitaker 1981a).

Movement implications

It appears that the reference species all use inshore areas for some of all of their life history. Juvenile stages, in particular, are using shallow near shore areas for rearing. As the animals grow their is a tendency to migrate to deeper waters with red drum and brown shrimp tending to move offshore while spotted seatrout remain in nearshore areas. Another difficult aspect to evaluate is the potential for shrimp to walk along the bottom. Accurate predictions of near bed velocities at the scale of a shrimp are not available. If shrimp are using the bottom, their ability to move may be related to velocity and other factors such as shear stress, turbulence, and bed

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composition making a simple comparison to velocity criteria problematic. The degree that the reference species use the GIWW and MRGO system as habitat is unknown but some use is expected and therefore some impact may occur.

Swimming speeds for reference species

Data on the swimming speeds for the reference species was limited. The swim speeds used to evaluate passage are summarized in Table 2-2. For red drum, several studies reported swimming speeds for small (5 to 25 mm total length) fish. No studies for subadult or adult fish were located. The relationship developed by Wolter and Arlinghaus (2003) shown in Figures 2-3 was used to estimate a critical swim speed.

For brown shrimp, no data of any kind were located. However, other species of shrimp with swimming estimates were found. Two classes of movement, tail flip and walking, were documented. The tail flip is used for short and rapid movement. Shrimp can also swim slowly using their pleopods but no swimming speeds for this activity were located.

Likewise, swimming data on spotted seatrout was limited (Table 2-2). Like red drum, the relationship developed by Wolter and Arlinghaus (2003) shown in Figure 2-3 was used to estimate a critical swim speed for two size classes.

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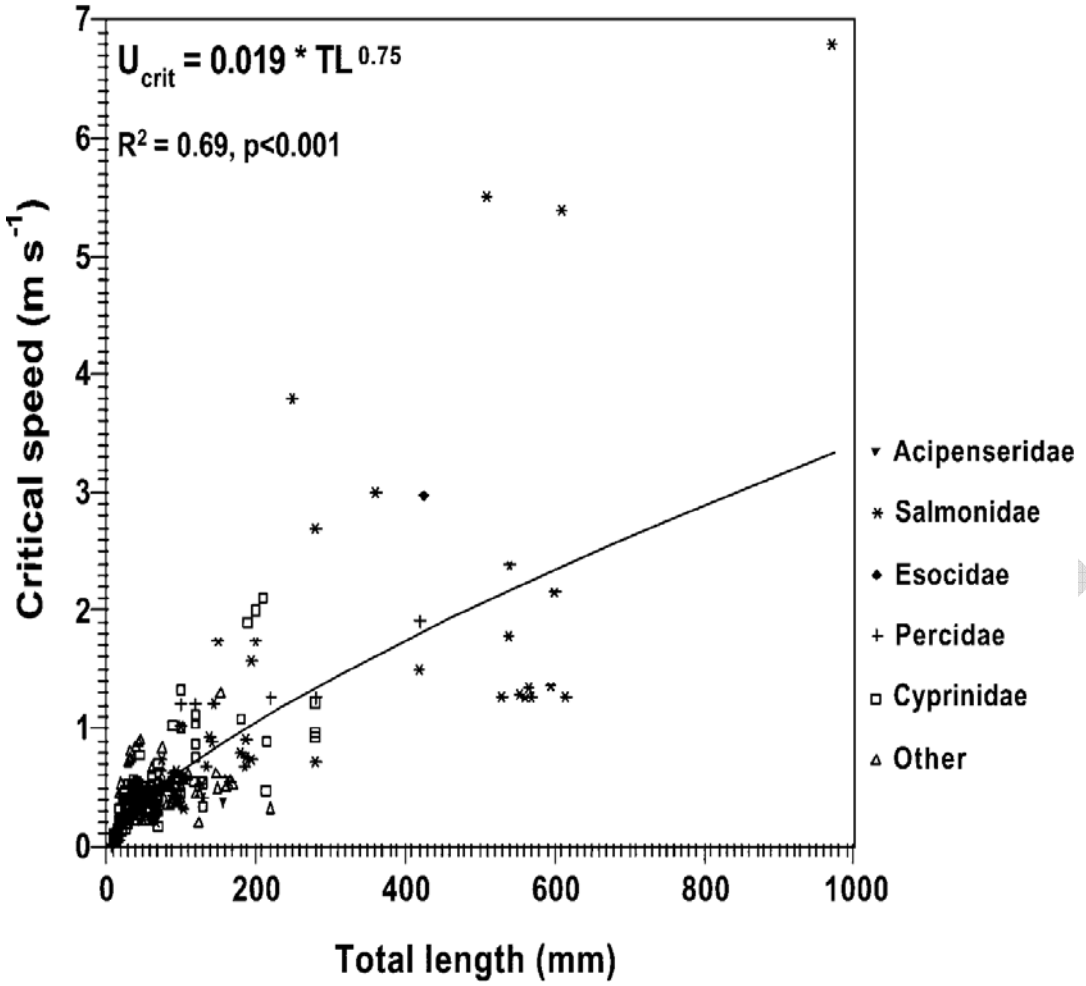

Figure 2-3. Relation between fish size and swim capacities (reproduced from Wolter and Arlinghaus 2003)

Table 2-1. Number of nodes extracted from TABS-3D model where velocities were analyzed.

Site	Base	Base with La Loutre	System A	System C
GIWW at Michoud	3	3	8	not extracted
GIWW Paris Road	5	5	not extracted	9
Bayou Bienvenue	2	2	8	not extracted
Seabrook	5	6	6	10

Table 2-2. Swim speeds used to compare with project water velocities in the MRGO/GIWW system.

Species	Size (mm)	Swim speed (mm/s)	Swim speed (ft/s)		Reference
red drum	5	12	0.04	mean	Smith and Fuiman 2004
	13	35	0.11	mean	
	28	40	0.13	mean	
red drum	5	10	0.03	mean	Fuiman et al. 1999
	10	10	0.03	mean	
	25	70	0.23	mean	
red drum	100	601	1.97	critical	Wolter and Arlinghaus 2003
red drum	300	1370	4.49	critical	
Penaeus eculentus	100	50	0.16	walking	Hill1985
brown shrimp	11	40	0.13	burst	Arnott et al. 1998
Crangon crangon	40	1000	3.28		
spotted seatrout	10	40	0.13	mean	Wuenschel et al. 2000
	50	357	1.17	critical	Wolter and Arlinghaus 2003
	400	1699	5.58	critical	Wolter and Arlinghaus 2003
generic	-	-	2.60	mean	NOAA

Table 2-3. Configuration of each alternative.

System	GIWW East of Michoud	IER 11 MRGO	Bayou Bienvenue	Paris Road	MRGO Deathorization	Seabrook
A	150 x 16 Gate	closed	56 x 8 Gate	existing/open	existing/open	existing/open
C	existing/open	existing/open	existing/open	350 x 40 Gate	closed	existing/open

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3 Results

Surface velocities

Without exception, the guidance criterion of 2.6 ft/s provided by NOAA is not exceeded as a consequence of project structures (Figures 3-1 and 3-2). Project structures in combination with the La Loutre closure generally result in a decrease in maximum velocities compared to current conditions. present. Post project velocities are less than 1 ft/s under the base condition with La Loutré closed. Velocities under System A and C are less than 0.5 ft/s.

Red drum greater than 100 mm have a greater critical swimming velocity than is projected from project implementation. Smaller red drum (5 to 40 mm) have mean swim speeds that are less than projected velocities (Table 2).

Brown shrimp burst swimming capacity exceeds the projected velocities using surrogate species information in Table 2. However, this should be viewed carefully as burst swimming is a very short term swimming behavior and this limits the distance a shrimp can move. Although no data on how far a shrimp can move under burst swimming was found, it is expected that this distance would be less than a few feet. This suggests that burst swimming would not be a sustainable passage behavior for shrimp. The alternative swimming mode is using the short pleopods which result in “very slow long duration swimming”. It also seems likely that such slow movement is currently impacted by existing base conditions.

Spotted sea trout greater than 50 mm have greater swimming velocity than is projected from project implementation. Smaller spotted sea trout (10 mm) have mean swim speeds that are less than projected velocities (Table 2)

Bottom velocities

Without exception, the guidance criterion of 2.6 ft/s provided by NOAA is not exceeded as a consequence of project structures (Figure 3-3- and 3-4). Project structures result in a decrease in maximum velocities present in most cases. Post project velocities are less than 1.2 ft/s under the base

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condition with La Loutré closed. Velocities under System A and C are less than 0.6 ft/s.

Red drum greater than 100 mm have a greater critical swimming velocity than is projected from project implementation. Smaller red drum (5 to 40 mm) have mean swim speeds that are less than projected velocities (Table 2-2).

Some shrimp walk along the bottom at 4 to 6 cm/s (Table 2-2). We do not know the velocities at the bottom and how shrimp respond to flowing water while walking. Thus, it is unknown whether bottom velocities might be an impediment to passage of brown shrimp.

Spotted sea trout greater than 50 mm have greater swimming velocity than is projected from project implementation. Smaller spotted sea trout (10 mm) have mean swim speeds that are less than projected velocities (Table 2-2).

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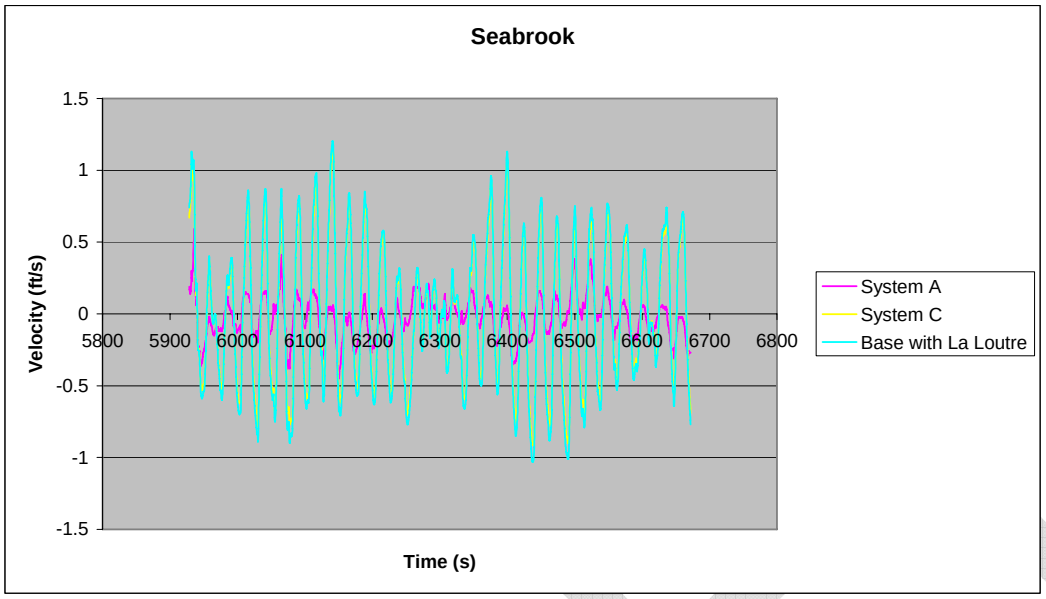


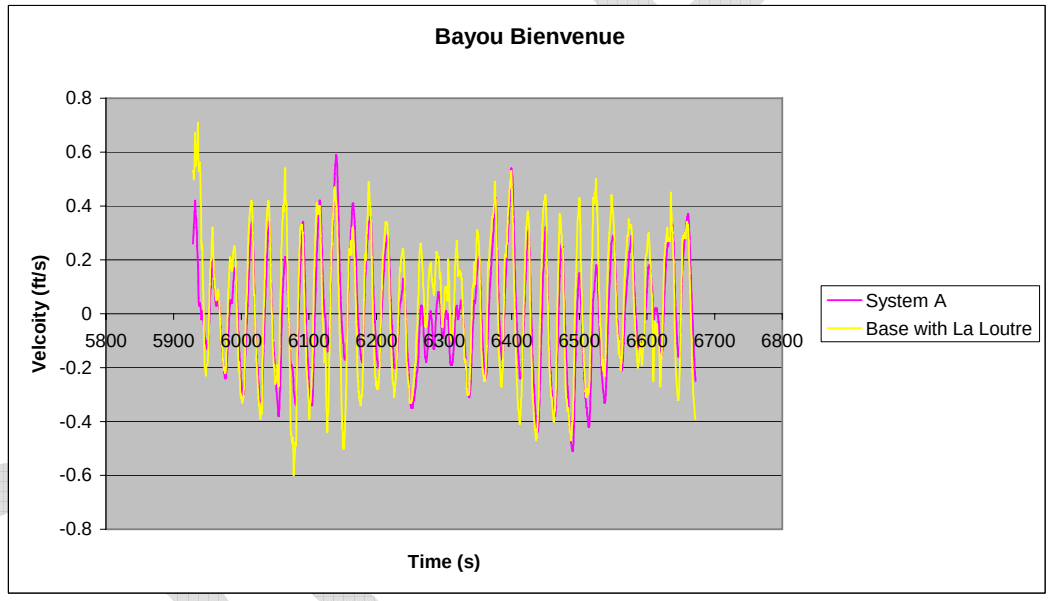
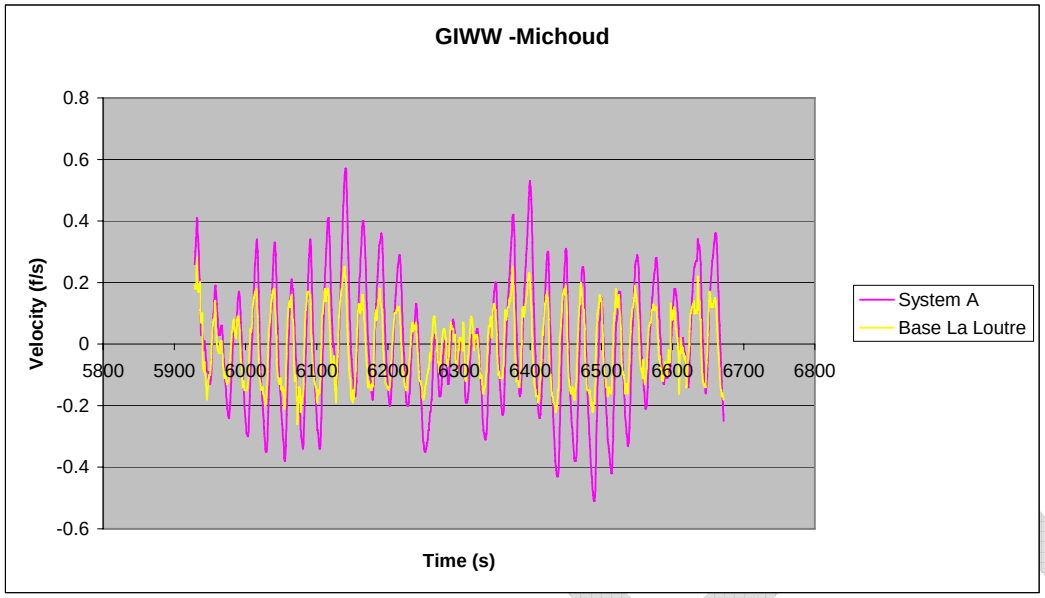


Figure 3-1. Maximum surface velocities measured at the channel center at Seabrook and Bayou Bienvenue



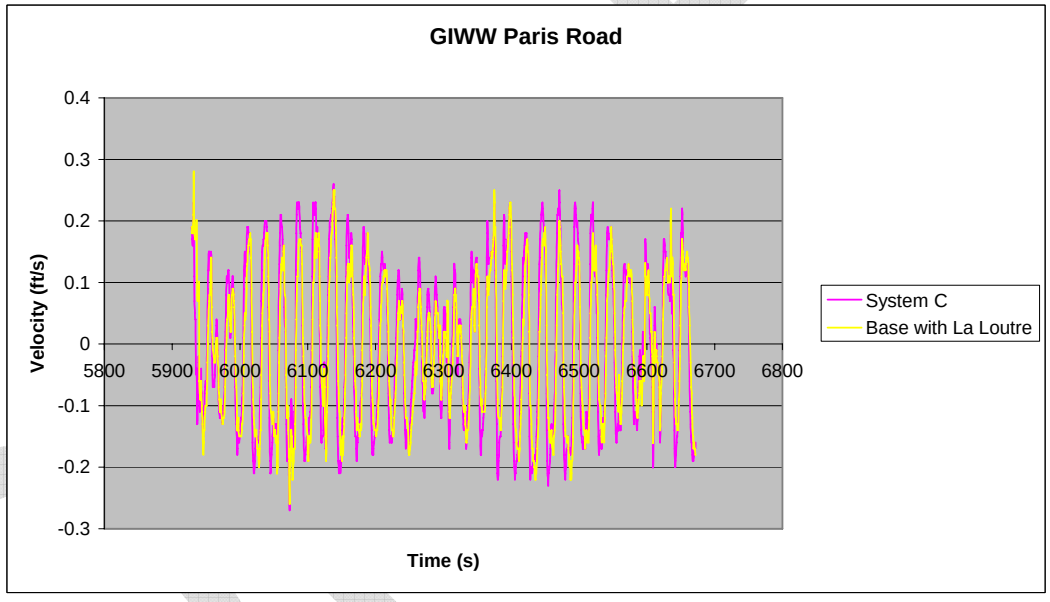
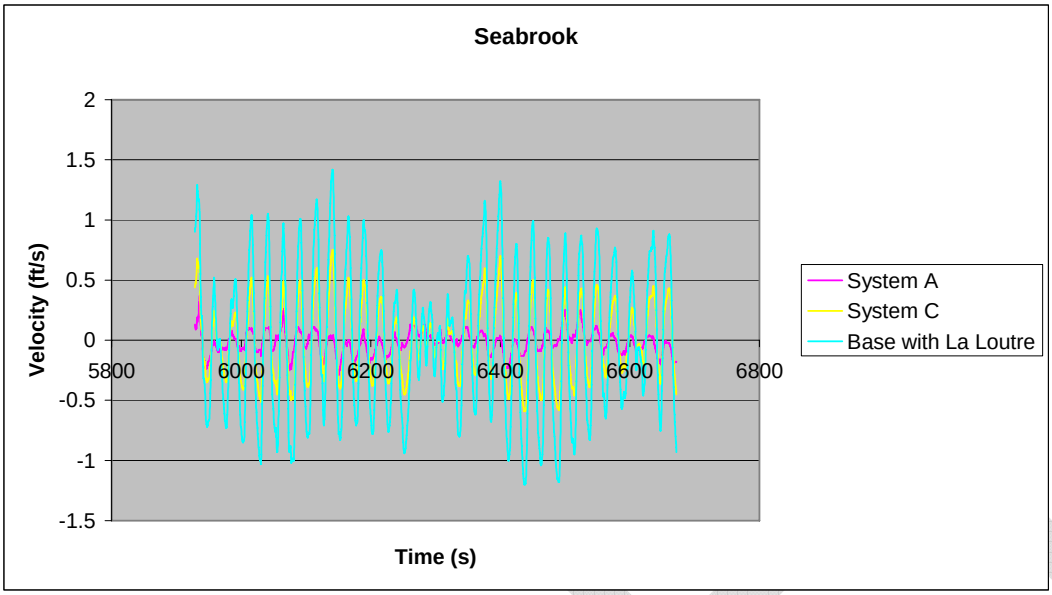


Figure 3-2. Maximum surface velocities measured at the channel center in the GIWW at Michoud and GIWW Paris Road.



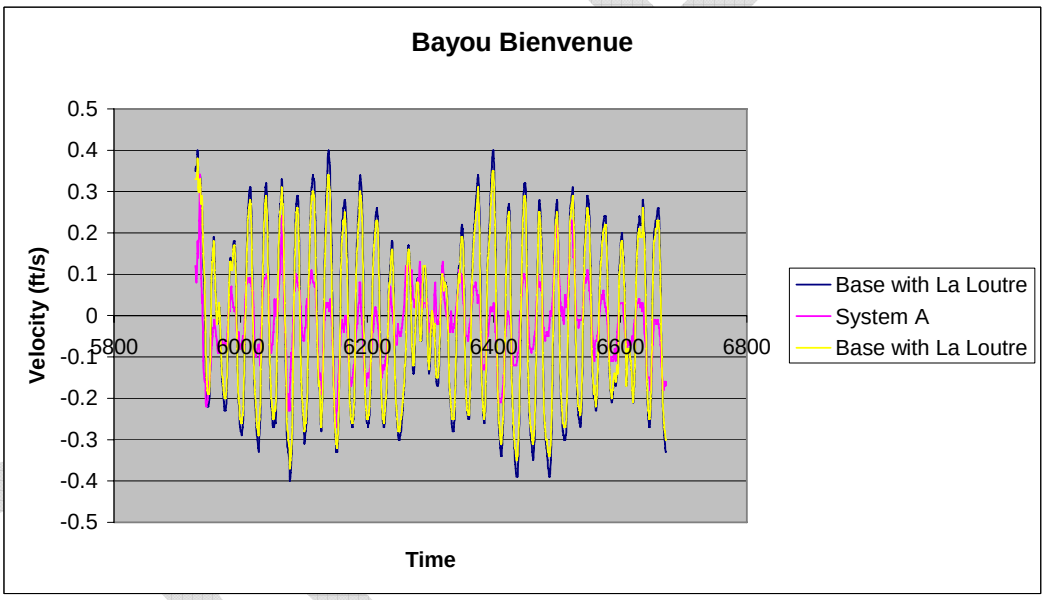


Figure 3-3. Maximum surface velocities measured at the channel center at Seabrook and Bayou Bienvenue.

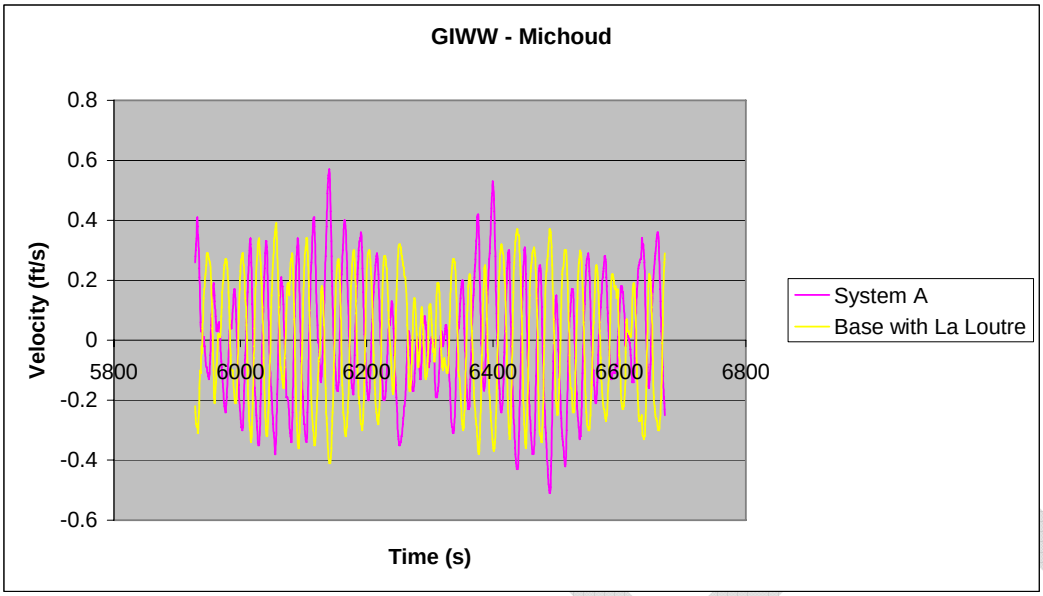


Figure 3-4. Bottom velocities in the GIWW at Michoud and GIWW Paris Road.

4 Discussion

This report documents the velocities projected to occur in the GIWW, MRGO, Seabrook, and Bayou Bienvenue. Project structures will alter water movement between Lake Ponchartrain and Lake Borgne. In general, project structures result in a decrease in velocities at Seabrook and small increases in the GIWW. Bayou Bienvenue under System A with the La Loutré closure is projected to have velocities less than 2 ft/s.

All project impacts on velocities near the surface and bottom are less than the NOAA criteria of 2.6 ft/s. In addition, estimates of swimming capacities for red drum and spotted seatrout greater than 50 mm in length suggest that maximum post project velocities will be manageable. In all cases, small fish (less 40 mm) are likely exposed to velocities greater than their swimming capacity under current conditions and projected post project conditions.

Fish and invertebrate passage are already altered from historic conditions by the presence of the GIWW and the MRGO. Current habitat occupancy and movement within the GIWW and MRGO systems is unknown. In addition, desired future habitat occupancy and movement needs are not known. All of these points highlight the difficulty in determining whether or not project structures will negatively alter animal movement.

Comparisons of estimated swimming performance to simple velocity criteria suggest that post project animal movement will be similar to existing conditions since there is little difference in post project velocities compared to existing velcoities. This implies that project impacts associated with velocity change are limited. However, the closure of the MRGO near Bayou Bienvenue and La Loutré will be complete passage barriers. The impacts of this are unknown since the extent that animals use the MRGO as habitat is unknown.

Using the maximum observed velocity at a point as criteria for assessing passage is simplistic and also conservative. Because the system is tidal, velocities move throughout a range over time or, more precisely, are time-varying. In addition, the direction of flow reverses. Taken together, there will always be time periods in any given tidal cycle where animals will ex-

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perience low velocities and reversing flows. This suggests that movement may be delayed by tidal flows under current conditions and that it may also be delayed in a similar manner under post project conditions but that suitable passage conditions will exist at some point in a given tidal cycle.

Project implementation will undoubtedly alter salinity and dissolved oxygen with cascading effects to other environmental conditions. Salinity, oxygen, and many other parameters alter fish swimming capacities. It is reasonable to anticipate that changing water quality will alter animal habitat occupancy and movement.

Future work should focus on defining the goals of facilitating animal movement within the MRGO and GIWW. Ideally, animal use of the system should be evaluated. If there are locations, species or life stages that are identified as potentially impacted from project structures, then a more complete analysis can be conducted. One possible tool for this would be the Numerical Fish Surrogate (NFS, Goodwin et al. 2003; Nestler et al. 2008). The NFS has been successfully used to guide the biological evaluation of fish passage in other locations and could be adapted to the GIWW and MRGO.

In summary, small fish (less than 40 mm) currently experience velocities that exceed their swimming capacities and will continue to experience similar velocities post project. Larger fish (greater than 50 mm) have swimming capacities greater than current or projected velocities. The NOAA passage criteria of 2.6 ft/s is not exceeded. Taken together, the impact of post project velocities on fish movement is likely similar to what already occurs in the MRGO and GIWW.

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