Potential Effects of Deepening of the Aransas Ship Channel on Particle Transport: Implications for Recruitment of Estuarine Dependent Larvae.

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Abstract

We present an investigation of the potential impact of deepening the Corpus Christi ship channel through Aransas Pass. In particluar, we consider the transport of red drum fish larvae, modeled as passive particles, from their offshore breeding grounds to appropriate nursery grounds along the ship channel. The transport of such larvae is established in a two step procedure. First, we model the circulation of the sea water to establish flow characteristics of both the current ship channel and the proposed channel. Second, we model red drum larvae as passive particles released in the nearshore region outside the Aransas Pass and track their trajectories due to the sea water circulation. We assess the difference in larvae that successfully reach appropriate nursery grounds for several flow conditions as well as initial larvae positions in the nearshore region. Our results indicate that the change in channel depth does not significantly alter the number of red Drum larvae that reach suitable nursery grounds.

1 Introduction

The Corpus Christi ship channel extends from the Gulf of Mexico to the port of Corpus Christi (POCC) through Corpus Christi bay and Aransas Pass [7] (see Figure 1). The current channel was established in 1989 and has an average depth of $14.33m$ $(47ft)$, which is maintained through a continuous dredging operation [7]. Along the ship channel, there are numerous bays and regions that serve as nursery grounds for fish larvae such as the red drum (Sciaenops ocellatus) [1]. Red drum spawn in the nearshore region in the evenings in the vicinity of tidal inlets (e.g., the Aransas Pass) from late August to December [1, 8]. These larvae are dependent on shallow seagrass habitats to develop [9], as found near the Corpus Christi ship channel. Hence, these larvae depend on the circulation of the coastal water to reach suitable habitats for their development. This circulation and the resulting transport of larvae has been modeled in e.g., [1, 2, 3] by Brown *et al.*

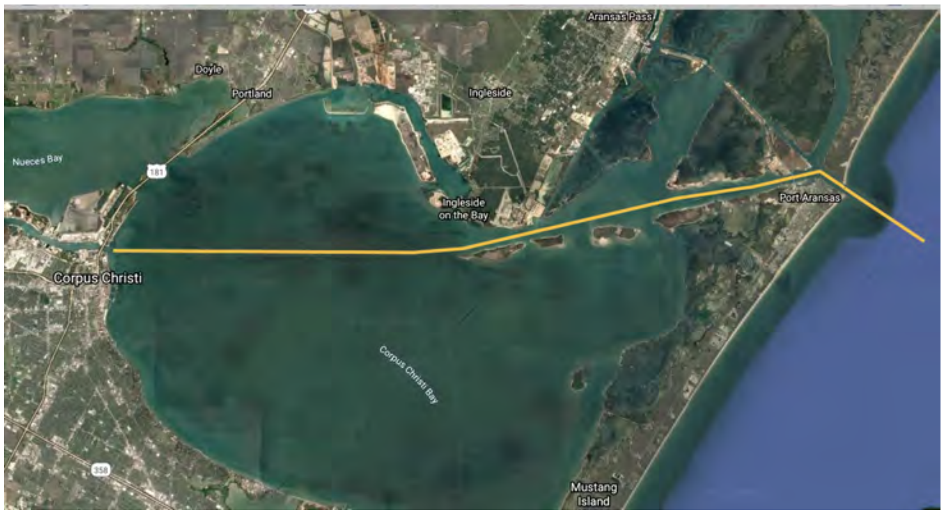


Figure 1: Location of the Corpus Christi ship channel.

Along with an expansion of the Port of Corpus Christi, and in an effort to accommodate larger ships, it has been proposed to deepen the channel to $21.33m$ $(70ft)$. Such a change in bottom topography will lead to changes in the flow characteristics of the water entering and exiting the area through Aransas Pass. To assess the effects of a deeper ship channel on the transport of red drum larvae through Aransas Pass to the seagrass beds, we developed a model governing the circulation of water using both existing and proposed channel depths. From this circulation model, we ascertain the water surface elevation as well as the velocity components throughout the modeled region. The larvae are modeled as passive particles whose transport is a result of the water circulation only. In literature, some authors propose that the transport of fish larvae is also affected by swimming type motion [10] and winds [1] but we shall only consider passive transport here.

In the following, we describe in detail the modeling methods used in Sections 2.1 and 2.2. In Section 3, we present the results from our model and compare findings based on current and proposed channel depths for several distinctive cases of hydrodynamic conditions. Finally, in Section 4 we conclude this report with remarks on the findings. The term "bathymetry" is used throughout this document and it refers to the depth of water relative to the North American Vertical Datum of 1988 (NAVD88). Here, we use the convention that the bathymetry is positive above NAVD88.

2 Modeling Methodology

To establish the passive transport of larvae, we first ascertain the flow characteristics of the coastal circulation (here referred to as hydrodynamics) by employing the advanced circulation (ADCIRC) model [11]. This model is well documented and has been extensively tested for a wide range of flow cases. The hydrodynamics are then used as input into a Lagrangian particle transport model, in which larvae are modeled as particles and their trajectories are tracked.

2.1 Hydrodynamics

To assess the difference in water dynamics due to the change in the channel bathymetry, The ADCIRC model we develop uses two meshes. There is a mesh with the current depth of the channel and one with the proposed deeper bathymetry. Other than the difference in bathymetry in the channel, the two meshes are identical. The meshes cover the entire Gulf coast out into the Atlantic Ocean with particularly high detail along the Texas coast. These meshes are specially constructed for modeling the Texas coast and contain a total of 3,352,598 nodes defined among 6,675,517 elements with refinement along the Texas coast ranging from 100 m down to 30 m.

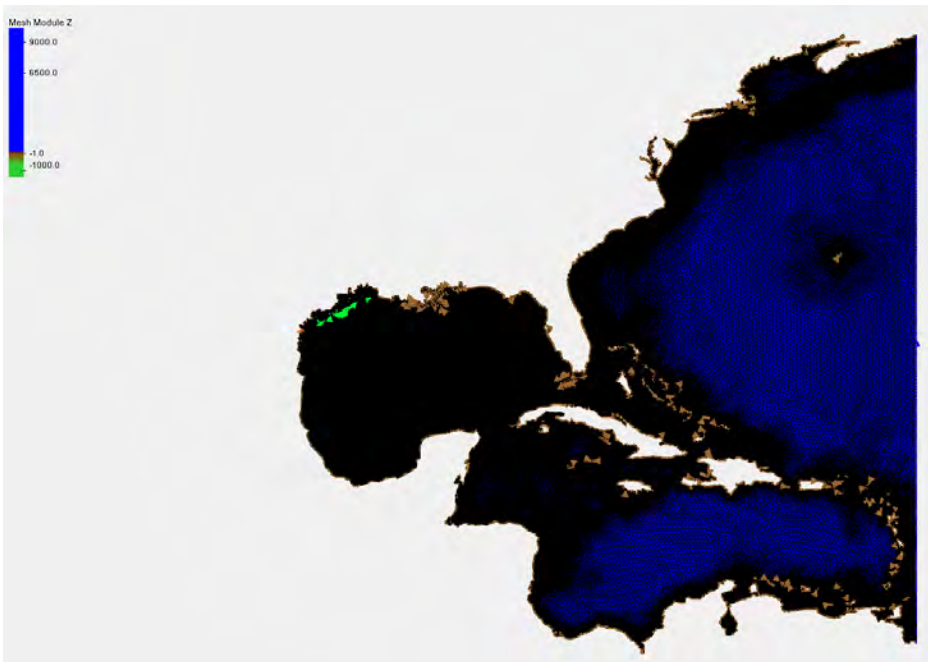


Figure 2: Extent of ADCIRC meshes

To accurately predict the circulation in the entire domain, we employ meteorological forcing and forcing due to tides. The tidal forcing for the ADCIRC model is obtained using OceanMesh2D [12], which utilizes the TPXO9 tidal model [6]. The meteorological forcing is obtained from the North American Mesoscale model(NAM) at `https://www.ncei.noaa.gov/data/north-american-mesoscale-model` given in 6 hour increments in the form of pressure and wind fields at 10m above the surface. The NAM data is then converted into a format which is ADCIRC readable.

Since the circulation pattern is greatly influenced by large scale, global, meteorological trends, we consider three distinctive cases of forcing data for completeness. To this end, we have selected the years 2011, 2012, and 2019 that represent an "average", a "wet", and a "dry" year, respectively. For each of these years, we use our ADCIRC model to establish the hydrodynamics of both the existing bathymetry as well as the proposed bathymetry with the deeper ship channel. We consider the most active period of red drum spawning, i.e., our simulations cover the time span from September 1st to October 31st of each year.

To calibrate the ADCIRC model, we consider the mesh with existing bathymetry and compare the elevation output data with available elevation gauge data over a 10 day period. The model with the forcing is first validated over a ten day interval from September 5 2020 to September 15 2020. The model is compared to available data from the following NOAA gauges: Port Aransas (ID 8775237), USS Lexington (ID 8775296), Bob Hall Pier (ID 8775870), and South Bird Island (ID 8776139). Note that the initial inaccuracy in the first 2 days is primarily due to a ramping up of the tidal forcing in order to preserve numerical stability. In Figure 4 we show the current and proposed bathymetries.

Figure 3: Water surface elevations in ADCIRC compared to nearby NOAA gauges during September 2020 for validation

2.2 Particle Transport

Given the velocity distribution computed from the ADCIRC model, we establish the trajectory of larvae, i.e., particles by the use of a Lagrangian particle tracking code. This particular code is described and developed in [5, 4], and considers the convective transport of particles through the domain.

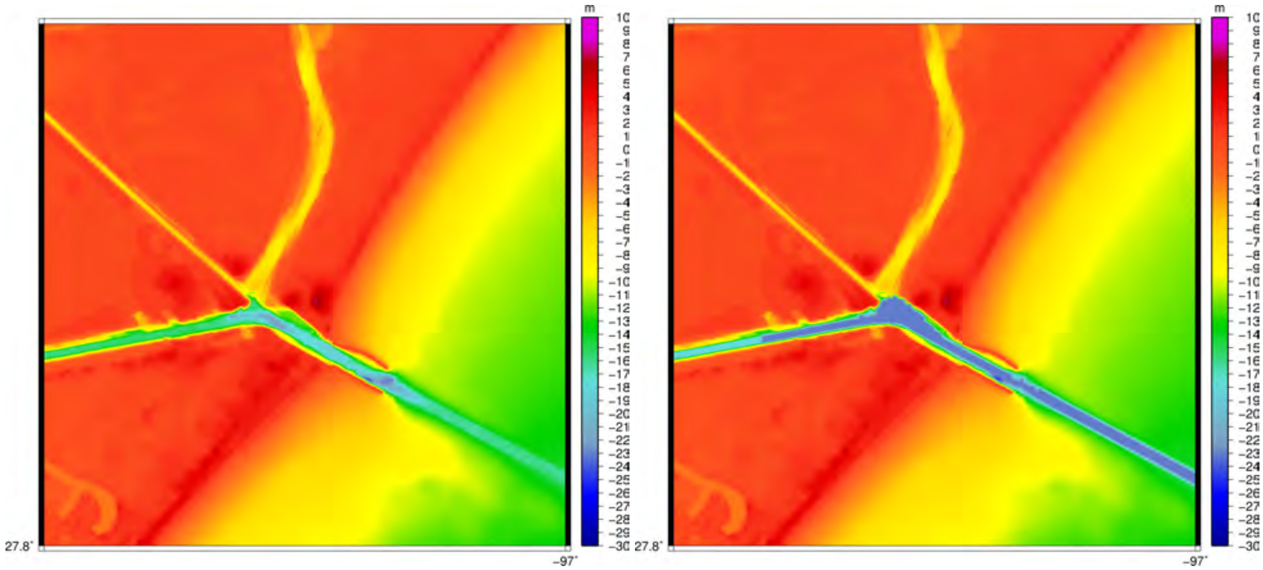
The required inputs for this particle tracker are the ADCIRC velocity fields and the initial distribution of particles in the domain. We make choices for initial particle locations based on the work of Brown *et al.* [2]. In total, we consider four initial conditions with different distribution and densities of particles. In Figure 5, we show the four locations in which we monitor the accumulation of particles. We use the same abbreviated designations as [2] for these locations: AB (Aransas Bay), CB (Corpus Christi Bay), and RB (Redfish Bay) 1 and 2. The initial particle locations are shown in Figures 6 and 7. The four cases we consider all start with particles in the nearshore region where the red drum spawn. Cases I and II are adapted from [2], and cases III and IV are chosen to compare the effect of increased particle release near the Aransas Pass inlet.

To analyze the data from the particle tracking algorithm, we developed a tool that monitors the particle location throughout the simulation. Once a particle reaches a suitable habitat, its velocity is set to zero and we consider it to be a successfully recruited larvae. This is a rather simplistic approach, however, our goal here is to ascertain if the number of larvae that reach the seagrass beds is impacted by the changed channel bathymetry.

3 Results

3.1 Velocity Comparison in the Aransas Pass

As the larvae must must enter Aransas Pass to reach the seagrass beds, it is natural to consider the flow characteristics here to check if the flow is severely impacted by a change in channel depth. To assess the difference in the velocities, we consider the maximum velocity established from the ADCIRC model for each



(a) Existing

(b) Proposed

Figure 4: Bathymetry (in meter) near the Aransas Pass.

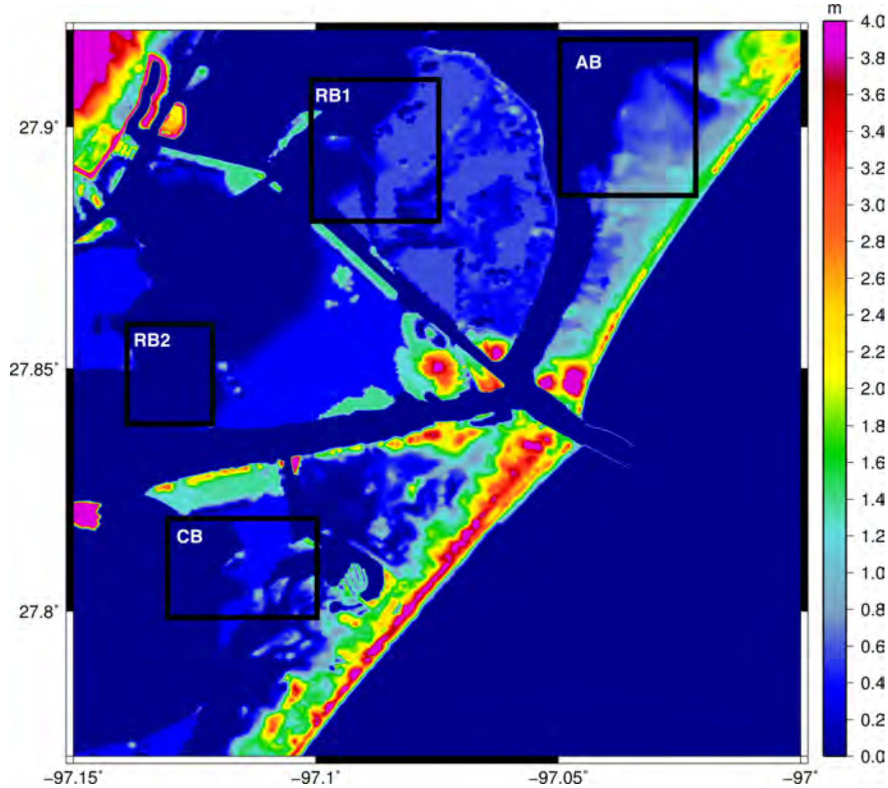
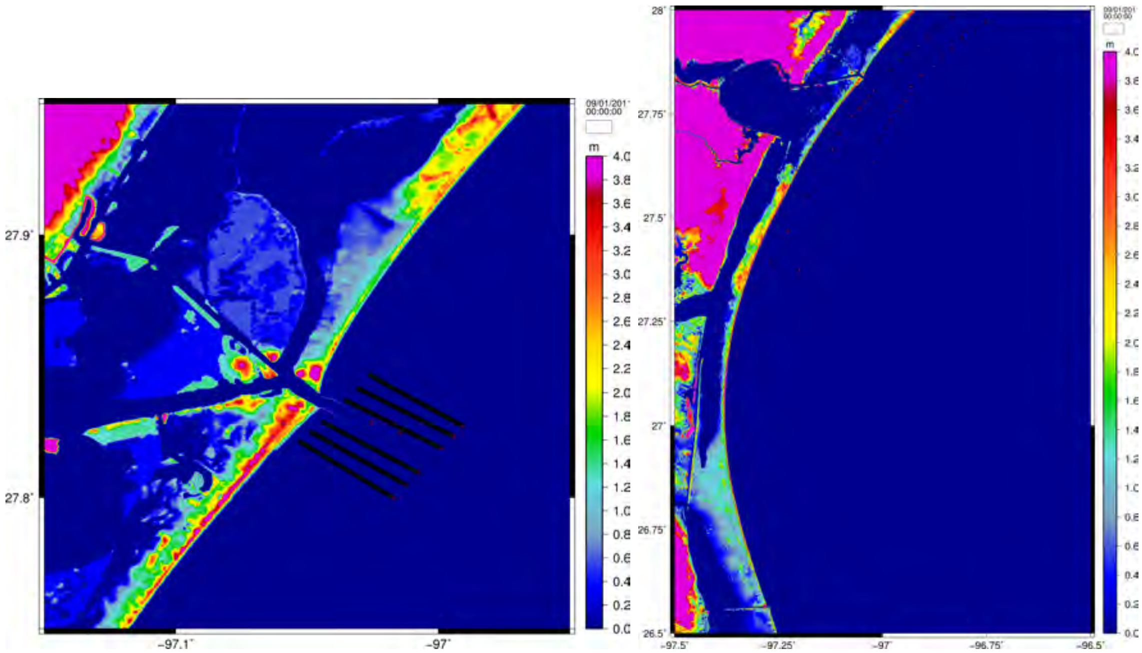


Figure 5: Monitoring locations, color spectrum denotes bathymetry above NAVD88 in meter.

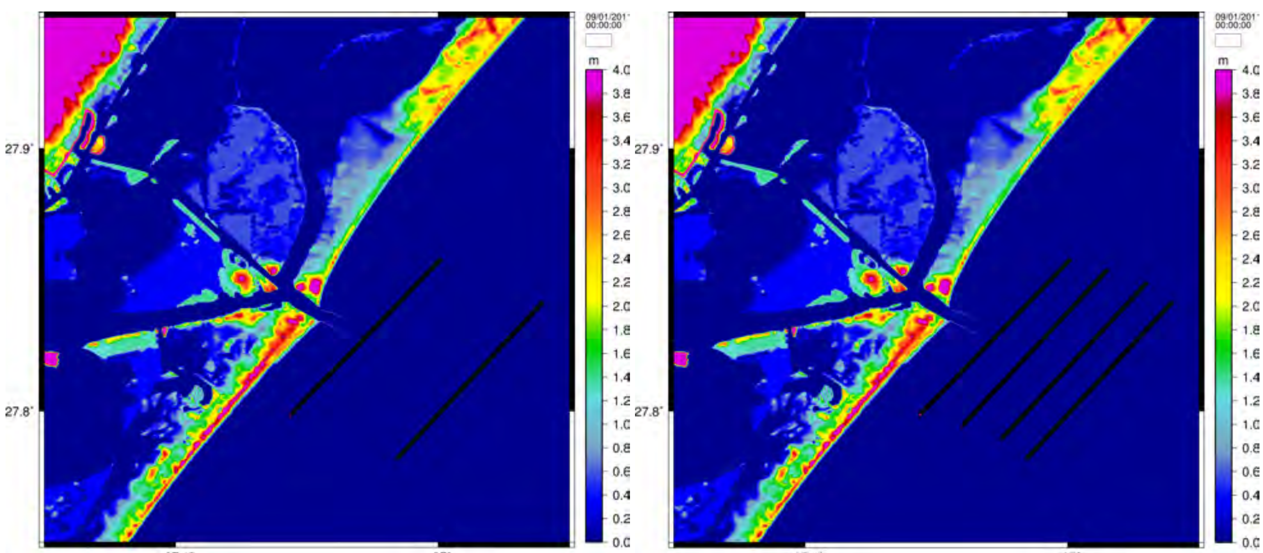
considered year. In Figure 8, the 2011 case is presented. Inspection of the two figures reveal a slight reduction on maximum velocity due to the deepened ship channel. Despite this decrease in velocity, the total flux of water into the bay (i.e. velocity times water depth) may be increasing (not shown here). Further analysis of the physics of the channel under various dredging scenarios may be warranted, but was deemed beyond



(a) Initial condition I - 1964 particles outside the Aransas Pass inlet.

(b) Initial condition II - 48 locations along the coast with 49 particles each.

Figure 6: Initial particle locations. The color spectrum denotes bathymetry above NAVD88 in meter

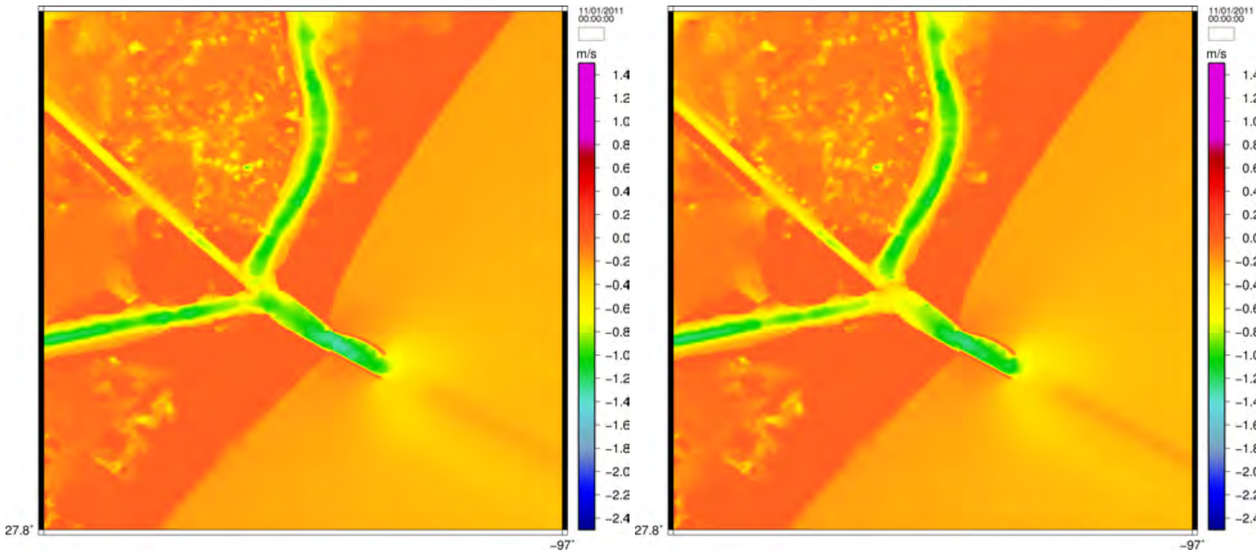


(a) Initial condition III - 2386 particles uniformly distributed outside Aransas Pass inlet.

(b) Initial condition IV - 4772 particles uniformly distributed outside Aransas Pass inlet.

Figure 7: Initial particle locations. The color spectrum denotes bathymetry above NAVD88 in meter.

the scope of this project. Similar results are observed for 2012 and 2019 as well and we omit the figures for brevity.



(a) Current batyhmetry.

(b) Proposed batyhmetry.

Figure 8: Maximum velocity component measured in meters per second in the Aransas Pass - 2011

3.2 Particle Tracking

For each considered year (2011, 2012, and 2019), we compute the total number of successfully recruited larvae in the four monitoring areas shown in Figure 5 for both the current and proposed channel bathymetry. As the change in bathymetry will likely lead to a change in how the water is distributed among the bays inside the Aransas Pass, we also report the number of larvae in each individual area to ascertain the difference for the year 2012.

In Tables 1, 2, and 3 the results for the total number of successfully recruited larvae are presented for years 2011, 2012, and 2019, respectively. From these three tables it is evident that the number of larvae that successfully reach the seagrass beds is highly dependent on the chosen initial conditions as well

Table 1: 2011 conditions successful larvae count.

Initial condition	Current bathymetry	Proposed bathymetry	% difference
I	347	344	-0.86
II	70	68	-2.86
III	307	302	-1.63
IV	1214	1206	-0.66
Total	1938	1920	-0.93

Table 2: 2012 conditions successful larvae count.

Initial condition	Current bathymetry	Proposed bathymetry	% difference
I	442	410	-7.24
II	144	106	-26.39
III	351	381	8.55
IV	1265	1342	6.09
Total	2205	2239	1.54

Table 3: 2019 conditions successful larvae count.

Initial condition	Current bathymetry	Proposed bathymetry	% difference
I	285	294	2.81
II	38	27	-28.95
III	209	216	3.35
IV	959	966	0.73
Total	1491	1503	0.80

as the hydrodynamic conditions. Comparison of the total number of larvae that reach the predetermined monitoring locations for the current and future bathymetries show that the effect of changes to the channel depth is small. The largest change in successful larvae are for the second initial condition (larvae distributed along the coast) for all three considered years. Comparison of the results for initial conditions III and IV reveal that doubling the number of initial larvae leads to roughy four times successfully recruited larvae in the monitoring locations. Hence, the initial number of particles has a significant impact on the total number that reaches the beds.

To provide further insight into the changes in successful larvae, we present the detailed data for each monitoring location for the 2012 case in Table 4. For both current and future channel depths we see that a the largest portion of the larvae reach location AB and the number of successful larvae here does not seem to be significantly impacted by the deeper channel. This tendency of the larvae is rather intuitive since the Lydia Ann channel (northern split of the Aransas Pass channel) is wider than the southern channel towards Corpus Christi. Also note that the location CB appears insensitive to the deeper channel as the number of successful larvae experiences very small changes.

3.3 Extreme Flow Conditions

As a final numerical experiment, we consider a case in which we incorporate extreme inflow into the domain from the Nueces river which enters into Corpus Christi bay from the Nueces bay. The Nueces River consists of multiple dams and reservoirs and the river is regulated by the Nueces River Authority. The volume of water entering Corpus Christi bay from this river is generally expected not to significantly impact the transport of larvae. However, it is possible that in extreme flooding scenarios, there will be an impact on the flow in Aransas Pass and thus on the transport of larvae.

To model such an extreme case, we consider the all-time peak flow in the Nueces river established from a United States Geological Survey (USGS) stream gauge (USGS 08211500 Nueces Rv at Calallen). The observed peak flow of $49,000$ cubic feet per second (cfs) was on September 16^{th} 2002 . As these events are isolated extremes, we consider a time span of ten days, five before and five after the peak flow. While this time span is too short to ensure accumulation of a similar number of particles as in Section 3.2, it allows us to compare accumulation for the current and proposed bathymetries in an extreme riverine inflow case. In Figure 9 the maximum velocities established from the ADCIRC model for the existing and proposed bathymetries are shown. For this extreme case, the difference between the maximum velocities is small, in the same fashion observed for the "normal" flow cases in, e.g., Figure 8. It should also be noted that the maximum velocity near the channel is unaffected by the very high inflow from the Nueces River.

In Table 5 the results for the total number of successfully recruited larvae are presented for the extreme scenario. While the number of successful particles is lower than for the past experiment due to the shorter time span, the effect of a deeper channel is small on the number of successfully recruited larvae. Comparison of Tables 5 and 2 reveals a similar trend across all four initial conditions.

4 Concluding Remarks

In this project, we have created mathematical models governing the transport of passive particles (red drum larvae) from the near-shore region outside Aransas Pass near Corpus Christi. The models consider identical

Table 4: 2012 conditions larvae counting location data.

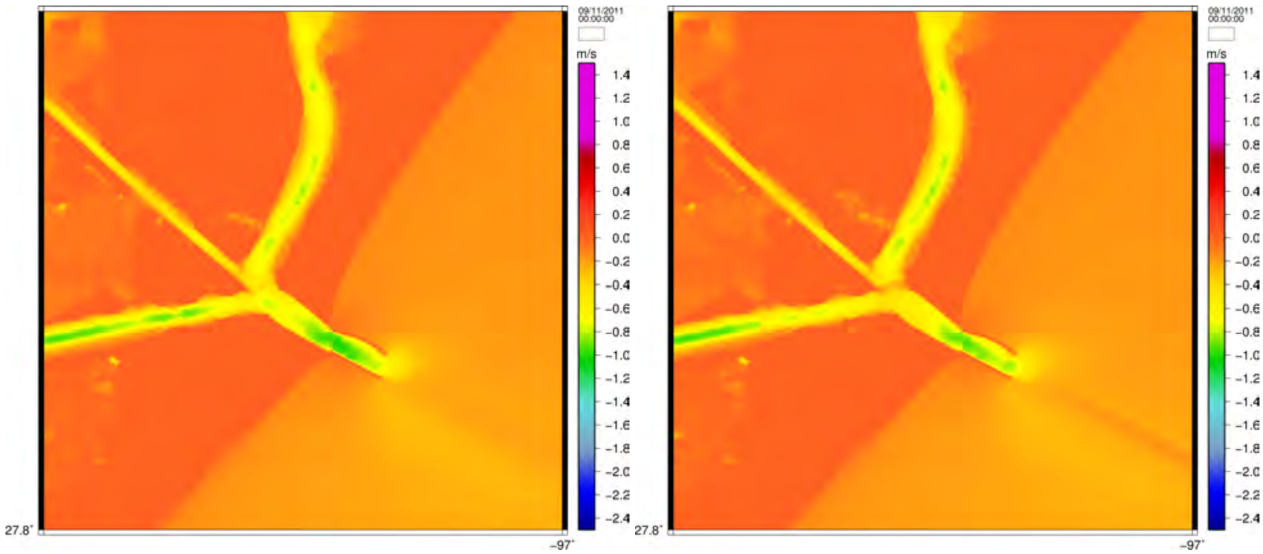
Monitoring location	Current bathymetry	Proposed bathymetry
Initial condition I		
AB	375	333
CB	35	40
RB1	20	26
RB2	12	11
Total	442	410
Initial condition II		
AB	103	70
CB	28	22
RB1	10	6
RB2	3	8
Total	144	106
Initial condition III		
AB	278	301
CB	39	48
RB1	19	24
RB2	15	8
Total	351	381
Initial condition IV		
AB	918	997
CB	194	188
RB1	98	87
RB2	55	70
Total	1265	1342

Table 5: Extreme river inflow condition successful larvae count.

Initial condition	Current bathymetry	Proposed bathymetry	% difference
I	166	161	-3.01
II	23	20	-13.04
III	125	144	15.20
IV	499	510	2.20
Total	813	835	2.71

time spans from September 1^{st} to October 31^{st} and employ meteorological forcing from 2011, 2012, and 2019 to establish the flow velocity and elevation throughout the domain of interest (the ADCIRC model). Red drum larvae are released in multiple locations September 1^{st} and are tracked throughout the following 60 days based on the established flow from the ADCIRC model. The ADCIRC and particle tracking models consider both the current bathymetric conditions for the Corpus Christi ship channel as well as the proposed future bathymetric conditions of a dredged channel.

The established results (see Tables 1, 2, and 3) indicate that the changes in channel bathymetry do not significantly change the number of successfully recruited Red drum larvae. However, as evident from these tables, the number of particles and their initial locations play an important role in the transport of particles.



(a) Existing bathymetry.

(b) Proposed bathymetry.

Figure 9: Maximum velocity components (in meters per second) for the extreme inflow case.

It should also be noted that we do not account for the transport of larvae near the water surface due to wind (wind is part of the ADCIRC model forcing), a potentially significant source of transport as noted by [1]. Fortunately, this type of larvae transport is likely to be unaffected by a change in channel bathymetry.

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