MEMORANDUM REPORT

27 June 2005

FLOW OBSERVATIONS
BOGUE INLET NORTH CAROLINA

Prepared for:

Carteret County Shore Protection Office and Town of Emerald Isle NC

CSE

MEMORANDUM REPORT

27 June 2005
Flow Observations
Bogue Inlet North Carolina

Prepared for:

Carteret County Shore Protection Office
PO Box 4297 Emerald Isle NC

and

Town of Emerald Isle
7500 Emerald Isle Drive Emerald Isle NC

Prepared by:

Coastal Science & Engineering (CSE)
PO Box 8056 Columbia SC 29202-8056

[2189MR]
SEPTEMBER 2005

TABLE OF CONTENTS

PAGE

1.0 INTRODUCTION 1

2.0 METHODS 2

3.0 RESULTS AND GENERAL OBSERVATIONS 8

4.0 RECOMMENDATIONS FOR FURTHER STUDY 16

REFERENCES 17

ACKNOWLEDGMENTS 17

1.0 INTRODUCTION

This memorandum report is prepared at the request of the Carteret County Shore Protection Office (NC) and the Town of Emerald Isle (NC). CSE completed a cursory set of flow measurements in Bogue Inlet on 27 June 2005 approximately two months after construction of the new channel through the mid inlet shoal (USACE 2004). The purpose of the flow study was to measure the ebb and flood discharge over a typical tidal cycle in the new channel and the old channel, and to determine the relative magnitudes of flows in each. The study was budget-limited and intended to provide a first-cut look at the tidal flows through the new system. Of particular concern is the degree to which the new channel has captured the tidal prism of the inlet such that scour and erosion will lessen along the Emerald Isle shoreline.

This report presents an updated bathymetric map (raw data courtesy of Geodynamics Group Inc), representative flow cross-sections, current measurements at six stations over a tidal cycle, tide height measurements in the old channel, and instantaneous discharge calculations for each measurement time. The series of discharge calculations were integrated over the flood and ebb cycle to provide estimates of flood and ebb tidal prisms of both channels. Time and budget did not allow a comprehensive analysis of hydraulics of the inlet, shoals and marginal channels, or morphologic changes associated with the new inlet channel.

2.0 METHODS

CSE mobilized a field team and equipment to Bogue Inlet on 25-26 June 2005 and set up a tide staff and six current measurement stations (temporary moorings) in the old channel and the new channel. Survey line CSE119 was used for the current measurement stations because it was situated near the throat of the old channel and intersected easily located navigation buoys in the new channel. By standard convention, the monitoring stations were positioned approximately one-sixth, one-half, and five-sixths of the distance across each channel such that the cross-section could be divided into thirds. A tide staff was placed on a fixed dock ~100 feet (ft) north of line119 along the shoreline of The Pointe at Emerald Isle (Fig 1) and leveled in via RTK-GPS.

Flow measurements were made approximately hourly at each station on 27 June along with readings of water levels at the tide staff. That date was chosen for measurements because predicted flood and ebb tide ranges for the day were nearly equal (reference: NOAA – Co-ops.nos.noaa.gov). Predicted times of low tide were 06:48 and 19:00 local standard time (LST). Predicted high tide was 12:57 hours. Predicted tide range in the inlet was 2.4 ft (daylight flood) and 2.1 ft (daylight ebb). This timing allowed measurement of one full tide cycle during daylight hours.

Currents were measured using a Marsh-McBirney Model 201 flowmeter with digital read-out. Readings were made at 2-ft intervals (new channel) and 5-ft intervals (old channel) by lowering the electromagnetic sensor by cable from CSE's survey vessel, RV *Irie*. A Sontek™ ADP provided backup and was rigged in the downward-looking mode. The ADP acquires vertical current profiles at ~0.25 meter "bin" intervals. It was used for the final two cycles of measurements at the end of the day after the Marsh-McBirney cable was damaged. Appendix A gives the hourly current readings by station and depth.

CSE surveyed the flow cross-sections on 28 June via RTK-GPS linked to a precision depth sounder. In August, raw data files were received (from a June 2005 bathymetric survey by Geodynamics Group Inc). CSE imported their data into HydroPro™ software, performed a quality check, and then contoured the x-y-z digital data in 2-ft intervals to prepare the contour map in Figure 1. A previously referenced inlet cross-section (7E/7W) is also given on Figure 1 (CSE 2001).

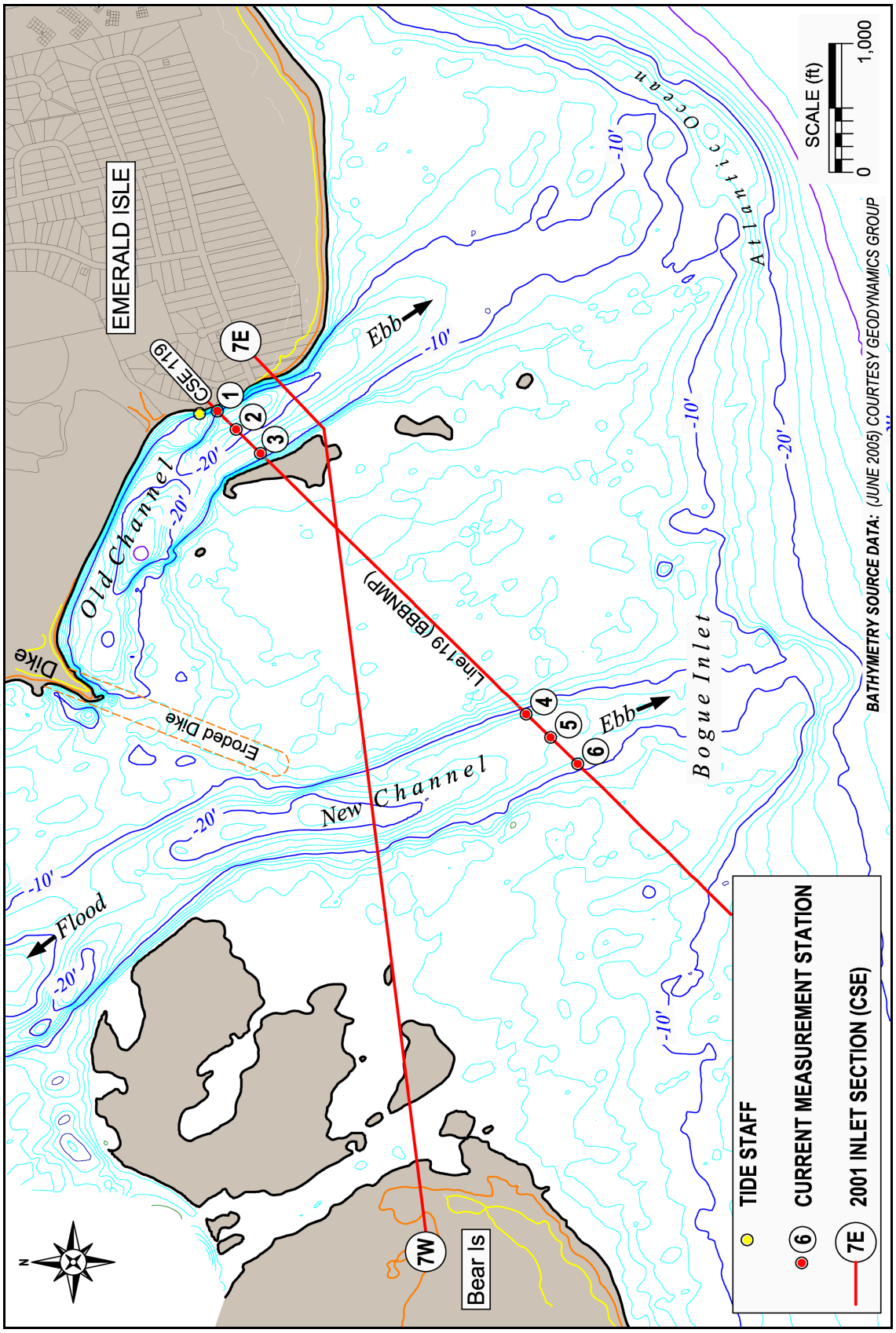


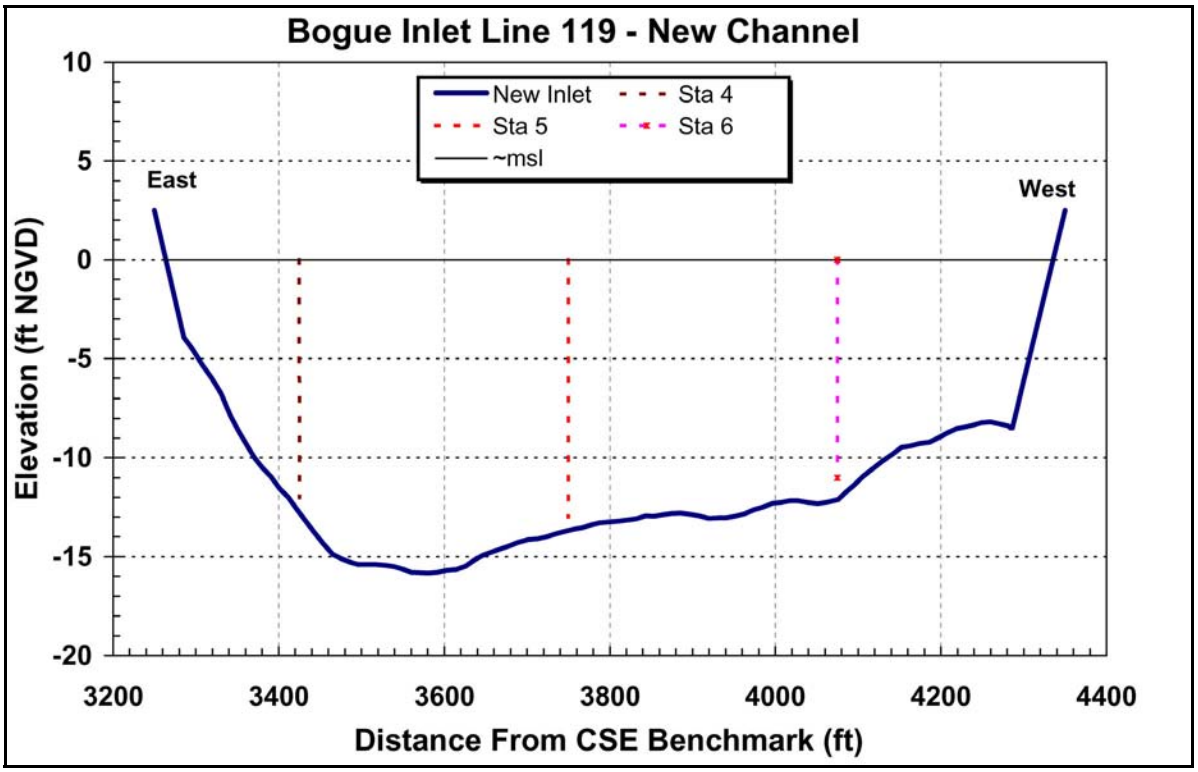
FIGURE 1. Bogue Inlet bathymetry and current measurement transects. Bathymetry contours prepared by CSE using source data courtesy of Geodynamics Group Inc.

Navigation between the old and new inlets was via the old channel and around the "training" dike remnant shown on Figure 1. Line119 was chosen for current measurements in the new channel because the flows appeared more confined at that locality. However, the channel margins of the new inlet are actually open boundaries with tides flowing freely across the remnants of the mid inlet shoal. Consequently, identification of the "throat" section of the new channel was problematic until receipt of the detailed bathymetry.

For purposes of defining effective flow cross-sections for comparison, CSE had to assume some cutoff for the new inlet cross-section at the margins of the mid inlet shoal. Figure 2 (upper) shows the resulting new channel section (~1,100 ft wide), although the east and west boundaries were actually open above the (~)–5-ft contour. Also shown in Figure 2 are the locations of current measurement stations (4, 5 and 6). Figure 2 (lower) shows the corresponding old channel cross-section along measurement stations 1, 2 and 3. The old channel at this locality remains bounded on the east by sandbags at The Pointe and on the west by a prominent shoal.

Figure 3 shows the section for CSE line119 and the relative size of the old and new channels. The old inlet remains deeper but narrower than the new inlet along this alignment. Another section (7E/7W), developed after the June 2005 current survey using the Geodynamics Group data set, crosses a deeper section of the new channel and a shallower section of the old channel (Fig 4). Along this alignment, the two channels have similar maximum depths (approximately –20 ft NGVD), but the new channel is about 50 percent wider. Figure 4 shows the same cross-section in October 2001, before inlet construction.

For the discharge estimates, flow cross-sections were computed for the range of observed water levels during the survey. Appendix B provides the calculations at 0.25-ft intervals (NGVD datum) for the old channel and the new channel. Each channel was also divided in thirds for purposes of computing the applicable flow areas for each current measurement station and time of measurement. As Appendix B shows, the old inlet flow cross-section (A_C) ranged from ~7,300 square feet (ft^2) at –2.5 ft NGVD to ~9,900 ft^2 at +2.5 ft NGVD. The corresponding A_C for the new channel along line119 (stations 4, 5, and 6) ranged from ~10,000 ft^2 at –2.5 ft NGVD to ~16,000 ft^2 at + 2.5 ft NGVD.



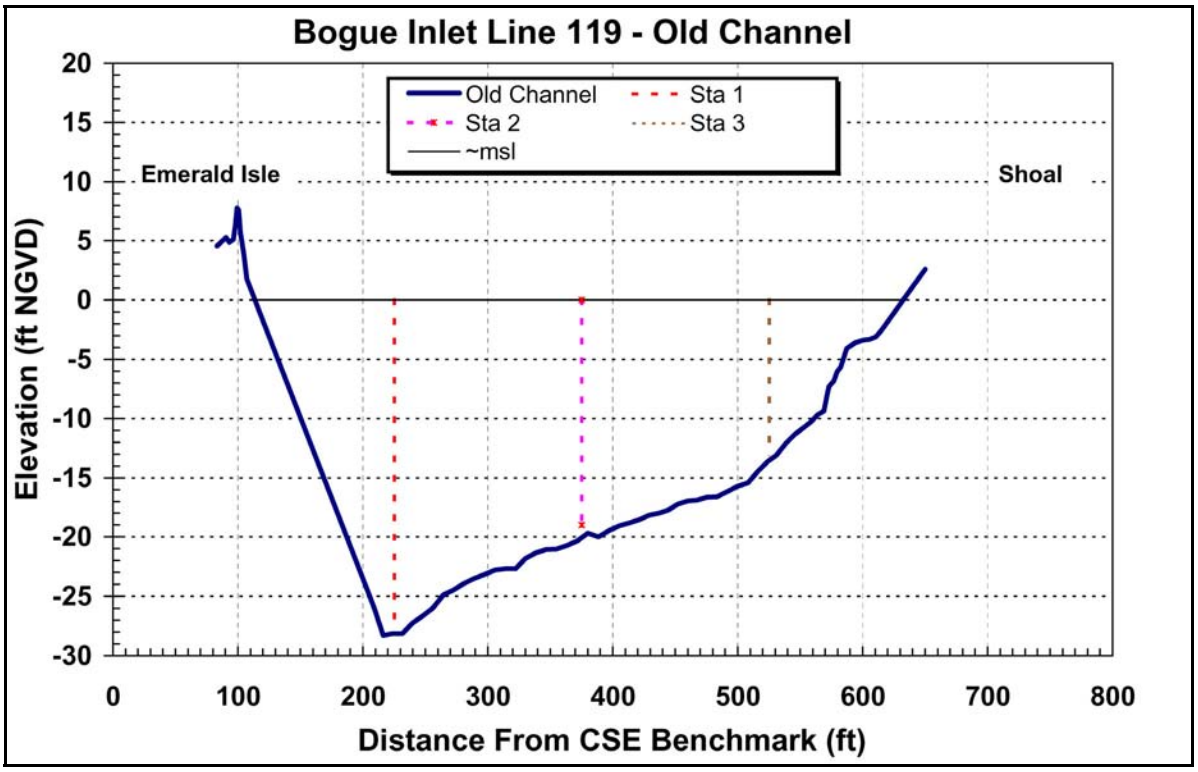


FIGURE 2. New channel (upper) and old channel (lower) current measurement stations and sections used for discharge calculations (boundaries closed for computations to high water level).

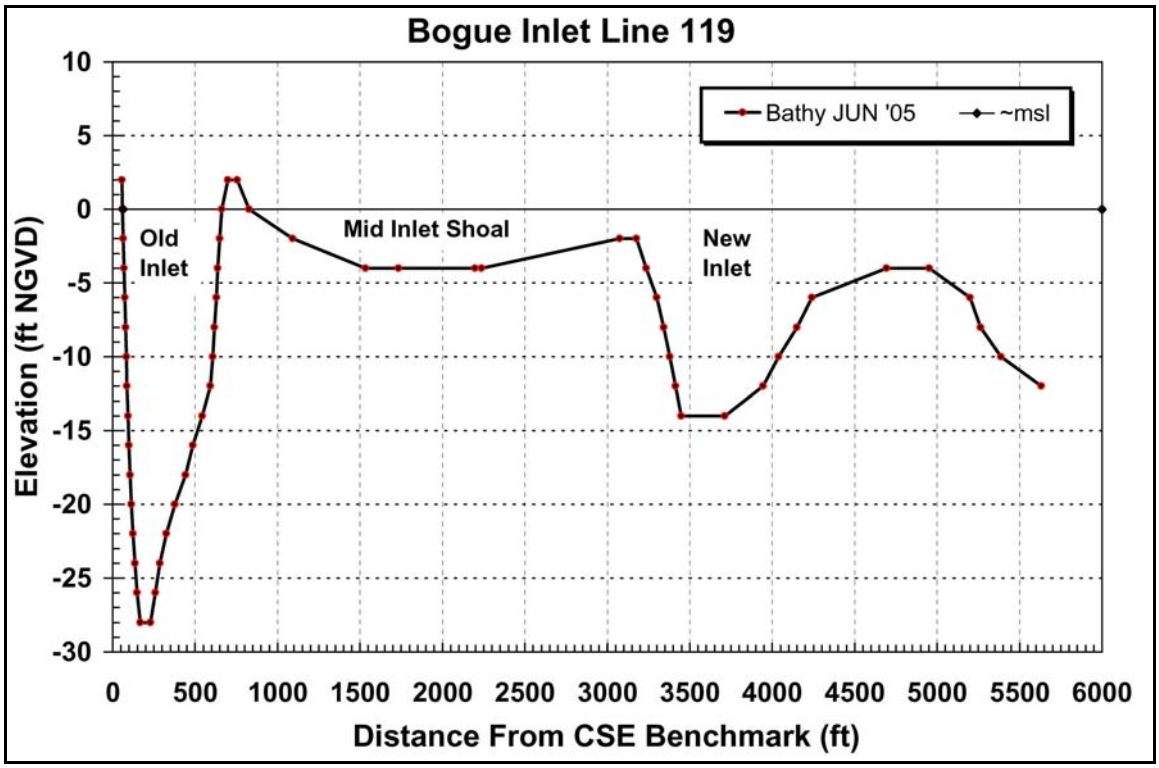


FIGURE 3. Bogue Inlet section line 119. See Figure 1 for location.

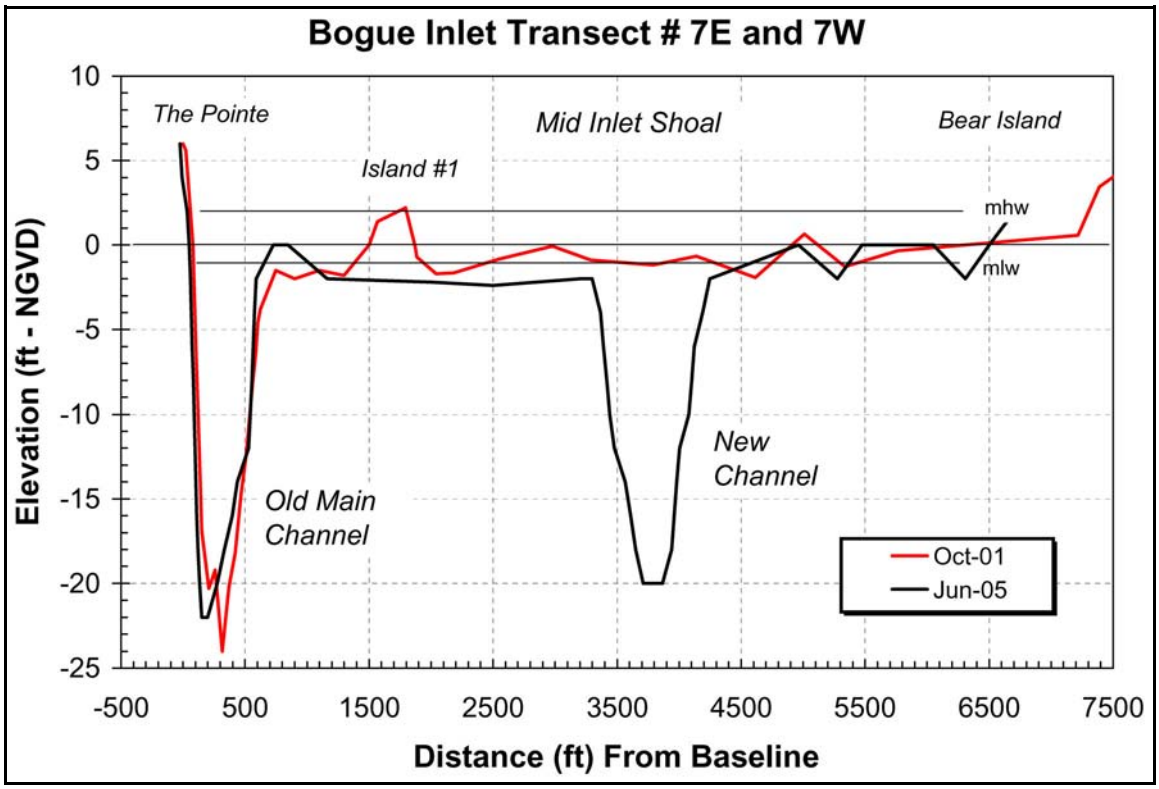


FIGURE 4. Bogue Inlet section comparing 2001 and 2005 conditions. See Figure 1 for location.

Discharge was computed as the product of current speed (measured in meters per second) and cross-sectional area at the time of each measurement. [Discharge units were converted to cubic feet per second (cfs).] Each calculation of "instantaneous" discharge was applied over an applicable time period to yield a net discharge for the period. Then, all flood period discharges were totaled to estimate the flood tidal "prism" (ie, total volume of water entering the channel on the particular rising tide). Similarly, an estimate of ebb-tidal prism was made by summing the net discharges for each outgoing tidal period. This latter calculation was impacted by truncation of the velocity curve due to a stronger than expected phase lag between the time of low or high water and the time slack water was achieved.

Two methods were used to project the last 1-2 hours of the tidal discharge curve, estimate the time of slack water, and complete the p.m. ebb cycle:

> *Method 1* – Projection of rates to zero assuming a symmetrical discharge curve during the p.m. ebb phase.
>
> *Method 2* – Applying the rates derived from the end of the ebb discharge curve of the preceding (ie, a.m.) ebb cycle.

The two methods each provided two estimates of tidal prisms on the flood and ebb for each channel. The average of the results of the two methods was adopted for purposes of comparing flows in this case.

3.0 RESULTS AND GENERAL OBSERVATIONS

Figures 5 and 6 show the tide heights and instantaneous discharge (cfs) for the measurement cycle on 27 June 2005. The discharge calculations using Method 1 and Method 2 are given in Appendix C.

Figure 5 shows the approximate time of low tide was ~06:40 a.m. at the beginning of the survey. High tide occurred around 12:52 p.m. followed by low tide around 06:50 p.m. Measured tide ranges were ~4.0 ft on the a.m. (rising) tide and 3.8 ft on the p.m. (falling) tide.

Figure 6 shows the instantaneous discharge over the measurement cycle (upper – Method 1, lower – Method 2). The times of slack flows were found to be ~09:45 a.m. (slack low) and ~02:52 p.m. (slack high) in both channels. This confirms there was a large phase lag (2-3 hours) between the times of low tide or high tide and the times of slack water. In other words, ebb currents continued for hours in the channels while the tide was rising, then flood currents continued long after the tide started to fall that day. Phase lags of the order ~15 minutes are common in single inlet systems because of inertial effects of flows through the channels (eg, Nummedal and Humphries 1978). Longer phase lags are typical of systems where multiple inlets are connected to a single estuary/lagoon system. Phase lags also increase in connection with attenuation of the tide wave into marsh lagoons. For example, the measured tide range in the mouth of the old channel was ~4 ft the day of the measurements. Predicted tide ranges in White Oak River are of the order 2 ft. This difference, combined with the propagation of the tide wave, changes the times of high tide and low tide throughout the estuary. The result is varying heads of water produced by height and time differences that continue to drive currents while low tide or high tide is occurring at a particular point.

Notwithstanding the observed phase lag in the system, the measurements show distinct differences in discharge between the old channel and new channel (the main point of the present study). **Flows in the new channel exceeded those in the old channel on the flood and ebb cycle. Peak discharge in the new channel was nearly three times greater on the ebb and about 50 percent greater on the flood.** The peak flood and ebb discharges in the **old** channel were approximately balanced. In contrast, the peak ebb discharge in the **new** channel was much greater than the peak flood discharge.

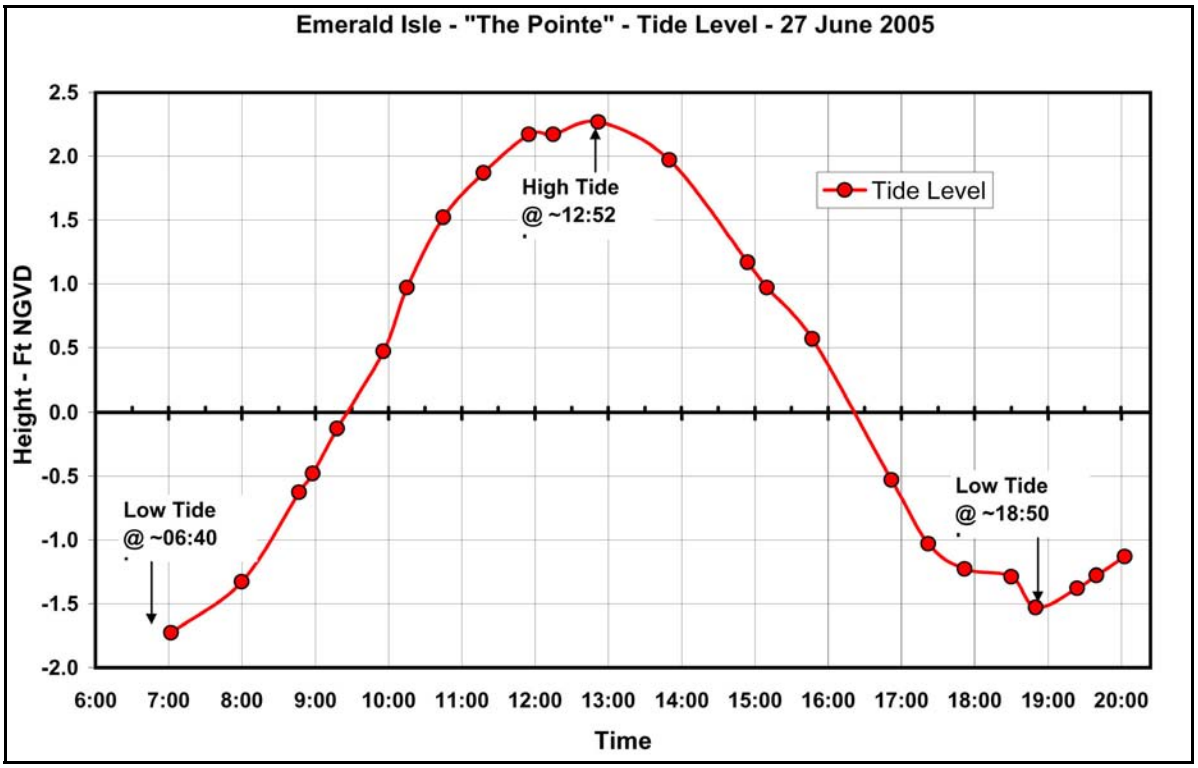
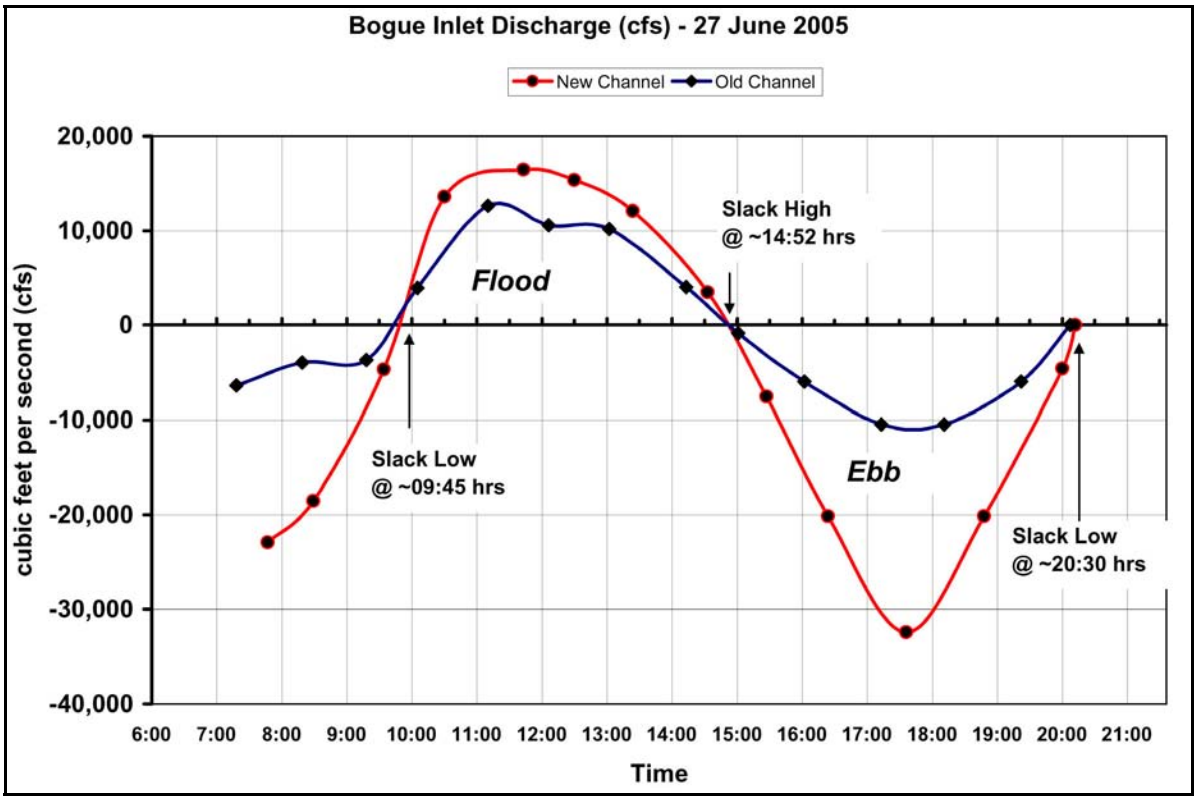


FIGURE 5. Tide height near station 1 in old channel at The Pointe along Emerald Isle.



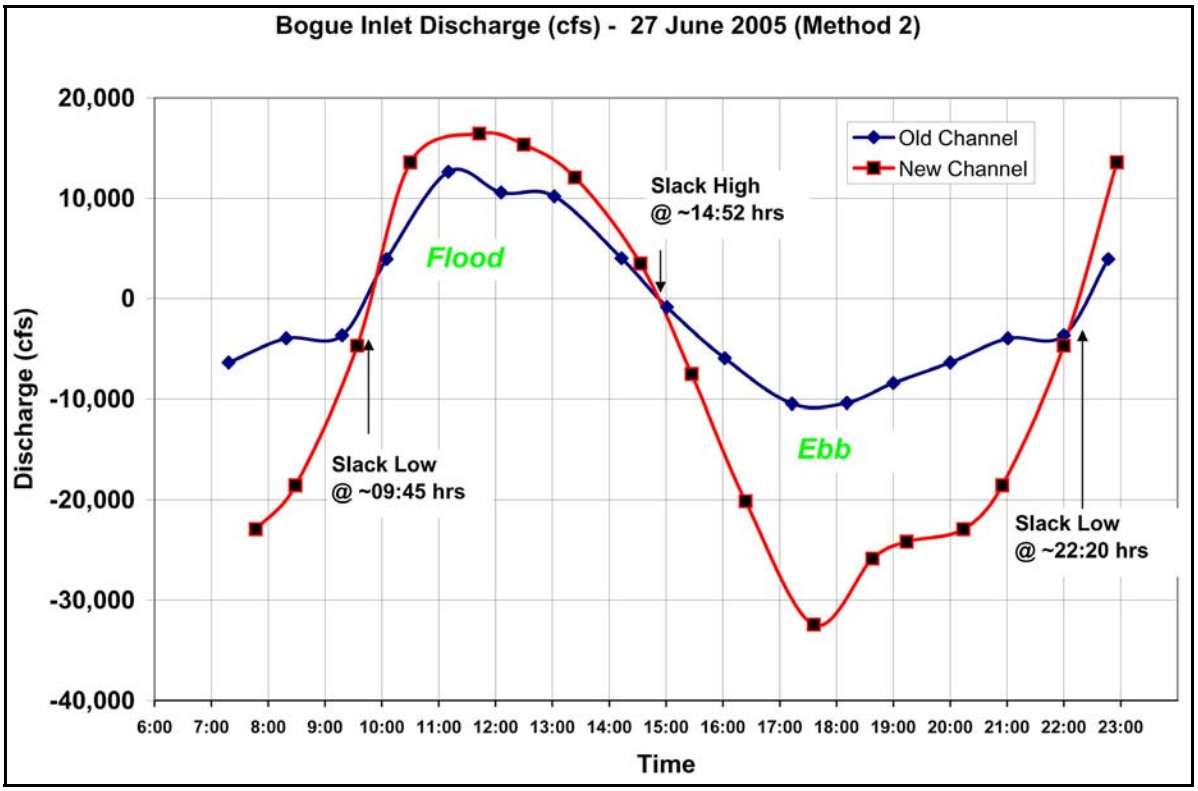


FIGURE 6. Bogue Inlet discharge measurements in the old and new channels. **[UPPER]** Method 1 – assumed end of cycle at 20:30 hours. **[LOWER]** Method 2 – assumed end of cycle similar to data from previous cycle.

Table 1 summarizes the discharge rates for the two channels on the flood and ebb cycles. Pairs of estimates are made in each case: simple arithmetic mean and weighted means. The former represent simple averages of the observed instantaneous rates (Appendix C) on the flood and on the ebb. Weighted means are calculated by taking the computed tidal prism (flood or ebb) and dividing by the applicable number of seconds in the half-tidal cycle. The weighted average discharge is considered more representative of typical conditions of each channel. Table 1 also provides ratios between the mean discharges in the old and new channels. The results suggest the following:

During Ebb Flows –

- New channel discharge **three** times greater than old channel's discharge

During Flood Flows –

- New channel discharge **~1.5** times greater than old channel's discharge

Ebb to Flood Ratios –

- New channel ebb discharge is ~2 times greater than flood discharge
- Old channel ebb discharge is approximately equal to flood discharge

As Table 1 indicates, the new channel accounted for ~74 percent of the total discharge of both channels combined on the ebb and ~59 percent of the total discharge of both channels on the flood. Thus, **the new channel was handling 2-3 times more flow than the old channel on 27 June 2005.** Figure 7 provides a simple illustration of the mean discharge in the new and old channels on the flood and ebb tides. Combining the two ebb discharges gives a total discharge of ~30,000 cfs. This is about 75 percent of CSE's (2001) ebb discharge estimate for the entire inlet before the new channel was cut (Fig 8). The principal difference (not accounted for in the present study) is assumed to be flows propagating over the shoals adjacent to the new channel.

The flood discharge of the two channels combined averaged only about 18,000 cfs. This represents 50 percent of CSE's (2001) flood discharge estimate, suggesting a large part of the flood prism must propagate over the mid inlet shoals.

TABLE 1. Computed discharge for Bogue Inlet.

	Old Channel		New Channel		Ratio	Total Discharge (New + Old)	
	Discharge (cfs)		Discharge (cfs)		New/Old-Ebb	Ebb Discharge (cfs)	
Ebb	Simple	Weighted	Simple	Weighted	Simple	Simple	Weighted
Method 1	-5610	-7217	-14140	-19275	2.52	-19750	-26492
Method 2	-6257	-8465	-19545	-24810	3.12	-25802	-33275
Average	**-5934**	**-7841**	**-16843**	**-22043**	**2.84**	**-22776**	**-29884**
						Total Discharge (New + Old)	
	Old Channel		**New Channel**		New/Old-Flood	Flood Discharge (cfs)	
Flood	Discharge (cfs)		Discharge (cfs)		Weighted	Simple	Weighted
Method 1	8260	8381	12186	12246	1.46	20446	20627
Method 2	8260	6340	12186	9264	1.46	20446	15604
Average	**8260**	**7361**	**12186**	**10755**	**1.46**	**20446**	**18116**
	Old Channel		**New Channel**			Old/Total	New/Total
Ratios (on Avg's)	Simple	Weighted	Simple	Weighted		Weighted	Weighted
Flood/Ebb	1.39	0.94	0.72	0.49		Ebb	Ebb
Ebb/Flood	0.72	**1.07**	1.38	**2.05**		**0.26**	**0.74**
						Flood	Flood
						0.41	**0.59**
Note: Inlet Flow Areas (Estimates)							
	Old Inlet	Old Inlet	New Inlet	New Inlet			
	Line 7E	Line 119	Line 7E	Line 119			
Oct-01	10,500	N/A	N/A	N/A			
May-05	8,800	8,800	11,050	13,500			

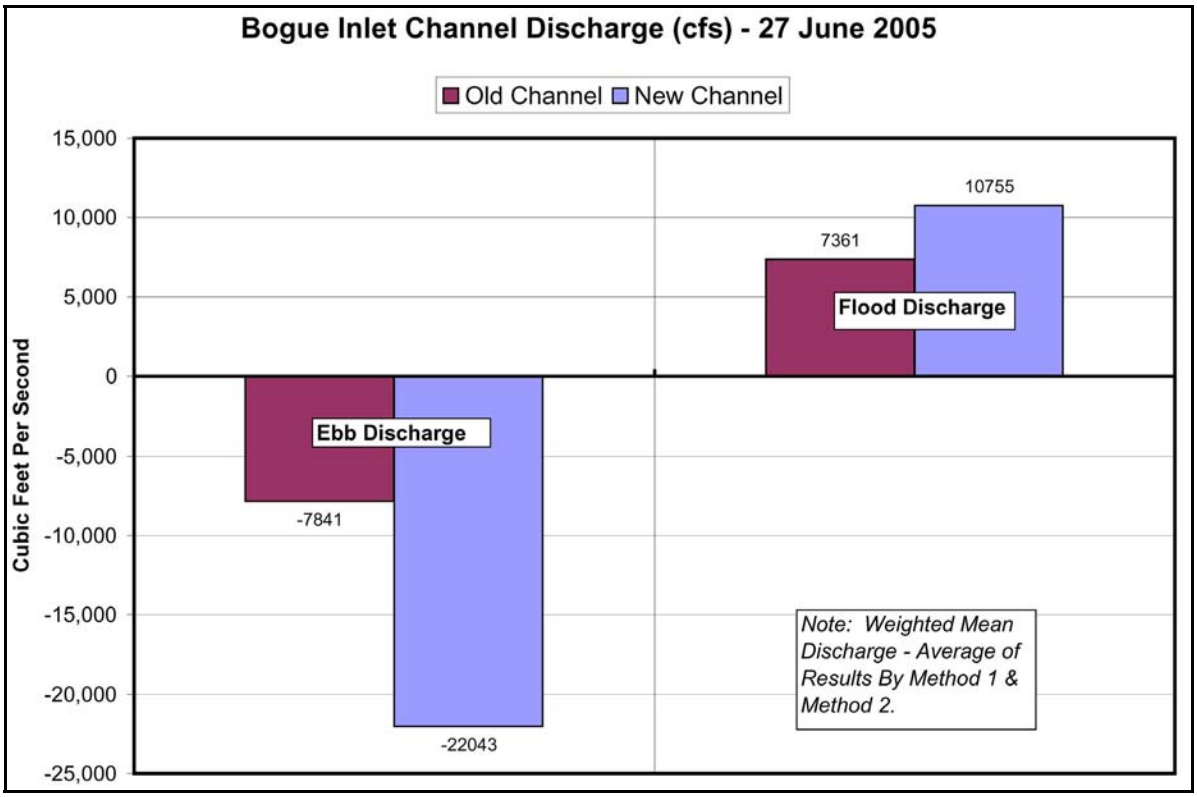


FIGURE 7. Estimated average discharge in the old and new channels of Bogue Inlet during a typical ebb tide and a typical flood tide in June 2005.

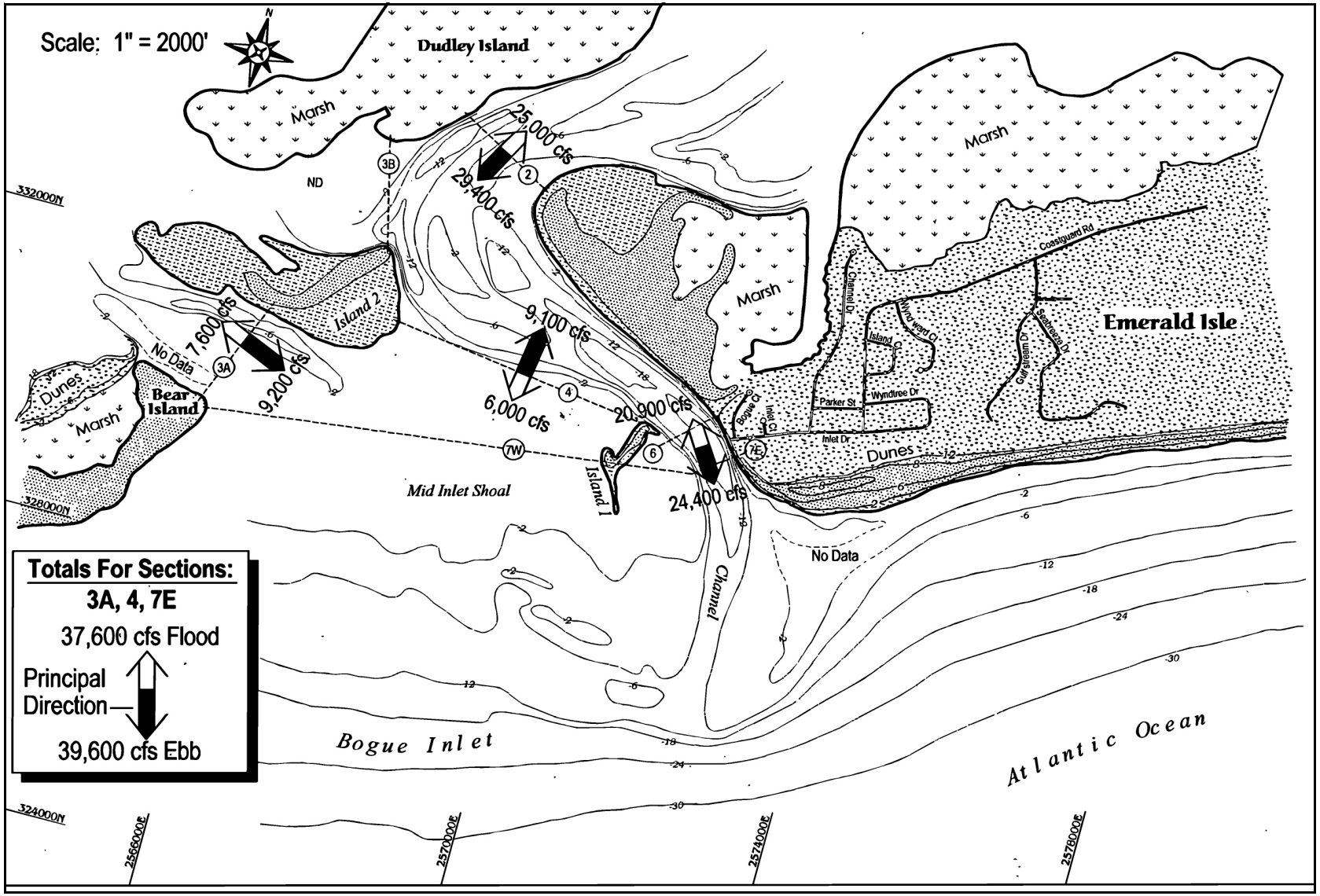


FIGURE 8. Average discharge over a tidal cycle through Bogue Inlet in mid October 2001. Principal flow direction is represented by the solid arrow. [From CSE 2001]

Figure 9 summarizes the ebb and flood discharges in the new system and provides an estimate of unmeasured discharges over the shoals. It is clear from this that the new channel has become the dominant one. However, significant flows are still occurring through the old channel. While velocities (Appendix A) on the flood and ebb in the old channel were never as high as those recorded in the new channel, speeds at station 2 reached 0.5 meter per second (~1.6 feet per second – ft/s) which is sufficient to move sand-sized material that becomes suspended. The present data indicate the ebb discharge in the old channel is slightly stronger than the flood discharge. This will tend to retard accretion in the old throat section or recovery of the beach along The Pointe. A somewhat surprising observation was the depth and seaward extent of the old ebb-tidal delta (see Fig 1). There is little evidence, so far, of shoreward movement of the outer delta lobe. Landward movement of this feature is a key for eventual closure of the old channel.

During the current measurement period, CSE noted a strong westerly flow across the training dike during much of the flood tide cycle. Spot measurements of current speed showed readings >1 meter per second near the end of the dike, clearly indicating a large head of water between the old channel throat (near line119) and the landward end of the new channel (a distance of ~3,000 ft). This head difference during the **flood** tide is believed to be the principal cause of erosion to the dike. By the time of CSE's measurements (27 June 2005), the dike had become less effective with only a small remnant left in place. Despite the free flow of water over the dike remnant on the flood tide, flows across it during the ebb tide were much less pronounced, suggesting it was still serving to direct the outgoing tide toward the new channel. Flows in the old channel are likely to persist as long as there are significant head differences between the old inlet and the new inlet. Time and budget did not allow detailed analysis of this effect.

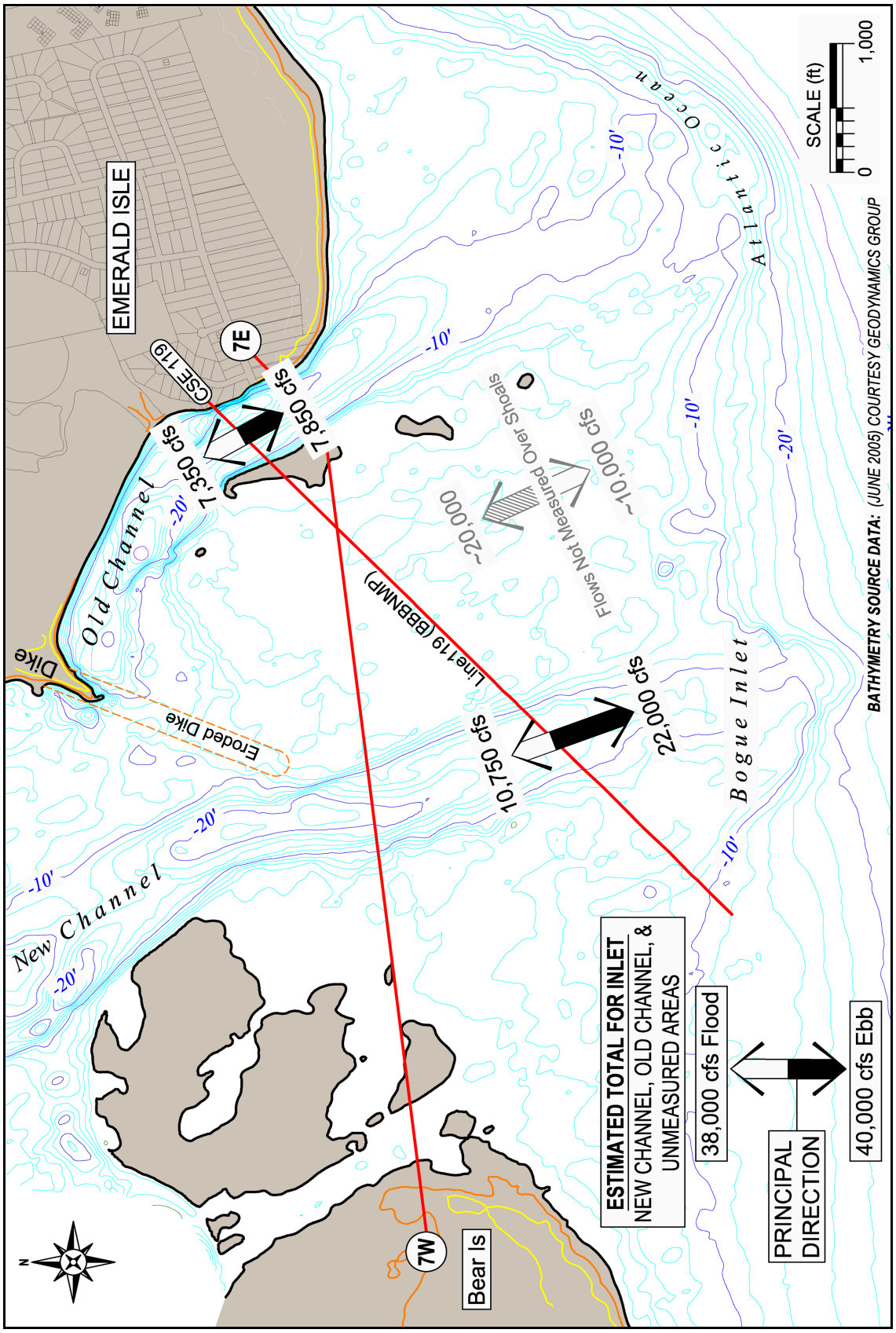


FIGURE 9. Estimated average discharges through Bogue Inlet (27 June 2005). Totals based on CSE (2001).

4.0 RECOMMENDATIONS FOR FURTHER STUDY

The new channel for Bogue Inlet has captured the majority of ebb flows in the inlet but only about 50 percent more of the flood flow than the old channel. There is rapid attenuation of the tide wave into the lagoon/estuary system of Bogue Sound and White Oak River. This produces height and phase differences along the channels as well as across the shoal-dominated entrance.

A full understanding of the hydraulics of the inlet would require time-series field data from an extensive network of tide gauges and current meters, combined with sophisticated 2-D or 3-D hydrodynamic modeling. When calibrated against site-specific tide observations, the hydrodynamic model could be combined with a sediment transport algorithm to estimate fluxes of sediment and begin to establish patterns of shoaling and erosion. Periodic bathymetric surveys and sediment sampling would be required to test the validity of the sediment transport model and allow refinements to sediment transport coefficients on which such models depend. Such a study would provide useful data for future projects. However, CSE cautions that a system the size of Bogue Inlet adds a level of complexity to the hydrodynamics that is not easily resolved. Hydrodynamic models have trouble accurately accounting for “sheet flow” over shoals and alternate wetting and drying of large marsh areas through the tidal cycle. CSE is aware of no comparable study that has been accomplished successfully to date for such a morphologically complex inlet system.

In the meantime, some limited tide gauging in the inlet is recommended, combined with in-situ current gauges in key channels to begin accumulating field data for future modeling efforts. Yearly bathymetric mapping should be completed to track principal morphological features such as the old and new ebb tidal deltas to the mouths of each channel. Comparative bathymetry will provide a direct measure of the results of flows (if not the driving forces accounting for accumulations or erosion of sediment). This is reasonably straight forward, but time consuming, data analysis that would provide empirical guidance on the changes occurring in the new system.

The key question for the community is how long will it take for the old channel to shoal and the beach along The Pointe to be restored. Comparative bathymetric and profile surveys remain the only cost-effective approach to answering that question in CSE’s opinion.

REFERENCES

CSE. 2001. Analysis of alternatives for Bogue Inlet channel realignment and beach nourishment along western Emerald Isle, NC. Summary Report for Town of Emerald Isle, NC; CSE, Columbia, SC, 79 pp + appendix.

Nummedal, D, and SM Humphries. 1978. Hydraulics and dynamics of North Inlet, South Carolina, 1975-1976. GITI Rept No 16, Coastal Eng Res Cntr, US Army Corps of Engineers, Ft Belvoir, VA, 214 pp.

USACE. 2004. Final environmental impact statement, Bogue Inlet channel erosion response project, Emerald Isle, North Carolina. Prepared by Coastal Planning & Engineering Inc, Boca Raton, FL, 291 pp.

ACKNOWLEDGMENTS

This study was commissioned by the Town of Emerald Isle and the Carteret County Shore Protection Office. We thank Frank Rush and Greg “Rudi” Rudolph for coordinating the study.

Bathymetric data was provided courtesy of Geodynamics Group Inc and the NC Division of Coastal Management through the Carteret County Shore Protection Office.

Field data collection and analyses were performed by Doug Dusini, Philip McKee, and Tim Kana. The report was prepared by Dr. Tim Kana and Doug Dusini (coastal engineer) with assistance by Trey Hair and Diana Sangster.

APPENDIX A

Bogue Inlet
Instantaneous Current Measurements

APPENDIX A. Bogue Inlet - Instantaneous current measurements via Marsh McBirney Flowmeter and Sontek ADP. [2 pages] 27-Jun-05

Bogue Inlet Old Channel (Stations 1-3); New Channel (Stations 4-6). (-) Ebb; (+) Flood

Time (EDT)

0705		*0720*		*0730*		*0740*		*0747*		*0753*	
STA 1		**STA2**		**STA3**		**STA4**		**STA5**		**STA6**	
Depth (ft)	Speed (m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)
0.0	-0.46	0.0	-0.32	0.0	-0.19	0.0	-0.74	0.0	-0.88	0.0	-0.75
5.0	-0.44	5.0	-0.37	5.0	-0.10	2.0	-0.75	2.0	-0.92	2.0	-0.79
10.0	-0.30	10.0	-0.32	10.5	-0.05	4.0	-0.60	4.0	-0.86	4.0	-0.61
15.0	-0.25	15.0	-0.32			6.0	-0.65	6.0	-0.65	6.0	-0.52
20.0	-0.18	18.0	-0.15			8.0	-0.50	8.0	-0.67	8.0	-0.45
23.0	-0.05					9.0	-0.49	10.0	-0.65		0.00
Avg	**-0.28**		**-0.30**		**-0.11**		**-0.62**		**-0.77**		**-0.52**

0803		*0809*		*0815*		*0824*		*0828*		*0836*	
STA 1		**STA2**		**STA3**		**STA4**		**STA5**		**STA6**	
Depth (ft)	Speed (m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)
0.0	-0.28	0.0	-0.12	0.0	-0.10	0.0	-0.65	0.0	-0.70	0.0	-0.45
5.0	-0.30	5.0	-0.20	5.0	-0.10	2.0	-0.56	2.0	-0.62	2.0	-0.39
10.0	-0.29	10.0	-0.14	9.0	-0.05	4.0	-0.50	4.0	-0.64	4.0	-0.40
15.0	-0.18	15.0	-0.09			6.0	-0.50	6.0	-0.68	6.0	-0.39
20.0	-0.10	19.0	-0.09			8.5	-0.36	8.0	-0.40	7.0	-0.35
22.0	-0.10							10.0	-0.38		
Avg	**-0.21**		**-0.13**		**-0.08**		**-0.51**		**-0.57**		**-0.40**

0900		*0908*		*0915*		*0927*		*0934*		*0942*	
STA 1		**STA2**		**STA3**		**STA4**		**STA5**		**STA6**	
Depth (ft)	Speed (m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)
0.0	-0.24	0.0	-0.20	0.0	-0.08	0.0	-0.12	0.0	-0.23	0.0	-0.13
5.0	-0.23	5.0	-0.16	5.0	-0.10	2.0	-0.08	2.0	-0.30	2.0	-0.09
10.0	-0.18	10.0	-0.13	10.0	-0.02	4.0	-0.05	4.0	-0.26	4.0	-0.11
15.0	-0.19	15.0	-0.10			6.0	-0.06	6.0	-0.20	6.0	-0.05
20.0	-0.15	17.0	-0.08			8.0	-0.06	8.0	-0.20	8.0	-0.05
23.5	-0.04					9.0	-0.03	10.0	-0.15		
								11.0	-0.16		
Avg	**-0.17**		**-0.13**		**-0.07**		**-0.07**		**-0.21**		**-0.09**

0958		*1005*		*1012*		*1023*		*1030*		*1037*	
STA 1		**STA2**		**STA3**		**STA4**		**STA5**		**STA6**	
Depth (ft)	Speed (m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)
0.0	0.03	0.0	0.00	0.0	0.22	0.0	0.34	0.0	0.36	0.0	0.30
5.0	0.11	5.0	0.12	5.0	0.25	2.0	0.31	2.0	0.35	2.0	0.28
10.0	0.11	10.0	0.24	10.0	0.30	4.0	0.33	4.0	0.33	4.0	0.24
15.0	0.05	15.0	0.26	12.0	0.20	6.0	0.32	6.0	0.34	6.0	0.29
20.5	0.05	19.0	0.10			8.0	0.31	8.0	0.36	8.0	0.32
						10.0	0.22	10.0	0.25	10.0	0.32
								12.0	0.22	11.0	0.20
Avg	**0.07**		**0.14**		**0.24**		**0.31**		**0.32**		**0.28**

1103		*1111*		*1116*		*1137*		*1144*		*1148*	
STA 1		**STA2**		**STA3**		**STA4**		**STA5**		**STA6**	
Depth (ft)	Speed (m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)
0.0	0.51	0.0	0.54	0.0	0.32	0.0	0.29	0.0	0.47	0.0	0.42
5.0	0.44	5.0	0.50	5.0	0.38	2.0	0.30	2.0	0.46	2.0	0.37
10.0	0.41	10.0	0.50	10.0	0.38	4.0	0.39	4.0	0.40	4.0	0.33
15.0	0.32	15.0	0.46	15.0	0.37	6.0	0.24	6.0	0.44	6.0	0.40
20.0	0.31	20.0	0.45	16.0	0.31	8.0	0.28	8.0	0.40	8.0	0.40
		22.0	0.25			10.0	0.28	10.0	0.36	10.0	0.38
						11.0	0.16	12.0	0.24	12.0	0.23
								13.0	0.24		
Avg	**0.40**		**0.45**		**0.35**		**0.28**		**0.38**		**0.36**

1200		*1206*		*1212*		*1222*		*1232*		*1237*	
STA 1		**STA2**		**STA3**		**STA4**		**STA5**		**STA6**	
Depth (ft)	Speed (m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)
0.0	0.28	0.0	0.53	0.0	0.42	0.0	0.31	0.0	0.42	0.0	0.32
5.0	0.30	5.0	0.46	5.0	0.44	2.0	0.33	2.0	0.46	2.0	0.24
10.0	0.28	10.0	0.48	10.0	0.39	4.0	0.30	4.0	0.47	4.0	0.31
13.0	-0.18	15.0	0.42	15.0	0.33	6.0	0.32	6.0	0.45	6.0	0.31
		20.0	0.25	16.0	0.25	8.0	0.26	8.0	0.36	8.0	0.30
		21.5	0.21			10.0	0.28	10.0	0.36	10.0	0.20
						12.0	0.18	12.0	0.40	12.0	0.20
								14.0	0.30		
Avg	**0.17**		**0.39**		**0.37**		**0.28**		**0.40**		**0.27**

1256		*1303*		*1308*		*1317*		*1324*			
STA 1		**STA2**		**STA3**		**STA4**		**STA5**		**STA6**	

APPENDIX A. Bogue Inlet - Instantaneous current measurements via Marsh McBirney Flowmeter and Sontek ADP. [2 pages] 27-Jun-05

Bogue Inlet Old Channel (Stations 1-3); New Channel (Stations 4-6). (-) Ebb; (+) Flood

Time (EDT)

Depth (ft)	Speed (m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)
0.0	0.22	0.0	0.42	0.0	0.23	0.0	0.28	0.0	0.30	0.0	0.30
5.0	0.27	5.0	0.45	5.0	0.31	2.0	0.25	2.0	0.34	2.0	0.30
10.0	0.26	10.0	0.45	10.0	0.41	4.0	0.25	4.0	0.31	4.0	0.30
13.0	0.20	15.0	0.48	15.0	0.35	6.0	0.31	6.0	0.29	6.0	0.22
		20.0	0.39	16.0	0.30	8.0	0.29	8.0	0.27	8.0	0.20
		22.0	0.19			10.0	0.25	10.0	0.25	10.0	0.18
						12.0	0.20	12.0	0.20	12.0	0.12
								14.0	0.22		
Avg	**0.24**		**0.40**		**0.32**		**0.26**		**0.27**		**0.23**

1407		*1414*		*1417*		*1426*		*1435*		*1439*	
STA 1		**STA2**		**STA3**		**STA4**		**STA5**		**STA6**	
Depth (ft)	Speed (m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)
0.0	0.10	0.0	0.32	0.0	0.23	0.0	0.08	0.0	0.22	0.0	0.10
5.0	0.18	5.0	0.22	5.0	0.19	2.0	0.10	2.0	0.19	2.0	0.15
10.0	0.08	10.0	0.20	10.0	0.09	4.0	0.16	4.0	0.08	4.0	0.10
15.0	0.08	15.0	0.17	13.5	0.05	6.0	0.15	6.0	0.04	6.0	0.07
20.0	0.06	20.0	0.01			8.0	0.03	8.0	0.02	8.0	0.00
						10.0	0.04	10.0	0.04	10.0	0.05
						12.0	0.01	12.0	0.03	11.0	0.00
								14.0	0.00		
Avg	**0.10**		**0.18**		**0.14**		**0.08**		**0.08**		**0.07**

1456		*1501*		*1506*		*1515*		*1531*		*1536*	
STA 1		**STA2**		**STA3**		**STA4**		**STA5**		**STA6**	
Depth (ft)	Speed (m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)
0.0	-0.03	0.0	0.00	0.0	-0.09	0.0	-0.03	0.0	-0.29	0.0	-0.10
5.0	-0.04	5.0	0.00	5.0	-0.08	2.0	-0.04	2.0	-0.32	2.0	-0.18
10.0	-0.01	10.0	0.00	10.0	-0.07	4.0	-0.09	4.0	-0.34	4.0	-0.27
15.0	0.02	15.0	0.00	13.0	-0.04	6.0	-0.14	6.0	-0.34	6.0	-0.18
20.0	-0.06	20.0	0.00			8.0	-0.09	8.0	-0.25	8.0	-0.18
21.0	-0.05					10.0	-0.05	10.0	-0.23	10.0	0.00
								12.0	-0.20		
Avg	**-0.03**		**0.00**		**-0.07**		**-0.07**		**-0.28**		**-0.15**

1557		*1602*		*1606*		*1618*		*1625*		*1630*	
STA 1		**STA2**		**STA3**		**STA4**		**STA5**		**STA6**	
Depth (ft)	Speed (m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)
0.0	-0.20	0.0	-0.30	0.0	-0.12	0.0	-0.45	0.0	-0.98	0.0	-0.52
5.0	-0.25	5.0	-0.30	5.0	-0.20	2.0	-0.41	2.0	-0.90	2.0	-0.43
10.0	-0.26	10.0	-0.28	10.0	-0.18	4.0	-0.30	4.0	-0.90	4.0	-0.10
15.0	-0.18	15.0	-0.18	12.0	-0.12	6.0	-0.28	6.0	-0.82	6.0	-0.10
20.0	-0.20	20.0	-0.23			8.0	-0.20	8.0	-0.75		
25.0	-0.06							10.0	-0.80		
								11.0	-0.65		
Avg	**-0.19**		**-0.26**		**-0.16**		**-0.33**		**-0.83**		**-0.29**

1706		*1713*		*1719*		*1728*		*1736*		*1743*	
STA 1		**STA2**		**STA3**		**STA4**		**STA5**		**STA6**	
Depth (ft)	Speed (m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)	Depth (ft)	Speed(m/s)
0.0	-0.25	0.0	-0.55	0.0	-0.25	0.0	-0.92	0.0	-1.20	0.0	-1.05
5.0	-0.54	5.0	-0.57	5.0	-0.31	2.0	-0.93	2.0	-1.13	2.0	-1.03
10.0	-0.46	10.0	-0.52	10.0	-0.30	4.0	-0.92	4.0	-1.04	4.0	-0.95
15.0	-0.43	15.0	-0.41			6.0	-0.70	6.0	-0.96	6.0	-0.78
20.0	-0.40	20.0	-0.24			8.0	-0.55	8.0	-0.88	8.0	-0.75
24.0	-0.28					10.0	-0.25	10.0	-0.85	9.0	-0.83
Avg	**-0.39**		**-0.46**		**-0.29**		**-0.71**		**-1.01**		**-0.90**

1802	
STA 1	
Depth (ft)	Speed (m/s)
0.0	-0.50
5.0	-0.46
10.0	-0.44
15.0	-0.40
20.0	-0.28
23.0	-0.12
Avg	**-0.37**

APPENDIX B

Computed Flow Cross-sections
as a Function of Water Level

Bogue Inlet Line 119 - New Inlet Channel - Ac (Total)

Lenses	Invert	Re-invert
	Bottom (ft)	Bot (ft)
Lens 1	2.5	-2.50
Lens 2	2.25	-2.25
Lens 3	2	-2.00
Lens 4	1.75	-1.75
Lens 5	1.5	-1.50
Lens 6	1.25	-1.25
Lens 7	1	-1.00
Lens 8	0.75	-0.75
Lens 9	0.5	-0.50
Lens 10	0.25	-0.25
Lens 11	0	0.00
Lens 12	-0.25	0.25
Lens 13	-0.5	0.50
Lens 14	-0.75	0.75
Lens 15	-1	1.00
Lens 16	-1.25	1.25
Lens 17	-1.5	1.50
Lens 18	-1.75	1.75
Lens 19	-2	2.00
Lens 20	-2.25	2.25
Lens 21	-2.5	2.50
Lens 22	-2.75	2.75
Lens 23	-3	3.00

Offset (ft):	3,000.00
Cutoff:	None

Date	Lens	Unit Volume		Ac - ft^2	
		Lens (cy/ft)	Cumulative (cy/ft)	WL ft-NGVD	Cumulative (sq ft)
New Channel	1	369.89	369.89	-2.50	9,987
	2	10.83	380.72	-2.25	10,279
	3	10.86	391.58	-2.00	10,573
	4	10.88	402.46	-1.75	10,866
	5	10.91	413.37	-1.50	11,161
	6	10.94	424.31	-1.25	11,456
	7	435.27	435.27	-1.00	11,752
	8	10.99	446.26	-0.75	12,049
	9	11.01	457.27	-0.50	12,346
	10	11.04	468.31	-0.25	12,644
	11	11.07	479.38	0.00	12,943
	12	11.09	490.48	0.25	13,243
	13	501.59	501.59	0.50	13,543
	14	11.15	512.74	0.75	13,844
	15	11.17	523.91	1.00	14,146
	16	11.20	535.11	1.25	14,448
	17	11.22	546.34	1.50	14,751
	18	11.25	557.59	1.75	15,055
	19	568.86	568.86	2.00	15,359
	20	11.30	580.17	2.25	15,665
	21	11.33	591.50	2.50	15,970
	22	12.50	604.00	2.75	16,308
	23	12.50	616.50	3.00	16,645

Bogue Inlet Line 119 - Old Channel Section Ac (Total)

Lenses	Invert	Re-Invert
	Bot (ft)	Bottom (ft)
Lens 1	3.00	-3.00
Lens 2	2.75	-2.75
Lens 3	2.50	-2.50
Lens 4	2.25	-2.25
Lens 5	2.00	-2.00
Lens 6	1.75	-1.75
Lens 7	1.50	-1.50
Lens 8	1.25	-1.25
Lens 9	1.00	-1.00
Lens 10	0.75	-0.75
Lens 11	0.50	-0.50
Lens 12	0.25	-0.25
Lens 13	0.00	0.00
Lens 14	-0.25	0.25
Lens 15	-0.50	0.50
Lens 16	-0.75	0.75
Lens 17	-1.00	1.00
Lens 18	-1.25	1.25
Lens 19	-1.50	1.50
Lens 20	-1.75	1.75
Lens 21	-2.00	2.00
Lens 22	-2.25	2.25
Lens 23	-2.50	2.50

Offset (ft):	100.00
Cutoff:	650.00

		Unit Volume		Ac - ft^2	
Date	**Lens**	Lens (cy/ft)	Cumulative (cy/ft)	WL ft-NGVD	Cumulative (sq ft)
Old Channel	1	261.04	261.04	-3.00	7,048
	2	4.52	265.56	-2.75	7,170
	3	4.55	270.11	-2.50	7,293
	4	4.57	274.68	-2.25	7,416
	5	4.60	279.27	-2.00	7,540
	6	4.62	283.90	-1.75	7,665
	7	288.54	288.54	-1.50	7,791
	8	4.67	293.21	-1.25	7,917
	9	4.69	297.90	-1.00	8,043
	10	4.72	302.62	-0.75	8,171
	11	4.74	307.36	-0.50	8,299
	12	4.77	312.13	-0.25	8,427
	13	316.92	316.92	0.00	8,557
	14	4.81	321.73	0.25	8,687
	15	4.84	326.57	0.50	8,817
	16	4.86	331.43	0.75	8,949
	17	4.89	336.32	1.00	9,081
	18	4.91	341.23	1.25	9,213
	19	346.17	346.17	1.50	9,346
	20	4.96	351.13	1.75	9,480
	21	4.98	356.11	2.00	9,615
	22	5.00	361.11	2.25	9,750
	23	5.02	366.12	2.50	9,885

APPENDIX C

Tidal Prism Calculations
Method 1 and Method 2

Appendix C. Tidal Prism Calculation: Method 2- Superposition of First Part of Curve onto End

	Bogue Inlet Flow Study. June 27, 2005										
Min after		Old Channel		Min after		New Channel		Min after	Time	Tide Level
Midnight	Time	Q (ft^3/s)	Volume (ft^3)	Midnight	Time	Q (ft^3/s)	Volume (ft^3)	Midnight	Hrs-Min	True Ele (ft-NGVD)
438	7:18	-6,364	-11,645,256	467	7:47	-22,941	-28,906,002	422	7:02	-1.7
499	8:19	-3,965	-14,274,455	509	8:29	-18,560	-59,576,899	480	8:00	-1.3
558	9:18	-3,673	-11,680,588	574	9:34	-4,687	-17,014,007	527	8:47	-0.6
605	10:05	3,924	13,184,073	630	10:30	13,579	52,552,266	538	8:58	-0.5
670	11:10	12,636	45,867,620	703	11:43	16,445	59,201,770	558	9:18	-0.1
726	12:06	10,558	35,475,074	750	12:30	15,351	46,513,898	596	9:56	0.5
782	13:02	10,181	38,788,068	804	13:24	12,078	44,566,040	615	10:15	1.0
853	14:13	4,001	14,284,775	873	14:33	3,475	12,824,551	645	10:45	1.5
901	15:01	-863	-2,822,871	927	15:27	-7,527	-25,063,413	678	11:18	1.9
962	16:02	-5,948	-23,553,370	984	16:24	-20,140	-77,942,258	715	11:55	2.2
1033	17:13	-10,451	-40,443,587	1056	17:36	-32,448	-140,175,319	735	12:15	2.2
1091	18:11	-10,451	-40,443,587	1128	18:48	-20,140	-87,005,311	772	12:52	2.3
1162	19:22	-5,948	-20,698,416	1200	20:00	-4,584	-11,550,924	830	13:50	2.0
1207	20:07	0	0	1212	20:12	0	0	894	14:54	1.2
		Simple Averages	Totals			Averages	Totals	910	15:10	1.0
	(-) Ebb	-5,610	-127,961,831		(-) Ebb	-14,140	-341,737,225	947	15:47	0.6
	(+) Flood	8,260	147,599,609		(+) Flood	12,186	215,658,524	1012	16:52	-0.5
		Wt'd Averages				Wt'd Averages		1042	17:22	-1.0
		-7,217				-19,275		1072	17:52	-1.2
		8,381				12,246		1110	18:30	-1.3
								1130	18:50	-1.5
								1164	19:24	-1.4
								1180	19:40	-1.3
								1203	20:03	-1.1

Appendix C. Tidal Prism Calculation: Method 2- Superposition of First Part of Curve onto End

Bogue Banks Old Inlet Line 119

Hour	Seconds after midnig	Time (s)	Elevation (ft)	Cross- Sectional Area (ft^2) Total	sect. 1	sect. 2	sect. 3	Average Velocity (m/s) STA1	STA2	STA3	Discharge Rate (ft^3/s) STA1	STA2	STA3	Total	Discharge Volume (ft^3)
7:18	26280	1830	-1.62	7730	3289	2793	1648	-0.28	-0.30	-0.11	-3020.6	-2748.3	-594.6	-6363.5	-11,645,256
8:19	29940	3600	-1.20	7942	3365	2856	1721	-0.21	-0.13	-0.08	-2295.7	-1217.8	-451.6	-3965.1	-14,274,455
9:18	33480	3180	-0.31	8396	3528	2989	1879	-0.17	-0.13	-0.07	-1967.2	-1274.5	-431.4	-3673.1	-11,680,588
10:05	36300	3360	0.71	8928	3719	3142	2067	0.07	0.14	0.24	853.9	1442.8	1627.1	3923.8	13,184,073
11:10	40200	3630	1.79	9502	3925	3304	2273	0.40	0.45	0.35	5149.6	4876.7	2609.4	12635.7	45,867,620
12:06	43560	3360	2.17	9707	3999	3361	2347	0.26	0.39	0.37	3410.3	4299.4	2848.3	10558.1	35,475,074
13:02	46920	3810	2.22	9734	4008	3369	2357	0.25	0.40	0.32	3286.6	4420.1	2473.9	10180.6	38,788,068
14:13	51180	3570	1.69	9448	3906	3289	2253	0.08	0.18	0.14	1024.9	1941.8	1034.6	4001.3	14,284,775
15:01	54060	3270	1.08	9123	3789	3198	2136	-0.03	0.00	-0.07	-372.8	0.0	-490.4	-863.3	-2,822,871
16:02	57720	3960	0.32	8723	3646	3083	1994	-0.19	-0.26	-0.16	-2272.2	-2629.2	-1046.5	-5947.8	-23,553,370
17:13	61980	3870	-0.87	8104	3423	2904	1777	-0.39	-0.46	-0.29	-4378.7	-4381.6	-1690.3	-10450.5	-40,443,587
18:11	65460	3210	-1.26	7911	3354	2847	1710	-0.37	-0.56	-0.19	-4070.4	-5229.4	-1065.7	-10365.5	-33,273,114
19:00	68400	1470	-1.49	7751	3268	2812	1671	-0.34	-0.40	-0.19	-3665.9	-3698.6	-1063.3	-8427.8	-12,388,822
20:00	72000	1830	-1.62	7730	3289	2793	1648	-0.28	-0.30	-0.11	-3020.6	-2748.3	-594.6	-6363.5	-11,645,256
21:01	75660	3600	-1.20	7942	3365	2856	1721	-0.21	-0.13	-0.08	-2295.7	-1217.8	-451.6	-3965.1	-14,274,455
22:00	79200	3180	-0.31	8396	3528	2989	1879	-0.17	-0.13	-0.07	-1967.2	-1274.5	-431.4	-3673.1	-11,680,588
22:47	82020	2820	0.71	8928	3719	3142	2067	0.07	0.14	0.24	853.9	1442.8	1627.1	3923.8	11,065,204

	Simple Averages	Totals
(-) Ebb	-6,257	-150,082,062
(+) Flood	8,260	147,599,609
	Weighted Averages	
	-8,465	
	6,340	

Bogue Banks New Inlet Line 119

Hour		Time (s)	Elevation (ft)	Cross- Sectional Area (ft^2) Total	sect. 1	sect. 2	sect. 3	Average Velocity (m/s) STA4	STA5	STA6	Discharge Rate (ft^3/s) STA4	STA5	STA6	Total	Discharge Volume (ft^3)
7:47	28020	2520	-1.42	10877	3235	4059	3583	-0.62	-0.77	-0.52	-6578.7	-10251.4	-6111.2	-22941.3	-57,812,003
8:29	30540	3210	-0.90	11414	3401	4228	3785	-0.51	-0.57	-0.40	-5689.2	-7904.7	-4965.9	-18559.8	-59,576,899
9:34	34440	3630	0.12	11104	3305	4131	3668	-0.07	-0.21	-0.09	-758.8	-2845.4	-1082.8	-4687.1	-17,014,007
10:30	37800	3870	1.25	13643	4098	4927	4618	0.31	0.32	0.28	4166.8	5171.4	4241.2	13579.4	52,552,266
11:43	42180	3600	2.07	14616	4408	5229	4979	0.28	0.38	0.36	4048.3	6517.4	5879.2	16444.9	59,201,770
12:30	45000	3030	2.21	14648	4419	5239	4990	0.28	0.40	0.27	4058.4	6873.6	4419.1	15351.1	46,513,898
13:24	48240	3690	2.10	14533	4382	5203	4948	0.26	0.27	0.23	3737.0	4607.8	3732.8	12077.5	44,566,040
14:33	52380	3690	1.43	13831	4158	4985	4688	0.08	0.08	0.07	1091.1	1308.1	1076.4	3475.5	12,824,551
15:27	55620	3330	0.79	13262	3947	4778	4537	-0.07	-0.28	-0.15	-906.2	-4388.1	-2232.2	-7526.6	-25,063,413
16:24	59040	3870	-0.06	12284	3671	4502	4111	-0.33	-0.83	-0.29	-3973.5	-12256.2	-3910.4	-20140.1	-77,942,258
17:36	63360	4020	-1.12	11187	3331	4157	3699	-0.71	-1.01	-0.90	-7757.2	-13771.3	-10919.4	-32448.0	-130,440,921
18:38	67080	2940	-1.38	10919	3248	4072	3599	-0.56	-0.83	-0.74	-5965.9	-11125.7	-8782.7	-25874.3	-76,070,499
19:14	69240	1080	-1.42	10877	3235	4059	3583	-0.66	-0.68	-0.69	-6950.1	-9079.8	-8156.1	-24185.9	-26,120,825
20:14	72840	1230	-1.42	10877	3235	4059	3583	-0.62	-0.77	-0.52	-6578.7	-10251.4	-6111.2	-22941.3	-28,217,764
20:55	75300	3180	-0.90	11414	3401	4228	3785	-0.51	-0.57	-0.40	-5689.2	-7904.7	-4965.9	-18559.8	-59,020,105
22:00	79200	3630	0.12	11104	3305	4131	3668	-0.07	-0.21	-0.09	-758.8	-2845.4	-1082.8	-4687.1	-17,014,007
22:56	82560	3360	1.25	13643	4098	4927	4618	0.31	0.32	0.28	4166.8	5171.4	4241.2	13579.4	45,626,773

Indicates ADP data

	Averages	
(-) Ebb	-19,545	-439,889,793
(+) Flood	12,186	215,658,524
	Weighted Averages	
	-24,810	
	9,264	