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**Hydrodynamic Modeling in the Southern Coastal Bays:
Water level monitoring, September 7-October 12, 2004**

by
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Introduction

Chincoteague Bay is considered to be the most pristine of the Delmarva coastal bays. However, recent monitoring studies of the coastal bays have documented problems with low dissolved oxygen (DO) in Chincoteague Bay. In order to identify the cause of the low DO, additional information is needed on nutrient cycling within the coastal bays. The first step to developing a sophisticated ecological model for the bays is determining the hydrodynamic processes that control the circulation of the nutrients and the distribution of free-floating phytoplankton and macroalgae.

Over the past decade, the Army Corps of Engineers, Engineer Research & Development Center, Coastal & Hydraulics Laboratory (CHL) has been developing a comprehensive circulation model for the North Atlantic. This numeric model has been fine-tuned in the Ocean City Inlet area by increasing the computational mesh resolution in the vicinity of the Inlet and collecting current and tide data for model calibration. This fine-tuning was done to support of the Corps' rehabilitation of the South Jetty (Ocean City Inlet) and various projects relating to the Constructions Phase of the Ocean City and Vicinity Water Resource Project.

The Maryland Department of Natural Resources under a MCBP Implementation grant, initiated a project to collect additional tide and current data needed to refine the grid size and validate the model in Chincoteague, Newport and Sinepuxent Bays. This project consisted of two study components conducted over a one-month period:

- 1) The University of Maryland, Center for Environmental Science (UMCES) monitored currents velocities at Chincoteague and Ocean City Inlets utilizing both fixed Acoustic Doppler Current Profilers (ADCP) and towed ADCPs;
- 2) Concurrent with the UMCES ADCP monitoring, the Maryland Geological survey recorded water levels at four locations in the southern bays.

Descriptions of the instrumentation and methods used by the Maryland Geological Survey to collect the water level data are presented in this report.

Study Area

The study area encompassed Sinepuxent and Chincoteague Bays, located on the Atlantic coast of Maryland and Virginia (Figure 1). Sinepuxent Bay is north of and contiguous with Chincoteague Bay. Assateague Island separates Chincoteague and Sinepuxent Bays from the Atlantic Ocean. The northern two-thirds of Chincoteague Bay lie within Maryland. Two outlets connect the bays to the Atlantic Ocean: Ocean City Inlet located at the northern end of Sinepuxent Bay; and Chincoteague Inlet in Virginia to the south.

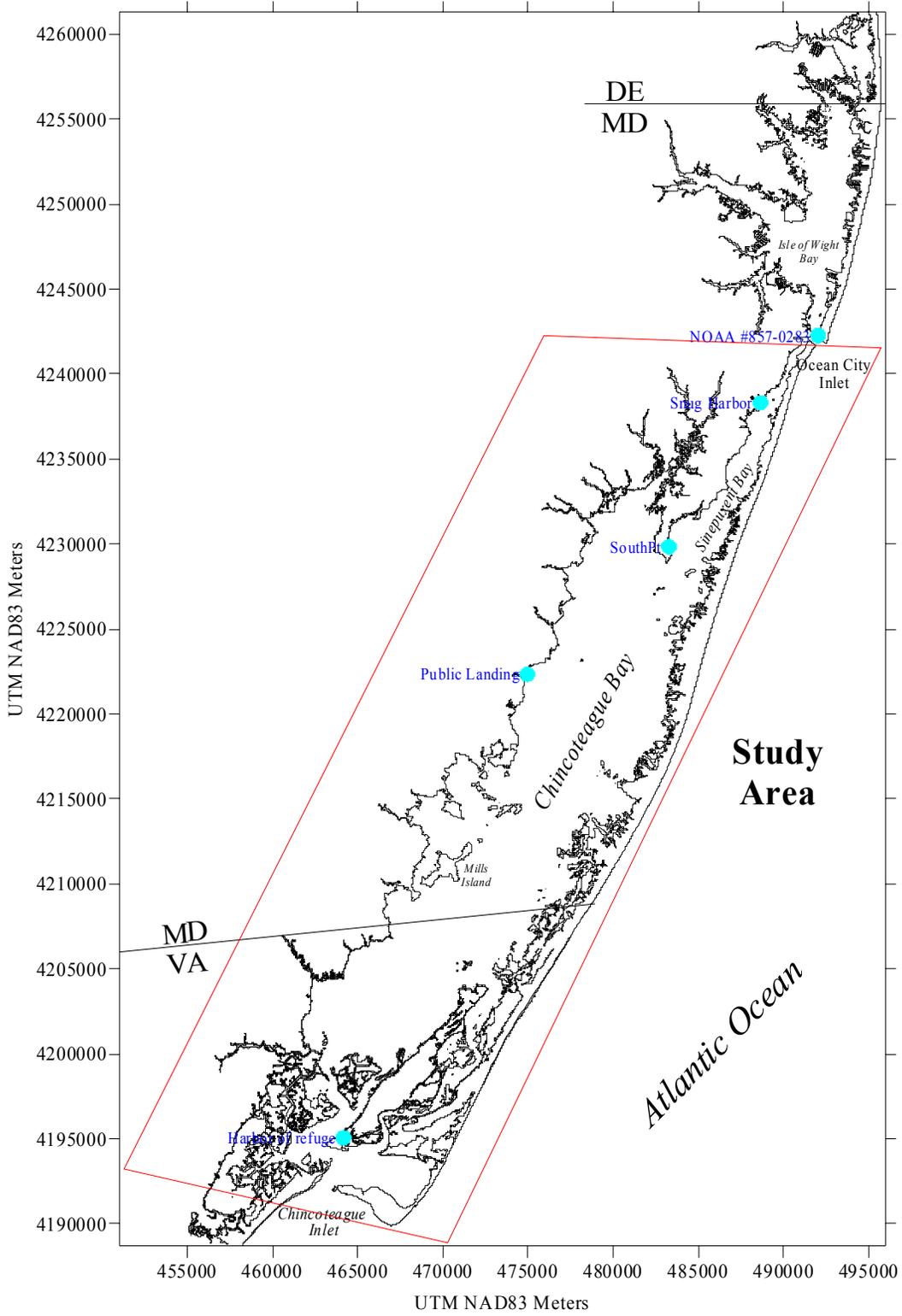


Figure 1. Study area showing locations of the water level recorders (blue dots).

Methods

Locations

Water level recorders were installed and operated at four locations within the study area: Snug Harbor and South Point, both located in Sinepuxent Bay; Public Landing located in Maryland portion of Chincoteague Bay; and Harbor of Refuge, located at the south tip of Chincoteague Island in Virginia (Figure 1). Locations of the water level recorders were selected to provide adequate coverage to study area reflecting the range of tides. The three locations within Maryland were sites at which MGS deployed WLR for previous studies (Wells and Ortt, 2002, Wells and others, 2004). Vertical control was available at these sites. Information such as UTM coordinate location, times of deployment and elevations for each water level recorder site are listed in Table 1.

Equipment

Water level data were collected using instruments manufactured by Global Water Instrumentation, Incorporated. Two models were used: GL400 logger with WL300 or WL400 sensor; and WL15 combined unit. Both systems consist of a data logger interfaced with a sensor for remote monitoring and recording of water level data. The level sensor is a submersible pressure transducer consisting of a solid-state pressure sensor encapsulated in a stainless steel submersible 3/4" diameter housing. The sensor is connected to the data logger by a 25-ft., molded-on waterproof cable that is vented to the atmosphere. The vent to the atmosphere minimized offsets caused by barometric changes. The reported accuracy of the sensor is +/- 0.2% full scale (range 0-15 ft, 35° F to 70° F) (Global Water Instrumentation, Inc., 2002c). Time accuracy of the data loggers is reported to be 0.0015% (Global Water Instrumentation, Inc., 2002b, 2002c).

To minimize noise from wave activity, each water level sensor was mounted in a "stilling well" which consisted of a 5-foot length of 3-inch PVC pipe. The sensor was affixed to the inside wall of the pipe. The level above the sensor was marked in 1-foot intervals on the outside of the pipe. The top and bottom of the PVC pipe were capped. To allow slow passage of water between the inside and outside of the pipe, four 1/8" holes were drilled through the PVC wall near the bottom of the pipe and two 1/8" holes at the top of the pipe. The PVC pipe was securely mounted on a piling, with the bottom of the pipe positioned on or just above the sediment surface.

The GL400 data logger was housed in a 254mm x 191mm x 114mm water resistant "pelican" box. The WL15's data logger, contained in a 7/8" diameter x 12" length weather-resistant cylindrical enclosure, was inserted in a 2" PVC pipe for mounting on site. The data loggers were mounted above the respective stilling wells where possible. After installation, the horizontal position of each water level recorder was determine, ± 3.0 meters, using a hand-held GPS unit (no differential correction) and recorded as UTM coordinates (NAD83, meters). Photographs of the water level recorder at each site are presented in Appendix A.

The data loggers were programmed to take a reading every minute or every two minutes, depending on the data logger model. Because of limited memory of the data loggers, data was downloaded weekly. A handheld PDA running Palm OS was used to download data from the units in the field (Global Water Instrumentation, Inc., 2002a). Time of day was synchronized with GPS time when water level data were downloaded to the palm pilot and data loggers were reset. Data output from the loggers included date (MM/DD/YYYY), time of day (UTC-hh:mm:ss), and water level (0.001 ft) in comma-delimited ASCII format. In the office, the water level data were transferred to PC and imported in MS Excel for verification and processing. Water level data were reduced to six-minute observations, by averaging consecutive water level readings taken over a 6-minute interval. Depending on how often measurement were taken (*e.g.*, every minute or every two minutes), averages were based on six or three readings. When a six minute interval was truncated during the downloading procedure, Time posted for the 6-minute average corresponds to the time of the last water level reading used in the average. Water level observations for the four locations are presented in space-delimited text (ASCII) files.

Elevation determinations of water level recorders

Each water level recorder site was surveyed to determine elevation of the water level sensor relative to NAVD88. One or more benchmarks (BM) were used at each recorder site and relative elevations between the BMs and 4 ft reference marks on the stilling well of the recorders were determined by differential leveling. Elevations (NAVD88) of the water level recorder (water level sensors) are listed in Table 1.

Table 1. Information on water level recorders deployed in this study. Station locations, identified by Sta #, are shown in Figure 1. Elevations for water level sensors were derived by differential leveling surveys (see Appendix A).

Sta #	Sta ID	Water Level logger model-serial # Sensor model-serial #	Date installed	Date removed	UTM NAD83-meters		Elevation of Water Level Sensor NAVD88-feet	Location-description/ Comments
					Northing	Easting		
1	Snug Harbor	GL400-#15304 WL400-#35033	9/8/04	10/12/04	4238320	488644	-1.105 ± 0.02	WLR mounted on bulkhead on north side of south harbor
2	South Pt.	WL15- 35032	9/7/04	10/12/04	4229842	483269	-1.98 ± 0.05	WLR mounted on south side bulkhead at South Pt. Boat Ramp, Sinepuxent Bay
3	Public Landing	GL400-#15303 WL300b-#5582	9/7/04	10/12/04	4222330	474972	-2.78 ± 0.0	WLR on public pier at end of Route 365, Public Landing
4	Harbor of Refuge, Chincoteague Island, Va.	WL15- 35031	9/9/04	10/12/04	4195066	464173	-2.63 ± 0.01	WLR on pilings at end of western-most pier in harbor

Quality Assurance of data

The manufacturer calibrated the water level recorders prior to shipping. Calibrations were confirmed in the field prior to deployment and again at the end of the study. Calibration check prior to deployment indicated that the recorders were accurately measuring water levels and time, and that the units were within 0.03 ft of each other. Appendix B details the results of the calibration checks.

At Snug Harbor, South Pt. and Public Landing, a metal 5-ft tide staff was mounted next to the stilling wells. The tide staffs, marked in 0.1-ft intervals, were mounted so that the 4.0 ft. mark lined up with 4- ft mark on the stilling wells. The tide staffs were used to verify the readings from the data recorders when downloading in the field. At Harbor of Refuge, an existing tide staff, located at the boat ramp, was used as a field check.

Problems

During this study, we did not encounter any serious problems with the recorders until we downloaded the South Point recorder (WL15-#35032) on October 8, 2004. The recorder was giving negative readings, which we attributed to bio-fouling or moisture collecting in venting cable. Based on the water level record from that download, the problem started 9/30/04 at 21:26. Data after that time was discarded.

When we opened the stilling well for #35032 in the lab, we discovered that several inches of sediment had accumulated in the bottom of the stilling well, burying the tip of the sensor. Post calibration check revealed that the sensor was off by more than a foot (-1.2 ft).

Post deployment calibrations for WL15-#35031 indicated the sensor was still in calibration. The results of the post deployment calibrations for WLR #15303 and WLR #15304 were inconsistent. Comparisons of sensor readings to staff readings at those locations suggest the accuracy of readings may have deteriorated toward the end of deployment (after September 30). However, any deterioration is not discernable in plots of the data (Figure 2).

Discussion

The water level data were collected over the period from September 7 to October 12, 2004. This time period includes the fall equinox (September 23), at which time, higher than normal tides are expected. Spring tides occurred on September 14 and 28 and neap tides were on Sept. 21 and Oct. 6. The study area was affected by two storm systems, remnants of Hurricane Ivan and Jeanne, on September 18-19 and 28-29, respectively. The extremely low water levels observed at South Point and Public Landing on the 18th may have been a result of steady winds during the first storm (Figure 2).

Observed tide ranges are similar to those published for the locations (Table 2). The observed tide range at Harbor of Refuge is 2.5 to 2.75 feet. Tide ranges in Chincoteague Bay are much smaller, depending on distance from the inlets. Mean tide range in Chincoteague Bay (South Point, Public Landing) is 6 to 8 inches. The tide range increases slightly toward Chincoteague Island in Virginia. Based on tide delays within the Bay (Wells and others, 2004), the point at which tidal influence is equal between the inlets is just south of Public Landing. Tides at Chincoteague Inlet are approximately 30 minutes to an hour behind Ocean City Inlet tides.

Table 2. Published tidal datums for Chincoteague Bay (from NOAA, 2004).

Station#	Name	State	UTM, NAD83, m		Mn	Gt
			Northing	Easting		
857-0280	Ocean City Fishing Pier	MD	4242076	492748	3.36	3.89
857-0283	Ocean City, Isle of Wright Bay	MD	4242632	492166	2.19	2.54
857-0284	Sinepuxent Bay	MD	4240600	490270	1.84	1.90
857-0563	South Point	MD	4229700	483254	0.46	0.65
857-0649	Public Landing	MD	4222325	475061	0.53	0.71
863-0316	Harbor of Refuge	VA	4195181	464280	2.43	2.81

Mean Range (Mn) = MHW-MLW

Gross Mean Range (Gt) = MHHW - MLLW

Water levels in southern Coastal Bays

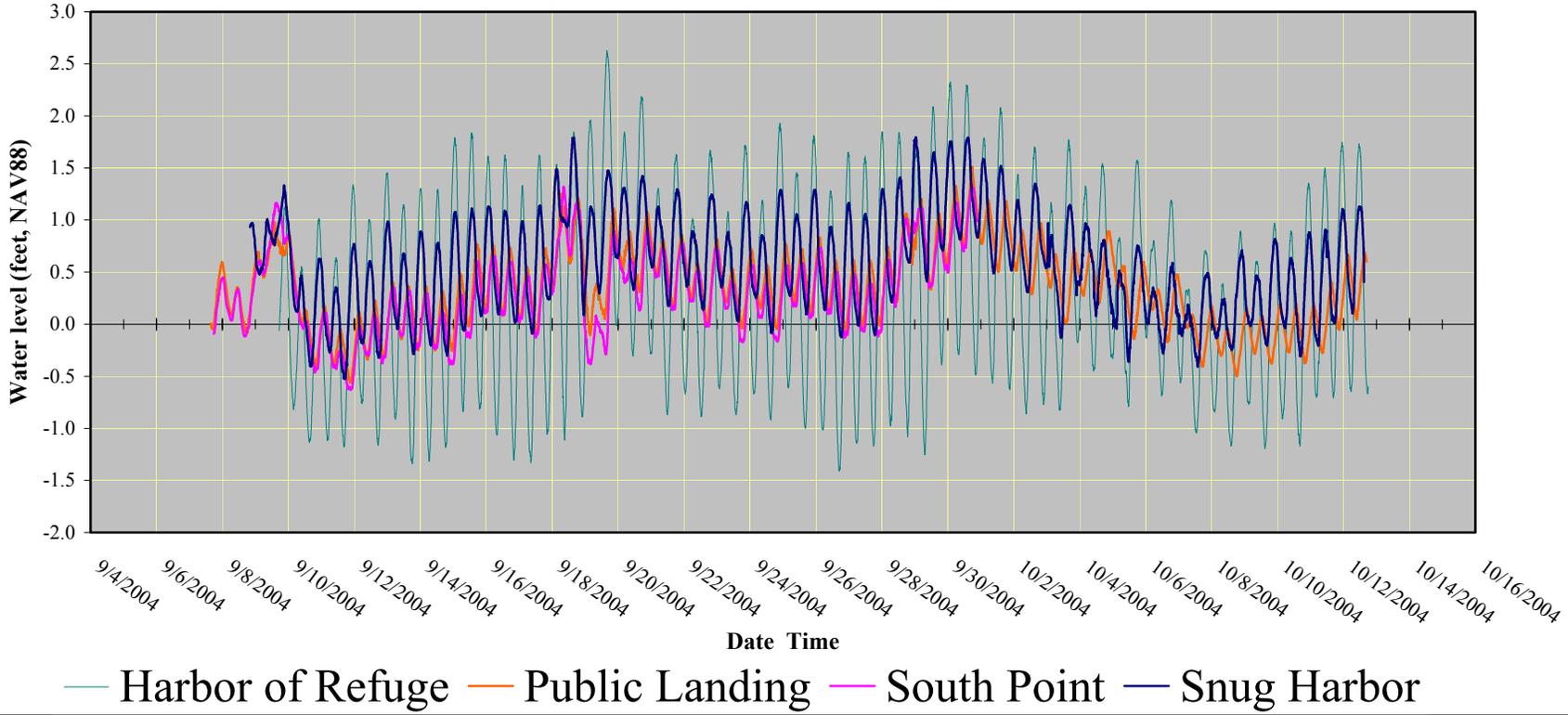


Figure 2. Comparison of water levels collected at the four stations.

References

- Global Water Instrumentation, Inc., 2002a, PLM: Global Logger for Palm OS, March 15, 2002, PDF format, 45 pp.
- Global Water Instrumentation, Inc., 2002b, GL400: Datalogger User's Guide, April 26, 2002, PDF format, 41 pp.
- Global Water Instrumentation, Inc., 2002c, WL15: Water Level Logger User's Guide, June 5, 2002, PDF format, 40 pp.
- Maryland Department of Natural Resources (DNR), 2004, Maryland Coastal Bays Volunteer Water Quality Monitoring Program web site:
<http://www.dnr.state.md.us/coastalbays/volunteer/stations.html>
- NOAA, 2004, NOS, CO-OPS web site: Retrieve Observed Water Levels and Associated Ancillary Data: http://140.90.78.170/data_res.html
- Wells, D.V., and Ortt, R.A., Jr., 2001, Bathymetric survey of Assawoman Bay, St. Martin River, Sinepuxent Bay and Newport Bay (Coastal and Estuarine Geology File Report No. 01-2): Maryland Geological Survey, Baltimore, Md., on Compact Disk (CD-ROM).
- Wells, D.V., Ortt, R.A., Jr., VanRyswick, S., Conkwright, R.D., and Offerman, K.A., 2004, Bathymetric survey of the Maryland portion of Chincoteague Bay, (Coastal and Estuarine Geology File Report No. 04-4): Maryland Geological Survey, Baltimore, Md., on Compact Disk (CD-ROM).

Appendix A
Site information on water level recorders

Snug Harbor

MGS installed and operated a water level recorder at this site in 2000 during hydrographic surveys of Sinepuxent Bay (Wells and Ortt, 2001).

Table a-1. Elevation determination of water level sensor at Snug Harbor						
Date surveyed: 9/9/04						
Location of WLR: E 488644 N 4238320 UTM, Meters, NAD83						
Pk Nail: E 488642 N 4238360 UTM, Meters, NAD83						
Point ID	Hi	+	-	Elevation NAVD88, ft.		Comments
Pk Nail *	8.02	5.27		2.75		Centerline of Snug Harbor Rd.
4' Nail			5.125	2.895		
Top of dock			6.33	1.69	1.73	x-brace end dock
WL Sensor				-1.105		
*Know elevation = 2.75 +/- 0.20 ft. NAVD88 from 2000 survey by DNR Public Lands Group; P.K. nail may not be same as the original one??						



Figure A-1. Aerial photograph of Snug Harbor showing location of water level recorder. Aerial photograph was taken April, 1989



Figure A-2. The stilling well was mounted on a piling and the recorder box (GL400) was placed under ornamental grass plantings (shown in photo to the right). The water depth at this location is approximately 2 feet.



Figure A-3. The water level recorder was installed on a privately owned bulkhead located on north side of the east end of the south canal at Snug Harbor (see aerial photo on previous page).

Table A-2. Snug Harbor Global Water Level Recorder WL400 15304: UTM E 488644 N 4238320					
Date Installed: 9/8/04 Date Removed: 10/12/04					
File has two columns: date / time (mm/dd/yyyy hh:mm:ss), water level (ft); times in UTC					
File name	Start		Stop		Comments
	Date	Time	Date	Time	
Installation	9/8/04	~19:00	9/8/04	~20:00	Same Piling as in 2000 Tide Staff = 2.00' WLR=2.02'
15304_09_09_04_21_18_38	9/8/04	19:58:45	9/9/04	21:18:32	Reset at 21:22, Tide Staff = ~2.5' +/- 0.2' WLR=2.385' 1523 data points
15304_09_15_04_18_59_49	9/9/04	21:23:03	9/15/04	18:59:43	Reset at 18:42, Replaced battery with #9 Tide Staff = 1.3' WLR=1.276' 8499 data points
15304_09_21_04_16_06_53	9/15/04	19:13:13	9/21/04	16:06:39	Reset at 16:24, Replaced battery #9 12.72V With # 3 13.19V Tide Staff = 2.1' WLR=2.112' Changed to log every 2 min 8458 data points
15304_09_30_04_16_17_13	9/21/04	16:23:56	9/30/04	16:17:03	Reset at ~16:30, Replaced battery #3 12.57V With # 6 13.15V Tide Staff = 2.6' WLR=2.590' 6478 data points

Table A-2. Snug Harbor Global Water Level Recorder WL400 15304: UTM E 488644 N 4238320					
Date Installed: 9/8/04 Date Removed: 10/12/04					
File has two columns: date / time (mm/dd/yyyy hh:mm:ss), water level (ft); times in UTC					
File name	Start		Stop		Comments
	Date	Time	Date	Time	
15304_10_08_04_17_27_36	9/30/04	16:27:23	10/8/04	17:27:06	Reset at ~17:42 Battery #6 OK 12.93V Tide Staff = 1.25' WLR=1.55' (1.39' based on 1 st reading of next download) 9167 data points
15304_10_12_04_15_05_26	10/8/04	17:46:03	10/12/04	15:05:22	Time of download: 15:05 Tide Staff = 1.74' WLR=1.783' 2802 data points Removed WLR

South Point

NOAA NOS operated tide gauge (#857-0536) at this location in 1976 for the marine boundary program. NOS tide data and bench mark information for this site are available for this location at NOS web site: http://140.90.78.170/data_res.html

Table A-3. Elevation determination of water level sensor at South Point boat ramp						
Date surveyed: 9/9/04						
Location of WLR: E 483269 N 4229842 UTM, Meters, NAD83						
NOS BM 857 536 A: E 483233 N 4229838						
NOS BM 857 0536 B E 483189 N 4229845						
Point ID	Hi	+	-	Calculated Elevation	Known elevation*	Comments
NOS BM 857 0536 B	6.85	3.63			3.26 ±0.05	Under Cedars
NOS BM 857 0536 A			5.22	1.63	1.65±0.05	Note: top disk loose
4' Nail			4.83	2.02		
WL Sensor				-1.98		
*Elevation (NAVD88) determined by DNR Engineering in 2000 (Wells and Ortt, 2001)						



Figure A-4. Aerial photograph of the South Point public boat ramp, showing location of water level recorder. Aerial photograph was taken April, 1989

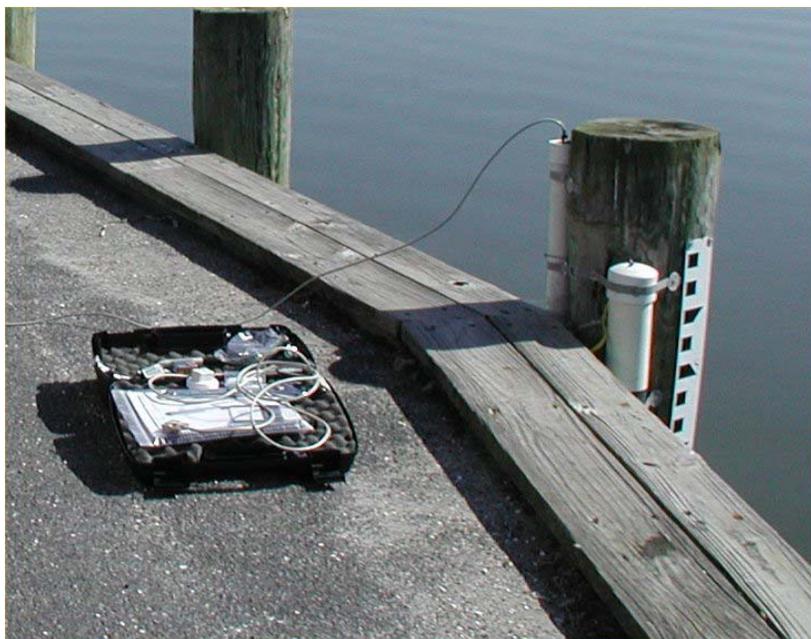


Figure A-5. Downloading water level data from WL15 data logger (housed in) to a hand-held PDA. The data logger is housed in the PVC tubing mounted on left side of the piling.

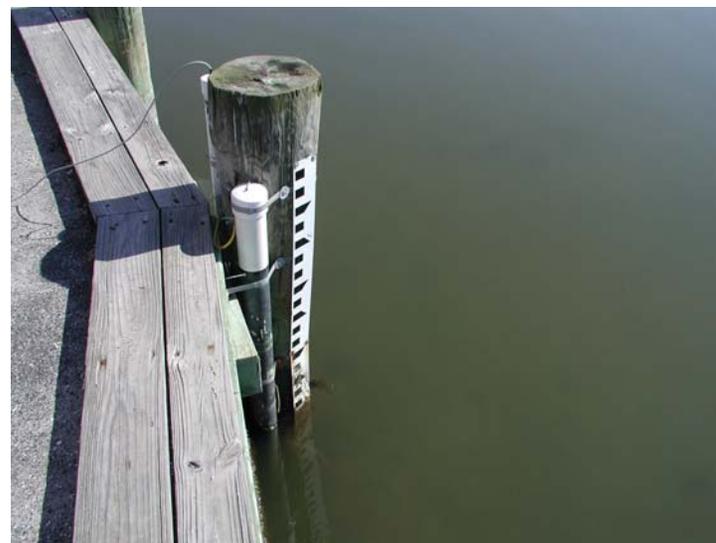


Figure A-6. The water level sensor is mounted in the bottom of a stilling well consisting of a 5-foot length of 3-inch PVC pipe. Also shown is a 5-foot tide staff. The water level is the photograph is approximately 2.2 feet.

Table A-4. South Point Global Water Level Recorder WL15X 35032: UTM N 4229842 E 483269

Date Installed: 9/7/04 Date Removed: 10/12/04

File has two columns: date / time (mm/dd/yyyy hh:mm:ss), water level (ft)

File	Start		Stop		Comments
	Date	Time	Date	Time	
Installation	9/7/04	16:00	9/7/04	17:40	17 th Piling from end of Bulkhead Tide Staff = 1.8' WLR=1.884' Replaced 9V battery: New reads 9.80V Replaced Absorbent Pack
35032_09_09_04_20_49_12	9/7/04	17:36:39	9/9/04	20:49:03	Reset at 19:48, Tide Staff = 2.78' WLR=2.773' 3074 data points
35032_09_15_04_18_35_00	9/9/04	20:55:03	9/15/04	18:34:52	Reset at 18:42 Tide Staff = 2.5' WLR=2.490' 8502 data points
35032_09_21_04_16_40_58	9/15/04	18:43:03	9/21/04	16:40:49	Reset at 16:50 Tide Staff = 2.14' WLR=2.133' 8519 data points
35032_09_30_04_14_28_54	9/21/04	16:50:20	9/30/04	14:28:03	Reset at 14:43 Tide Staff = 3.0 WLR=3.038 12818 data points

Table A-4. South Point Global Water Lever Recorder WL15X 35032: UTM N 4229842 E 483269

Date Installed: 9/7/04 Date Removed: 10/12/04

File has two columns: date / time (mm/dd/yyyy hh:mm:ss), water level (ft)

File	Start		Stop		Comments
	Date	Time	Date	Time	
35032_10_08_04_15_05_19	9/30/04	14:44:03	10/8/04	15:05:02	Reset at 16:36 Tide Staff = 1.55' WLR=1.03' 11543 data points SENSOR FOULED----BAD DATA starting at row 33318 (9/30/04 21:25)
35032_10_12_04_15_49_35	10/8/04	16:29:50	10/12/04	15:49:07	Tide Staff = 2.58' WLR=1.469' 5723 data points SENSOR FOULED----BAD DATA Recorder Removed @ 15:54

Public Landing

NOAA NOS operated tide gauge (#857-0649) at this location in 1976-1977 for the marine boundary program. NOS tide data and benchmark information for this site are available for this location at NOS web site: http://140.90.78.170/data_res.html In 2003, Maryland State Highways Department resurveyed (2nd order) tidal benchmarks to determine geodetic elevations (NAVD88) and submitted datasheets to NOAA for the National Geodetic Survey database . Copies of the preliminary data sheets are presented in Appendix C.

Table A-5. Elevation determination of water level sensor at Public Landing						
Date surveyed: 9/9/04						
Location of WLR: E 474972 N 4222330 UTM, Meters, NAD83						
NOS BM 857 0649 A 1985 E 474832 N 4222407						
OC9 E 474834 N 4222385						
Location	Hi	+	-	Calculated Elevation	Known Elevation	Comments
BM on steps	11.30	1.60			9.70	NOS 0649 A 1985
OC 9		2.20		9.10	9.10	Not a NOS tidal Bench mark
TP _F			7.04	4.26		
NE corner top of lamp post			5.87	5.43		
TP _B	8.90	4.64				Tripod on pier
TP _F			4.83	4.07		
TP _B	8.54	4.47				
WLR						
Top of Pier			4.58	4.07		
4' Nail			7.32	1.22		
Sensor				-2.78		NAVD88, ft
CLOSE						
TP _F			4.47	4.07		
TP _B	8.97	4.90				
TP _F			5.02	3.95		
TP _B	11.36	7.41				
OC 9			2.26	9.10	9.10	
BM Steps			1.66	9.70	9.70	



Figure A-7. Aerial photograph of Public Landing, showing location of water level recorder. Aerial photograph was taken April, 1989



Figure A-8. The water level recorder was mounted on the third light pole on the county recreation pier at Public Landing. The GL400 data recorder, which was housed in a weather resistant box, was mounted on the pole above the pier.

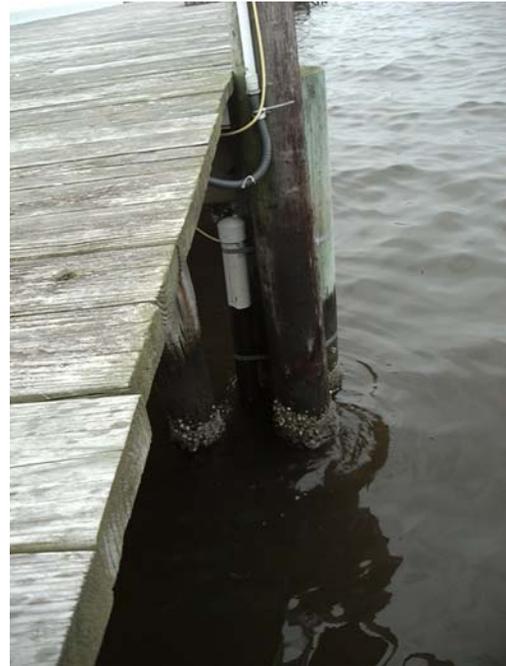


Figure A-9. The stilling well containing the water level sensor was attached to a support piling next the light pole. Water depth is approximately 3 feet.

Table A-6. Public Landing Global Water Level Recorder WL300 15303: UTM N 4222330 E 474972

Date Installed: 9/7/04 Date Removed: 10/12/04

File has two columns: date / time (mm/dd/yyyy hh:mm:ss), water level (ft)

File	Start		Stop		Comments
	Date	Time	Date	Time	
Installation	9/7/04	14:00	9/7/04	15:45	Tide Staff = ~2.8' (very choppy) WLR=2.800' Time Sync @ 15:37:30 Battery #1: 12.96 V
15303_09_09_04_19_38_09	9/7/04	15:38:17	9/9/04	19:37:03	Reset at 19:48, Tide Staff = 3.3 – 3.4' (waves ½ ft.) WLR=3.524' 3120 data points
15303_09_15_04_17_08_40	9/9/04	19:49:03	9/15/04	16:57:03	Reset at 17:09, Replaced Battery Tide Staff = ??? (water extremely choppy) WLR=3.554' 8471 data points
15303_09_21_04_17_45_24	9/15/04	17:22:00	9/21/04	17:37:16	Reset at 17:58, Replaced Battery # 5 12.92V with# 4 13.46V Tide Staff = 3.0' WLR=3.149' Switched to log every 2 min 8659 data points
15303_09_29_04_21_37_09	9/21/04	17:59:04	9/29/04	21:36:03	Reset at ~21:50, Replaced Battery # 4 12.76V with# 5 13.15V Tide Staff = 3.3' WLR=3.443' 5872 data points

Table A-6. Public Landing Global Water Lever Recorder WL300 15303: UTM N 4222330 E 474972

Date Installed: 9/7/04 Date Removed: 10/12/04

File has two columns: date / time (mm/dd/yyyy hh:mm:ss), water level (ft)

File	Start		Stop		Comments
	Date	Time	Date	Time	
15303_10_07_04_20_21_19	9/29/04	21:49:06	10/7/04	20:21:10	Reset at ~20:27, Tide Staff = 2.5' WLR=2.656' 5718 data points
15303_10_12_04_16_44_47	10/7/04	20:32:15	10/12/04	16:44:03	Tide Staff = 3.3' WLR=3.387' 3487 data points Recorder Removed @ 16:52

Harbor of Refuge, Chincoteague Island, Va.

NOAA NOS operated tide gauge (#863-0316) at this location in 1977 for the marine boundary program. NOS tide data and bench mark information for this site are available for this location at NOS web site: http://140.90.78.170/data_res.html However, we could not find any of the original NOS tidal bench marks at the time we were surveying in the recorder.

Table A-7. Elevation determination of water level sensor at Harbor of Refuge					
Date surveyed: 9/9/04					
WLR:		E 464173 N 4195066 UTM, Meters, NAD83			
BM stamped "BASIN 1 1984"***:		E 464413 N 4195200			
Rebar:		E 464313 N 4095026			
Location	Hi	+	-	Elevation	Comments
BM (Basin1 1984)	11.24	4.49		6.75	MLLW (NTDE '60-78)***
TP _F			5.02	6.22	
TP _B	11.59	5.37			
TP _F			3.69	7.90	
TP _B	12.32	4.42			
Rebar			3.80	8.52	
TP _F			5.97	6.35	
TP _B	10.43	4.08			
Nail end of Bulkhd			5.05	5.38	On 1 st Piling
4 ft. Nail			7.10	3.33	WayPT 55
WL Sensor				-0.67 MLLW	-2.63 NAVD88
Close - Harbor of Refuge					
	10.43	+	-		
TP _B			4.12	6.31	
TP _F	11.86	5.55			
Rebar			3.35	8.51	
TP _B			4.28	7.66	
TP _F	11.15	3.49			
BASIN1 1984			4.41	6.74	+ 0.01
**Bench mark stamped "BASIN 1 1984, Norfolk District, US Army Corps of Engineers"					
*** Elevation from Eric Legaspi, project manager for Chincoteague Bay navigation project, Norfolk District, USACE, ph: 757-441-1017. Bench mark was established by Norfolk District.					
MLLW based on NOAA datums (NTDE '60-'78) derived from tide gauge (Sta ID 863-0316) located at Harbor of Refuge in 1977. Based on the datum, MLLW is 1.14 feet below NGVD. Tidal datums were linked to NGS datums at two tidal bench marks for the tide station: PID# FW0142 and PID# FW0143. Based on NGS updated data sheets for those two bench marks, NAVD88 is 1.96 ft above MLLW and 0.82 ft above NGVD.					

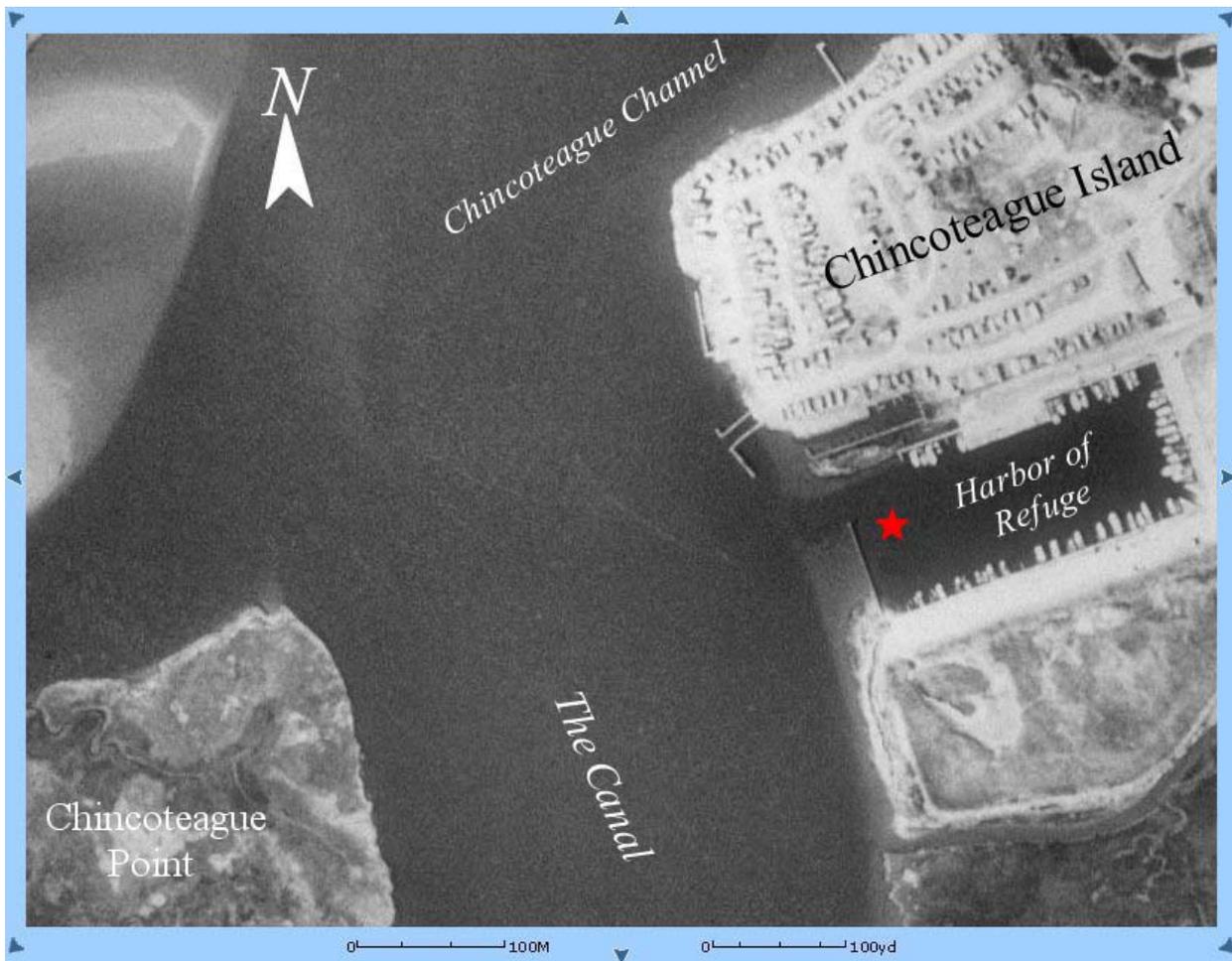


Figure A-10. Aerial photograph of Harbor of Refuge, showing approximate location of water level recorder. Aerial photograph was taken April, 1989, before the construction of the longer piers in the harbor. The recorder was mounted on the end of the pier closest to the harbor entrance (see photos next page).



Figure A-11. The water level recorder was attached to a set of three pilings at the end of the pier closest to the harbor entrance (above photograph- red square indicating the location of the recorder).



Figure A-12. The WL15 data logger, which was inserted in 2" PVC pipe, was mounted on the piling (noted in photograph to the left). The stilling well containing the water level sensor was mounted between the pilings below the pier (not visible in photograph). The water depth at this location is approximately 11 feet.

Table A-8. Harbor of Refuge Global Water Level Recorder WL15X 35031:

Date Installed: 9/9/04

Date Removed: 10/12/04

File has two columns: date / time (mm/dd/yyyy hh:mm:ss), water level (ft)

UTM N 4195066 E 464173

File	Start		Stop		Comments
	Date	Time	Date	Time	
35031_09_15_04_15_33_22	9/9/04	17:09:54	9/15/04	15:30:03	Reset at 15:40, Tide Staff = 2.80' WLR=3.648' 8542 data points
35031_09_22_04_21_28_10	9/15/04	15:42:03	9/22/04	21:28:03	Reset at 21:41, Tide Staff = 2.9' WLR=3.760' 10428 data points
35031_09_29_04_20_08_38	9/22/04	21:43:03	9/29/04	20:08:20	Reset at ~20:20, Tide Staff = 1.6' WLR=2.416' 9987 data points
35031_10_07_04_17_17_36	9/29/04	20:23:44	10/7/04	17:17:03	Reset at ~17:29, Tide Staff = 2.30' WLR=3.303' 11335 data points
35031_10_12_04_18_05_19	10/7/04	17:30:03	10/12/04	18:03:32	Tide Staff = 1.0' WLR=2.067' 7236 data points Recorder Removed @ 18:12

Appendix B
Quality Assurance/Quality Control

Initial Calibration Check

Global Water Instrumentation, Inc originally calibrated the water level sensors. The calibration was done over a depth range of 0 to 15 feet, and in ‘fresh’ water (0 ‰ salinity). Prior to deployment for this study, calibration of each unit was verified and compared with the other units. Calibration check was done after the level sensors were mounted in the stilling well. The still wells were set at the same depth, affixed to a dock located in an interior canal in the Ocean Pines Community and allowed to record one-minute observations for several days. Water levels for Unit #15304 were consistently lower than the other unit, so we recalibrated that unit (depth range 0 to 4 ft) in the canal.

Comparisons of the water level data from each of the recorders indicate good agreement with each other (Figure B-1) and with observed water levels in the canal. For a given time, the readings varied (maximum average standard deviation) within 0.027 ft of each other units. Average differences between units ranged from 0.002 ft to 0.044 ft, with the maximum difference in readings being 0.08 ft. We attributed any differences between recorder readings and actual depths to the fact that the original calibrations were done in water with 0 ppt salinity. We did not measure the salinity in the private canal during the initial calibration check. The salinity in an Ocean Pines canal can range from 15 ppt to over 30 ppt, depending in time of year and amount of rainfall (DNR, 2004). A change from 0 ppt salinity to 30 ppt salinity in 3 feet of water will yield an offset of 0.07 feet (assuming constant water temperature). Given the tide ranges and water depths encountered during this study, the actual offsets would be smaller. For this study, we did not correct water level readings for salinity or temperature.

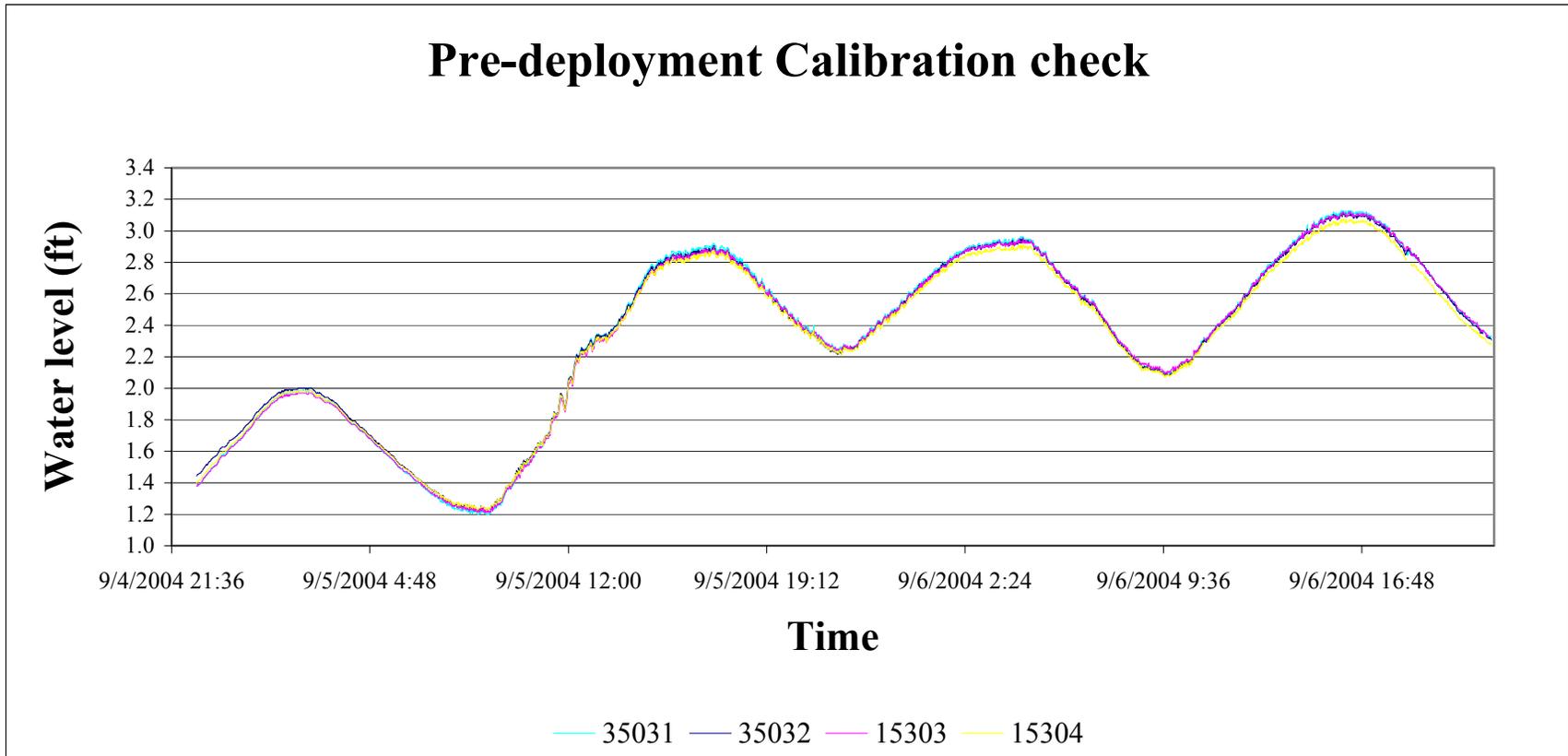


Figure B-1. Comparisons of the water level readings obtained from each recorder during pre- deployment calibration check.

Field check and Post- deployment calibration check

During the study, real-time output from each water level recorder was compared to tide staff observation at the time data was retrieved from the recorders (downloaded). At the end of the study, calibration of each recorder was checked in laboratory. Level sensors were removed from the stilling wells and cleaned. Calibration check was done in a plexiglas tube (1.77 meters high, 0.15 meters inside diameter) filled with deionized water.

Unit WL15-#35031-used at Harbor of Refuge, Chincoteague Island, Virginia

Table B-1. Unit WL15-#35031 Post-deployment calibration check Date: 10/15/2004	
Known depth	Instrument reading
0	0.008
0.5	0.506
1.2	1.22
1.5	1.519
2	2.05
2.5	2.524
3	3.063
3.5	3.536
4	4.076
4.5	4.557
5	5.072

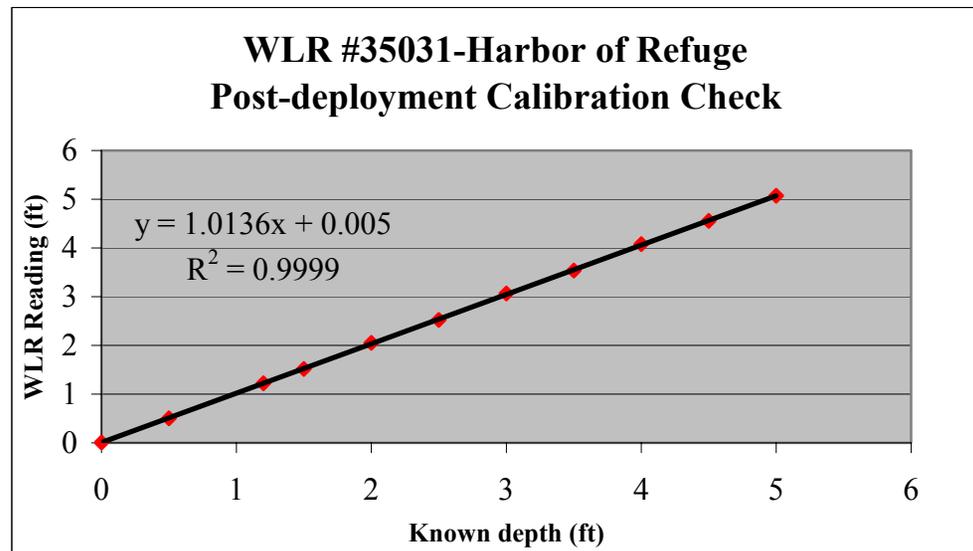


Figure B-2 . Plot of the instrument readings against the know depths obtained during the post deployment calibration check (Table B-1). Shown is the regression line for the data set.

Unit WL15-#35032-used at South Point

Table B-2. Field check			
Instrument reading vs. tide staff reading			
Date	Tide Staff	WLR	Comments
9/7/2004	1.8	1.884	Choppy water
9/9/2004	2.78	2.773	
9/15/2004	2.5	2.49	
9/21/2004	2.14	2.133	
9/30/2004	3	3.038	
10/8/2004	1.55	1.03	See note below
10/12/2004	2.58	1.469	

Note: On 10/8/04, after downloading, the recorder was reading a negative number, indicating a real problem. We noticed a thick covering of algae on the stilling well and tide staff. After cleaning the stilling well, subsequent recorder readings were positive, but still ~0.5 ft below that of tide staff. When we opened the stilling well in the lab, we discovered that several inches of sediment had accumulated in the bottom of stilling well, burying the tip of the sensor. Post- deployment calibration check revealed that the sensor was off by more than a foot (-1.2 ft).

WLR#15303 - used at Public Landing

Table B-3. Field check			
Instrument reading vs. stadia reading			
Date	Tide Staff	WLR	Comments*
9/7/2004	2.8	2.8	very choppy
9/9/2004	3.4	3.524	choppy- 1/2 ft waves
9/15/2004	???	3.554	extremely choppy
9/21/2004	3.0	3.149	choppy- 1/2 ft waves
9/29/2004	3.3	3.443	
10/7/2004	2.5	2.656	
10/12/2004	3.3	3.387	

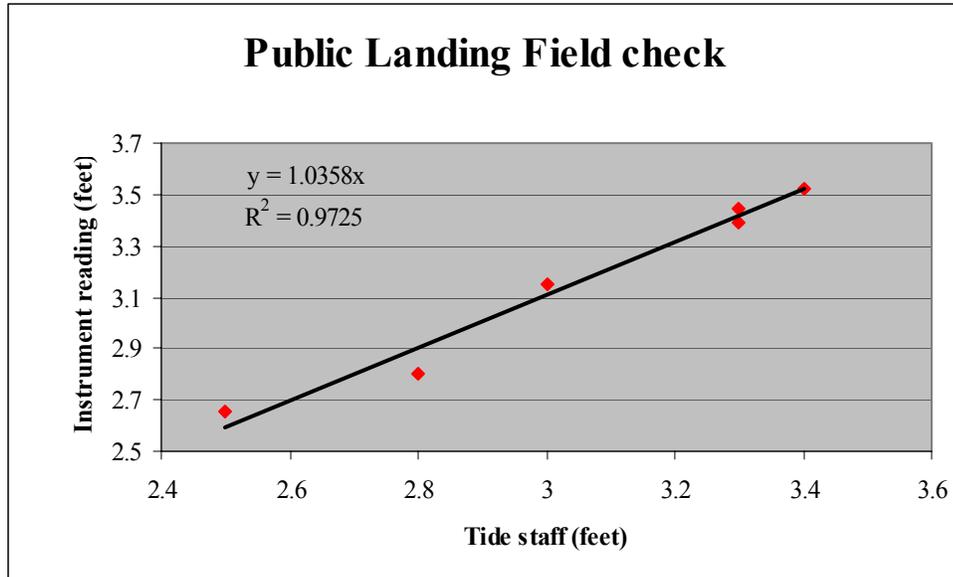


Figure B-3 . Plot of the recorder readings against the tide staff observations at Public Landing (see table above). Shown is the regression line for the data set.

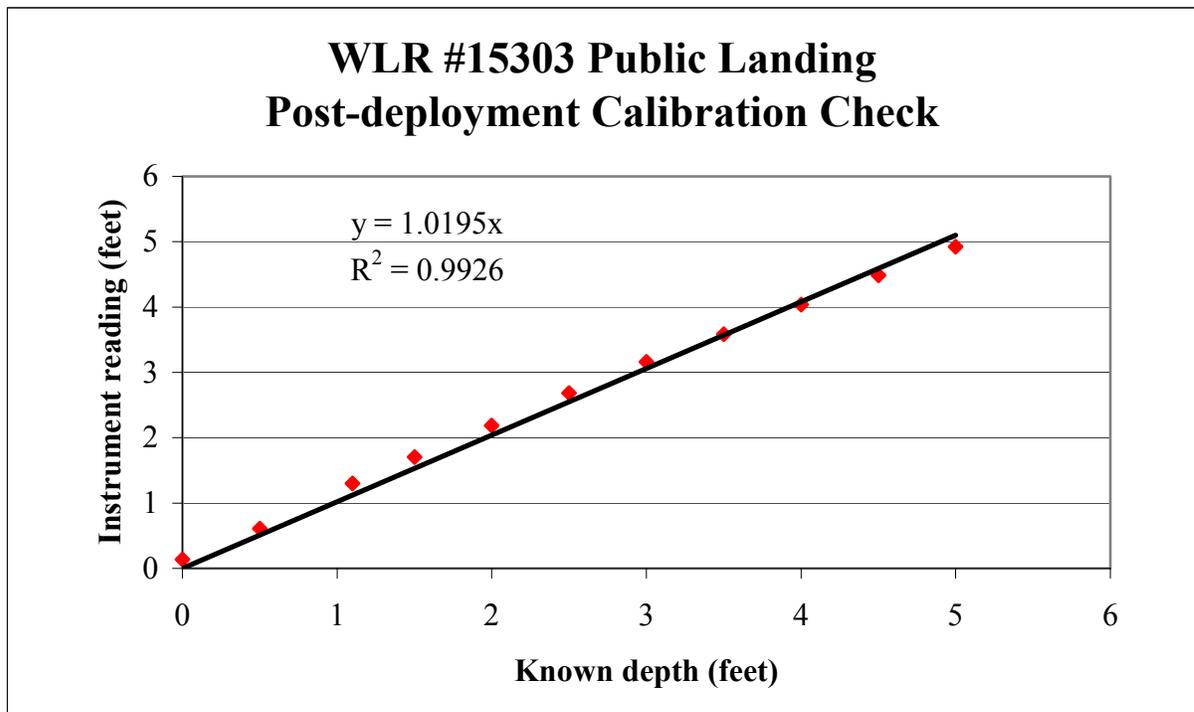


Figure B-4. Plot of the recorder readings against the know depths obtained during the post-deployment calibration check. Shown is the regression line for the data set. At the time of calibration check, sensor reading was off ± 0.1 feet. However, field calibration check suggests that readings were 0.1 foot higher than actual water level. We had a problem getting an accurate tide staff reading at this location due to wave action. The bay water surface at this location was often “confused” and very choppy. We noted this phenomenon during previous studies.

Unit WLR#15304 -used at Snug Harbor

Table B-4. Field check			
Instrument reading vs. tide staff reading			
Date	Tide Staff	WLR	Comments
9/8/2004	2	2.02	
9/9/2004	2.5	2.385	Choppy water
9/15/2004	1.3	1.276	
9/21/2004	2.1	2.112	
9/30/2004	2.6	2.59	
10/8/2004	1.25	1.39	????
10/12/2004	1.74	1.783	

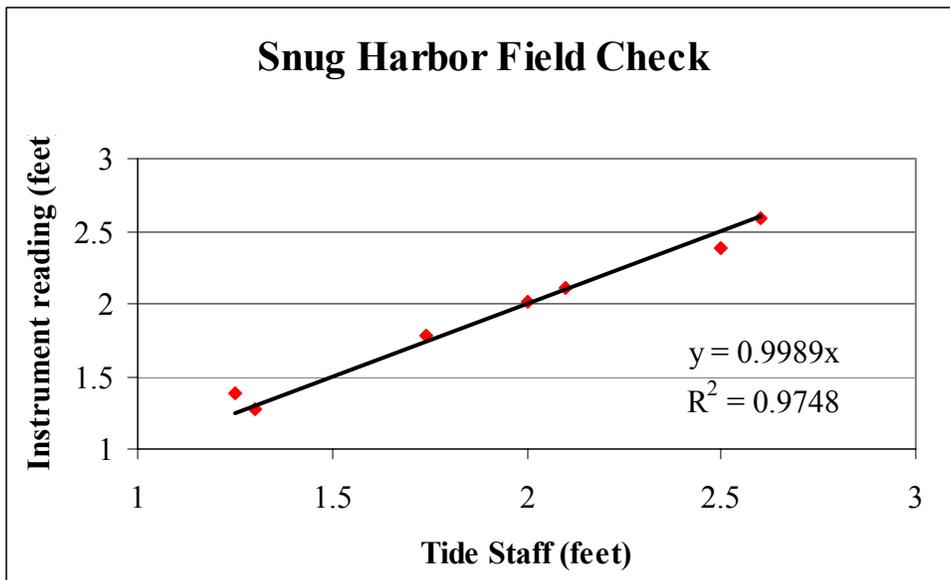


Figure B-5 . Plot of the recorder readings against the tide staff observation (See Table B-4). Shown is the regression line for the data set.

WLR#15304 Snug Harbor Post-deployment Calibration Check

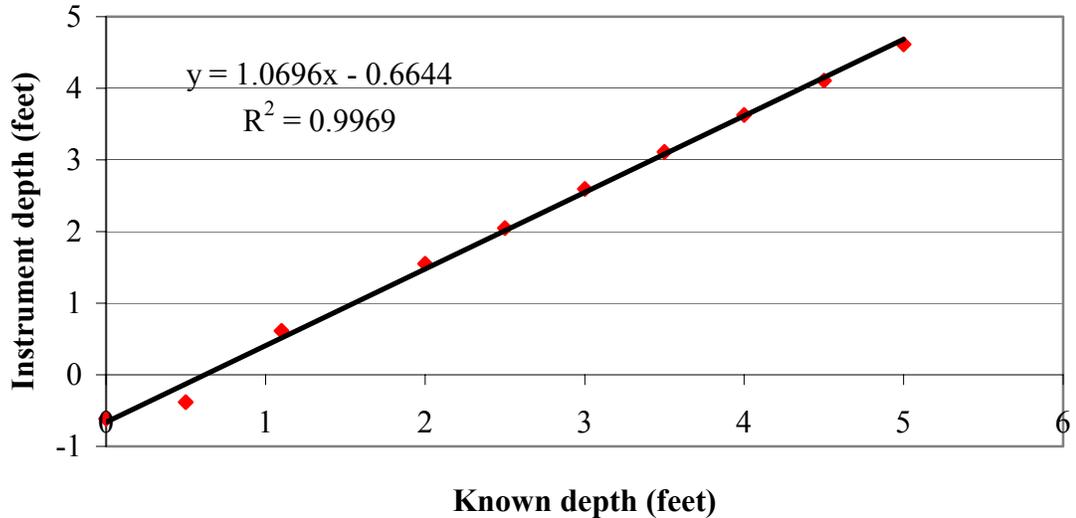


Figure B-6 . Plot of the recorder readings against the know depths obtained during the post-deployment calibration check. Shown is the regression line for the data set. At the time of the post-deployment calibration check, the sensor was reading approximately 0.5 ft lower that actual depth. However, field calibration check did not indicate a problem.

Appendix C

Benchmark Data Sheets

I. Preliminary data sheets for NOS tidal benchmarks at Public Landing, surveyed by the Maryland Department of Transportation, State Highways Administration in 2003. The data sheets were submitted to the National Oceanic and Atmospheric Administration (NOAA) National Geodetic Survey (NGS) database.

II. Data sheet for Benchmark at Harbor of Refuge

1

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MD0004 *****
MD0004 DESIGNATION - 857 0649 A
MD0004 PID - MD0004
MD0004 STATE/COUNTY- MD/WORCESTER
MD0004 USGS QUAD -
MD0004
MD0004 *CURRENT SURVEY CONTROL
MD0004
MD0004* NAD 83(1991)- 38 08 57.2 (N) 075 17 14.3 (W) SCALED
MD0004* NAVD 88 - 2.958 (meters) 9.70 (feet) ADJUSTED
MD0004
MD0004 VERT ORDER - SECOND CLASS I
MD0004
MD0004;
MD0004; SPC MD - North East Units Estimated Accuracy
MD0004; SPC MD - 180,362. 1,804,854. sFT (+/- 500 feet Scaled)
MD0004; SPC MD - 54,974. 550,120. MT (+/- 180 meters Scaled)
MD0004
MD0004.The horizontal coordinates were determined by AGPS and have an
MD0004.estimated accuracy of +/- 1 seconds.
MD0004
MD0004.The orthometric height was determined by differential leveling and
MD0004.adjusted by the Maryland State Highway Administration and is subject to
MD0004.final adjustment by the National Geodetic Survey.
MD0004
MD0004_MARKER: DJ = TIDAL STATION DISK
MD0004_SETTING: 30 = CONCRETE STEP
MD0004_STAMPING: 0649 A 1985
MD0004_STABILITY: D = MARK OF QUESTIONABLE OR UNKNOWN STABILITY
MD0004_SATELLITE: THE SITE LOCATION WAS REPORTED AS NOT SUITABLE FOR
MD0004+SATELLITE: SATELLITE OBSERVATIONS - 20031217
MD0004
MD0004 HISTORY - Date Condition Recov. By
MD0004 HISTORY - 1985 MONUMETED NOS
MD0004 HISTORY - 20031217 GOOD MDSHA
MD0004
MD0004 STATION RECOVERY (2003)
MD0004
MD0004'THE STATION IS LOCATED IN THE TOWN OF PUBLIC LANDING.
MD0004'TO REACH THE STATION FROM THE COURTHOUSE IN SNOW HILL, GO NORTHEAST
MD0004'ALONG BUSINESS U.S. 113 FOR 0.15 MI (0.24 KM) TO STATE HIGHWAY 365.
MD0004'TURN RIGHT AND GO SOUTHEAST ALONG STATE HIGHWAY 365 FOR 5.3 MI
MD0004'(8.53 KM) TO PUBLIC LANDING.
MD0004'THE STATION IN NOS TIDAL BENCH MARK DISK SET FLUSH IN THE BOTTOM
MD0004'CONCRETE STEP ON THE SOUTH SIDE OF THE DRISCOLL RESIDENCE, 37.3 FT
MD0004'(11.4 M) SOUTHEAST OF THE EXTENDED CENTER LINE OF BAYSIDE ROAD,
MD0004'27.3 FT (8.3 M) NORTHWEST OF A 24 INCH (61 CM) CEDAR TREE, 25.3 FT
MD0004'(7.7 M) NORTHEAST OF THE CENTER LINE OF STATE HIGHWAY 365. NOTE= VM
MD0004'NUMBER

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1

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MD0005 *****
MD0005 DESIGNATION - 857 0649 18 WDK RES 1976
MD0005 PID - MD0005
MD0005 STATE/COUNTY- MD/WORCESTER
MD0005 USGS QUAD -
MD0005
MD0005 *CURRENT SURVEY CONTROL
MD0005
MD0005* NAD 83(1991)- 38 08 58.0 (N) 075 17 16.5 (W) SCALED
MD0005* NAVD 88 - 2.758 (meters) 9.05 (feet) ADJUSTED
MD0005
MD0005 VERT ORDER - SECOND CLASS I
MD0005
MD0005;
MD0005; SPC MD - North East Units Estimated Accuracy
MD0005; SPC MD - 180,440. 1,804,676. SFT (+/- 500 feet Scaled)
MD0005; SPC MD - 54,998. 550,066. MT (+/- 180 meters Scaled)
MD0005
MD0005
MD0005.The horizontal coordinates were determined by AGPS and have an
MD0005.estimated accuracy of +/- 1 seconds.
MD0005
MD0005.The orthometric height was determined by differential leveling and
MD0005.adjusted by the Maryland State Highway Administration and is subject to
MD0005.final adjustment by the National Geodetic Survey.
MD0005
MD0005_MARKER: DS = TRIANGULATION STATION DISK
MD0005_SETTING: 30 = CONCRETE BASE
MD0005_STAMPING: 18 WDK 1963 RESET 1976
MD0005_STABILITY: D = MARK OF QUESTIONABLE OR UNKNOWN STABILITY
MD0005_SATELLITE: THE SITE LOCATION WAS REPORTED AS NOT SUITABLE FOR
MD0005+SATELLITE: SATELLITE OBSERVATIONS - 20031217
MD0005
MD0005 HISTORY - Date Condition Recov. By
MD0005 HISTORY - 1976 MONUMETED CGS
MD0005 HISTORY - 20031217 GOOD MDSHA
MD0005
MD0005 STATION RECOVERY (2003)
MD0005
MD0005'THE STATION IS LOCATED IN THE TOWN OF PUBLIC LANDING.
MD0005'TO REACH THE STATION FROM THE COURTHOUSE IN SNOW HILL, GO NORTHEAST
MD0005'ALONG BUSINESS U.S. 113 FOR 0.15 MI (0.24 KM) TO STATE HIGHWAY 365.
MD0005'TURN RIGHT AND GO SOUTHEAST ALONG STATE HIGHWAY 365 FOR 5.3 MI
MD0005'(8.53 KM) TO PUBLIC LANDING.
MD0005'THE BENCH MARK IS SET IN A 2 FOOT SQUARE CONCRETE BASE OF AN
MD0005'ABANDONED POLE, 153 FT (46.6 M) NORTHWEST OF THE CENTERLINE OF
MD0005'BAYSIDE ROAD, 21.7 FT (6.6 M) SOUTHWEST OF THE CENTER LINE OF STATE
MD0005'HIGHWAY 365 AND 4.0 FT (1.2 M) EAST OF POWER POLE 163. NOTE=VM
MD0005'NUMBER 3033

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1

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MD0006 *****
MD0006 DESIGNATION - 857 0649 C
MD0006 PID - MD0006
MD0006 STATE/COUNTY- MD/WORCESTER
MD0006 USGS QUAD -
MD0006
MD0006 *CURRENT SURVEY CONTROL
MD0006
MD0006* NAD 83(1991)- 38 09 00.7 (N) 075 17 19.8 (W) SCALED
MD0006* NAVD 88 - 3.320 (meters) 10.89 (feet) ADJUSTED
MD0006
MD0006 VERT ORDER - SECOND CLASS I
MD0006
MD0006; North East Units Estimated Accuracy
MD0006; SPC MD - 180,708. 1,804,408. sFT (+/- 500 feet Scaled)
MD0006; SPC MD - 55,080. 549,985. MT (+/- 180 meters Scaled)
MD0006
MD0006 The horizontal coordinates were determined by AGPS and have an
MD0006 estimated accuracy of +/- 1 seconds.
MD0006
MD0006 The orthometric height was determined by differential leveling and
MD0006 adjusted by the Maryland State Highway Administration and is subject to
MD0006 final adjustment by the National Geodetic Survey.
MD0006
MD0006_MARKER: DJ = TIDAL STATION DISK
MD0006_SETTING: 00 = STAINLESS STEEL ROD
MD0006_STAMPING: 0649 1985 C
MD0006_STABILITY: D = MARK OF QUESTIONABLE OR UNKNOWN STABILITY
MD0006_SATELLITE: THE SITE LOCATION WAS REPORTED AS SUITABLE FOR
MD0006+SATELLITE: SATELLITE OBSERVATIONS - 20031217
MD0006
MD0006 HISTORY - Date Condition Recov. By
MD0006 HISTORY - 1985 MONUMETED NOS
MD0006 HISTORY - 20031217 GOOD MDSHA
MD0006
MD0006 STATION RECOVERY (2003)
MD0006
MD0006' THE STATION IS LOCATED IN THE TOWN OF PUBLIC LANDING.
MD0006' TO REACH THE STATION FROM THE COURTHOUSE IN SNOW HILL, GO NORTHEAST
MD0006' ALONG BUSINESS U.S. 113 FOR 0.15 MI (0.24 KM) TO STATE HIGHWAY 365.
MD0006' TURN RIGHT AND GO SOUTHEAST ALONG STATE HIGHWAY 365 FOR 5.3 MI
MD0006' (8.53 KM) TO PUBLIC LANDING.
MD0006' THE STATION IN NOS TIDAL BENCH MARK DISK CRIMPED TO A STAINLESS
MD0006' STEEL ROD DRIVEN AN UNSPECIFIED DEPTH AND ENCASED IN A 5 INCH
MD0006' (13 CM) PVC PIPE AND CONCRETE KICKBLOCK. IT IS 91.0 FT (27.7 M)
MD0006' NORTHWEST OF THE CENTER LINE OF OUTTEN ROAD, 39.0 FT (11.9 M)
MD0006' NORTHEAST OF THE CENTER LINE OF STATE HIGHWAY 365 AND 2.3 FT (0.7 M)
MD0006' SOUTHWEST OF POWER POLE 120 AND ABOUT 0.5 FT (0.2 M) BELOW THE
MD0006' GROUND LEVEL. NOTE=VM NUMBER 3036

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1

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MD0007 *****
MD0007 DESIGNATION - 857 0649 D
MD0007 PID - MD0007
MD0007 STATE/COUNTY- MD/WORCESTER
MD0007 USGS QUAD -
MD0007
MD0007 *CURRENT SURVEY CONTROL
MD0007
MD0007* NAD 83(1991)- 38 09 03.6 (N) 075 17 24.5 (W) SCALED
MD0007* NAVD 88 - 3.814 (meters) 12.51 (feet) ADJUSTEDSCALED
MD0007
MD0007 VERT ORDER - SECOND CLASS I
MD0007
MD0007; North East Units Estimated Accuracy
MD0007;SPC MD - 180,994. 1,804,027. sFT (+/- 500 feet Scaled)
MD0007;SPC MD - 55,167. 549,868. MT (+/- 180 meters Scaled)
MD0007
MD0007
MD0007.The horizontal coordinates were determined by AGPS and have an
MD0007.estimated accuracy of +/- 1 seconds.
MD0007
MD0007.The orthometric height was determined by differential leveling and
MD0007.adjusted by the Maryland State Highway Administration and is subject to
MD0007.final adjustment by the National Geodetic Survey.
MD0007
MD0007_MARKER: DJ = TIDAL STATION DISK
MD0007_SETTING: 00 = STAINLESS STEEL ROD
MD0007_STAMPING: 0649 D 1985
MD0007_STABILITY: D = MARK OF QUESTIONABLE OR UNKNOWN STABILITY
MD0007_SATELLITE: THE SITE LOCATION WAS REPORTED AS SUITABLE FOR
MD0007+SATELLITE: SATELLITE OBSERVATIONS - 20031217
MD0007
MD0007 HISTORY - Date Condition Recov. By
MD0007 HISTORY - 1985 MONUMETED NOS
MD0007 HISTORY - 20031217 GOOD MDSHA
MD0007
MD0007 STATION RECOVERY (2003)
MD0007
MD0007'THE STATION IS LOCATED IN THE TOWN OF PUBLIC LANDING.
MD0007'TO REACH THE STATION FROM THE COURTHOUSE IN SNOW HILL, GO NORTHEAST
MD0007'ALONG BUSINESS U.S. 113 FOR 0.15 MI (0.24 KM) TO STATE HIGHWAY 365.
MD0007'TURN RIGHT AND GO SOUTHEAST ALONG STATE HIGHWAY 365 FOR 5.3 MI
MD0007'(8.53 KM) TO PUBLIC LANDING.
MD0007'THE STATION IN NOS TIDAL BENCH MARK DISK CRIMPED TO A STATINLESS
MD0007'STEEL ROD DRIVEN 32 FT (9.8 M) AND ENCASED IN A 5-INCH (13 CM) PVC
MD0007'PIPE AND CONCRETE KICKBLOCK. IT IS 0.2 MI (0.32 KM) NORTHWEST OF
MD0007'BAYSIDE ROAD, 171.5 FT (52.3 M) NORTHWEST OF POWER POLE 118,
MD0007'154.7 FT (47.2 M) SOUTHEAST OF POWER POLE 117, 104.0 FT (31.7 M)
MD0007'NORTHEAST OF THE NORTH CORNER OF A 2 STORY FRAME DWELLING (HAMAKERS
MD0007'RESIDENCE), AND 34.5 FT (10.5 M) NORTHEAST OF THE CENTER LINE OF THE
MD0007'HIGHWAY AND ABOUT 0.5 FT (0.2 M) BELOW THE LEVEL OF THE GROUND.
MD0007'NOTE= VM NUMBER 3037
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**MONUMENT DESCRIPTION FORM
U.S. ARMY
CORPS OF ENGINEERS
NORTH ATLANTIC DIVISION
NORFOLK DISTRICT**

NAME OF STATION: BASIN 1	COUNTY, STATE: ACCOMAC COUNTY, VA
ESTABLISHED BY: PARTY: HYDRO CHIEF: RPK	YEAR: 1984
LOCALITY: CHINCOTEAGUE, VA	QUAD: CHINCOTEAGUE WEST
CHARACTER OF MARK: ALUM PIPE	STAMPING: BASIN1 1984
HORZ. X VERT. X Elevation is 6.75 feet above NDS MLLW, NTDE 1960-1978	
DETAILED DESCRIPTION: APPROACHING CHINCOTEAGUE ISLAND TURN RIGHT AT STOP LIGHT PROCEED DOWN S MAIN ST. TO HARBOR REFUGE BASIN TURN LEFT AT REC CENTER OF INLET VIEW CAMP GRND MON IS APPROX 300' FROM TURN MON LIES BETWEEN 5 th & 6 th WOOD PILINGS OF THE CHAIN LINKED FENCE REFS: MON IS APPROX 50' FROM WHERE WOOD FENCE & CHAIN FENCE MEET " " 4' FROM CHAIN LINK FENCE MON IS 79.2' SSE OF REF 1 - A CORNER FENCE POST W/ NAIL IN IT " " 7.4' SSW OF REF 2 - 5 th CHAIN FENCE POST W/ NAIL IN CENTER OF TRIANGLE MON IS 6' NW OF REF 3 - 6 th CHAIN FENCE POST W/ NAIL IN CENTER OF TRIANGLE	

SKETCH:

