NOAA Technical Report NOS CO-OPS 076

Water Level Variations at Poplar Island, MD

Silver Spring, Maryland

April 2015

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U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

Center for Operational Oceanographic Products and Services
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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Water Level Variations at Poplar Island, MD

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April 2015

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INTRODUCTION

Poplar Island, once on the verge of disappearing due to sediment erosion and sea level rise, is today a national model for habitat restoration and the beneficial use of dredged material. Just off the Chesapeake Bay coastline, about 34 miles south of Baltimore in Talbot County, MD, Poplar Island is returning to its former size and will again serve an important ecological function while helping to ensure the economic vitality of the region.

The U.S. Army Corps of Engineers (USACE) are working in partnership with the Maryland Port Administration and other Federal and State agencies, to restore Poplar Island by using dredged material from the Baltimore Harbor and Channels Federal navigation projects. Approximately 68 million cubic yards of dredged material will be placed to develop 737 acres of wetlands, 840 acres of uplands, and 138 acres of open water embayment. The Poplar Island water level station is located on the east coast of Poplar Island, and was established in 2006 through a partnership between NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) and the Baltimore District, USACE (USACE, 2013).

The purpose of this report is to provide an analysis of water level data and tidal datums observed from Poplar Island, Maryland. For context, the analyses include comparisons with the nearby long-term water level station in Annapolis, Maryland and Cambridge, Maryland (Figure 1). This report includes comparative analyses of regional sea level trends, frequency and duration of inundation, and exceedance probabilities at these locations.

Figure 1. Site map displaying water level stations at U.S. Academy in Annapolis, MD and Poplar Island, MD. The inset depicts a more detailed image of Poplar Island.

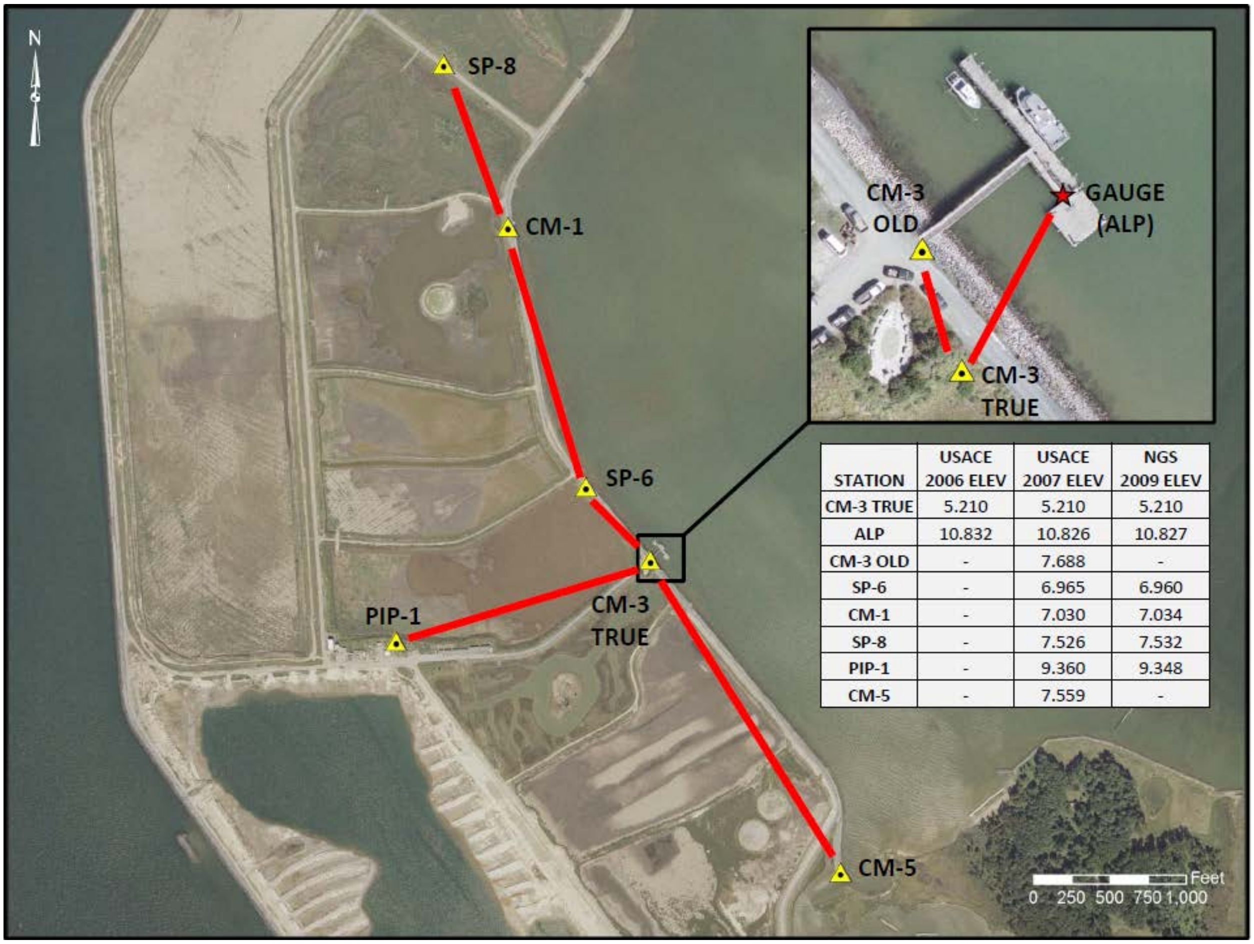
PROJECT INFORMATION

The Poplar Island, Maryland water level station was installed in October 2006 by the U.S. Army Corps of Engineers (USACE), in consultation with CO-OPS. CO-OPS' Coastal Oceanographic Applications and Services of Tides And Lakes (COASTAL) Program along with NOAA's National Geodetic Survey (NGS) and NOAA's Office of Coast Survey (OCS) comprise a Tri-Office initiative that provided USACE with an integrated suite of data products to help guide the reconstruction of Poplar Island in a manner that will provide sustainable wildlife habitat for years to come. CO-OPS' role included processing three years of data from the Poplar Island, MD water level station to calculate datums.

Land subsidence, rising sea level, and wave action are causing valuable remote island habitats to be lost throughout the Chesapeake Bay. As a result of the loss of these habitats, on May 12, 2009, President Barack Obama issued Executive Order 13508 on Chesapeake Bay Protection and Restoration. In the Executive Order, the President declared the Chesapeake Bay a "national treasure" and ushered in a new era of federal leadership, action, and accountability. The Paul S. Sarbanes Ecosystem Restoration Project at Poplar Island coordinated by USACE directly supported the Executive Order 13508 goals to recover habitat and sustain fish and wildlife (Federal Action Plan, 2012).

Actions planned by USACE at the nation's premier island habitat restoration site, Poplar Island, included developing 111 acres of wetland and tidal gut habitat to allow inflow of dredged material, and began the design of the expansion of the Poplar Island project. Fifty-five of 111 acres of wetlands were opened to fish and natural tidal flow in late 2014, and the remaining 56 acres are scheduled to be open in late fall 2015, increasing the area of fully restored/developed wetlands to 287 acres (Federal Action Plan, 2012).

The water level station for Poplar Island (Station ID: 8572271) was located on the east side of Poplar Island, MD on the USACE personnel pier. Five (5) bench marks located on the island were selected as tidal bench marks. The benchmarks were located along the islands perimeter road and cross dikes. The water level station is located at the southeast end of the personnel pier T-section. The gauge consists of a primary water level acoustic sensor and a data collection platform (DCP). The Poplar Island water level station was established and operated following CO-OPS specifications (CO-OPS, 2013).



STATION	USACE 2006 ELEV	USACE 2007 ELEV	NGS 2009 ELEV
CM-3 TRUE	5.210	5.210	5.210
ALP	10.832	10.826	10.827
CM-3 OLD	-	7.688	-
SP-6	-	6.965	6.960
CM-1	-	7.030	7.034
SP-8	-	7.526	7.532
PIP-1	-	9.360	9.348
CM-5	-	7.559	-

Figure 2. The benchmark network for station 8572271, Poplar Island, MD and a table of values for the initial, annual, and closing leveling in units of feet.

The tidal benchmarks were established for each station to preserve the elevations of the tidal datums and their relationship to geodetic (land-based) datums by periodic leveling and GPS surveys if the station was removed or destroyed. The primary benchmark is CM-3 TRUE and is at the northeast corner of cell 4D, 15.68 meters (51.44 feet) east of the east corner of the Murden Memorial monument stone, 10.62 meters (34.84 feet) WSW of the west corner of the landing craft ramp, and 1.02 meters (3.35 feet) NNW of a wooden bollard. The benchmark is set 15 centimeters (0.49 feet) below ground, crimped to an aluminum rod driven to an unknown depth to substantial resistance, and encased in a 5-inch logo cap. The locations of the remaining benchmarks are shown in Figure 2; descriptions of these locations can be found on the benchmark sheet (Appendix 1). Constructed cells at Poplar Island can be designed based on accurate relationships between land elevations and water levels within a consistent reference frame. This information is critical because the frequency and duration of flooding are both dependent upon elevation. The elevation and relative water levels of Poplar Island can be re-observed to a high level of accuracy because of the baseline elevation data collected. This information is cirtical in monitoring the impacts of change (inland elevation or water level) over time and projecting the long-term sustainability of the restoration project (NOAA's Contributions to the Poplar Island Restoration Project: A Chesapeake Bay Executive Order FY11 Accomplishments Report, 2011).

MONTHLY WATER LEVEL PROCESSING

The Poplar Island, MD water level data were processed by the CO-OPS Data Processing Team. The data were reviewed, outliers were removed, and gaps were filled where needed. Once the 6-minute interval water level data were processed other products could be generated. The typical monthly water level processing outputs were tabulated high and low waters, and hourly heights. (Figures 3, 4, and 5). Note that these products are shown relative to station datum (STND), which is an arbitrary zero point set low enough in the water such that the water level will never be below this point.

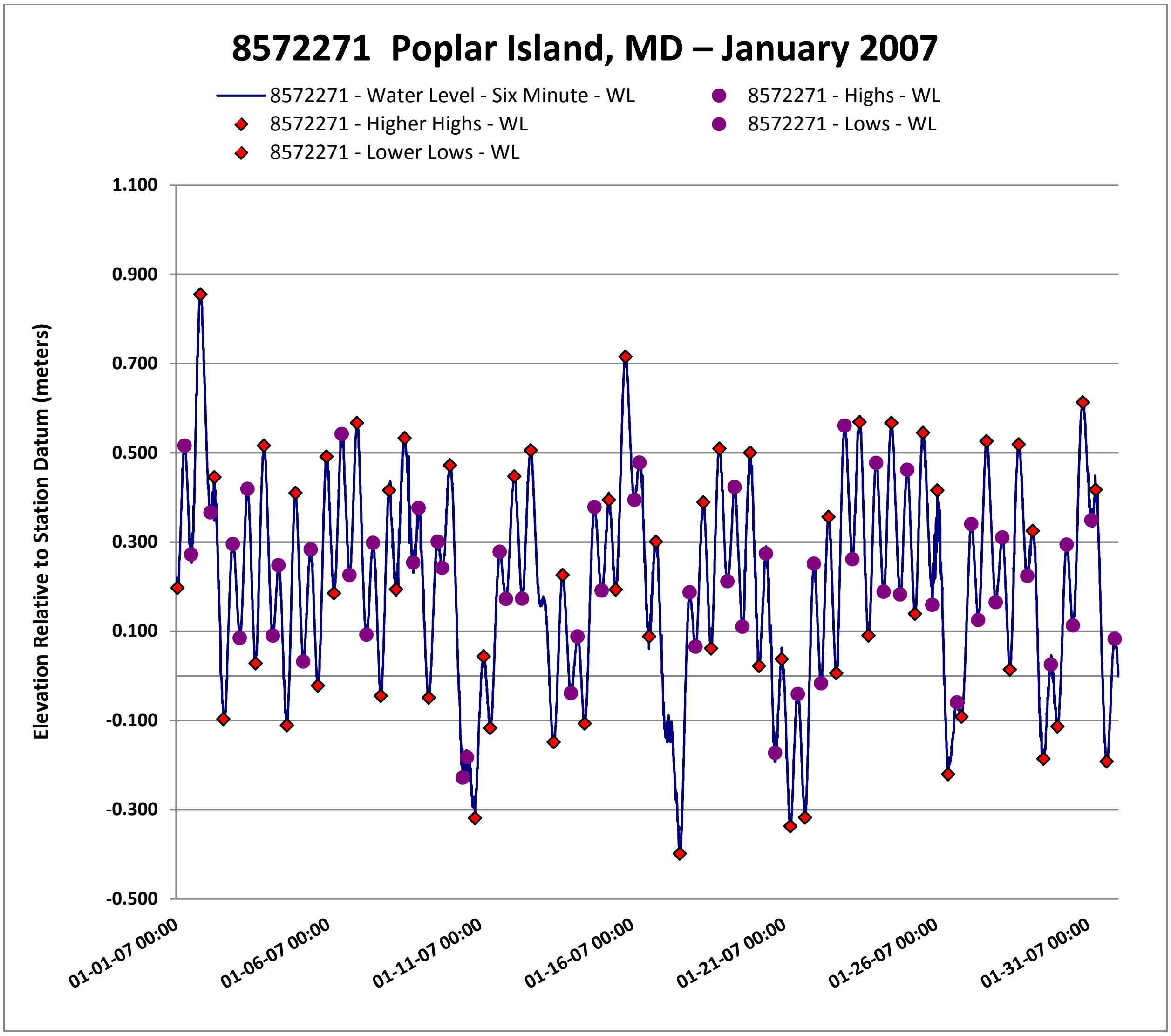


Figure 3. Monthly high and low tabulations for Poplar Island, January 2007.

```
Oct 10 2013 18:45 GMT     HIGH/LOW WATER LEVEL DATA      January, 2007
                         National Ocean Service (NOAA)
Station:  8572271                                        T.M.:     0 W
Name:     Poplar Island, MD                              Units:    Meters
Type:     Mixed                                          Datum:    STND
Note:     > Higher-High/Lower-Low   [] Inferred Tide     Quality:  Verified

         High             Low                     High             Low
Day   Time  Height     Time  Height     Day    Time  Height     Time  Height
---   ----  ------     ----  ------     ---    ----  ------     ----  ------
 1     6.7   0.516   >  1.0   0.197     16      6.0   0.478      1.9   0.394
     > 19.2  0.855     11.9   0.272           > 18.9  0.301   > 13.4   0.088
 2   >  6.4  0.445      3.3   0.366     17
       20.8  0.295   > 13.4  -0.097             21.5  0.187   > 13.7  -0.399
 3      8.3  0.419      2.4   0.085     18    >  8.2  0.389      2.1   0.065
     > 21.4  0.516   > 14.7   0.028           > 20.9  0.509   > 14.3   0.061
 4      9.0  0.248      4.4   0.090     19       8.9  0.423      3.3 [ 0.212]
     > 22.2  0.410   > 15.4  -0.111           > 21.3  0.500     15.2 [ 0.110]
 5     10.2  0.283      4.5   0.032     20       9.8  0.274   >  4.3   0.022
     > 22.9  0.491   > 15.9  -0.022           > 22.2  0.037     16.9  -0.173
 6     10.9  0.542   >  4.7   0.185     21      10.8 -0.041   >  5.0  -0.337
     > 22.9  0.567     17.0   0.226             23.6  0.251   > 16.5  -0.318
 7     11.5  0.298      6.3   0.092     22    > 11.2  0.356      5.2  -0.017
                     > 17.6  -0.045             23.9  0.561   > 17.3   0.006
 8   >  0.2  0.416   >  5.7   0.194     23    > 11.6  0.569      5.9   0.261
     > 12.4  0.533     19.3   0.254                           > 18.7   0.090
       23.5  0.376                      24       0.8  0.477      6.7   0.188
 9                   >  7.4  -0.049           > 12.8  0.567     19.7   0.182
       14.5  0.301     18.1   0.242     25       1.3  0.462   >  7.4   0.139
10   >  0.3  0.472     10.3  -0.228           > 13.7  0.545     21.1   0.159
       13.6 -0.183   > 19.9  -0.319     26    >  1.0  0.416   >  9.6  -0.221
11   >  2.8  0.043   >  8.1  -0.117             16.6 -0.060   > 20.0  -0.092
       15.6  0.278     20.4   0.172     27       3.9  0.340      9.4   0.125
12   >  3.0  0.447      9.3   0.173           > 16.0  0.526     23.2   0.165
     > 15.9  0.505                      28       4.3  0.310   > 10.3   0.014
13                   > 10.1  -0.149           > 17.4  0.519
     > 17.2  0.226     23.8  -0.039     29    >  4.4  0.325      0.1   0.224
14      5.0  0.088   > 10.5  -0.107             18.7  0.025   > 12.8  -0.186
       18.4  0.378                      30       7.2  0.294   >  0.0  -0.114
15   >  5.7  0.394      0.1   0.191           > 19.9  0.613     12.1   0.113
     > 18.8  0.715   > 11.0   0.193     31    >  6.1  0.417      2.8   0.349
                                                21.2  0.083   > 14.8  -0.192

Highest Tide:            0.855    19.2 Hrs   Jan  1 2007
Lowest  Tide:           -0.399    13.7 Hrs   Jan 17 2007

Monthly Means:     MHHW     0.454
                   MHW      0.371     DHQ     0.083
                   MTL      0.208                    GT     0.511     HWI    Hrs
                   DTL      0.199                    MN     0.326     LWI    Hrs
                   MSL      0.205
                   MLW      0.045     DLQ     0.102
                   MLLW    -0.057

Station # Sn PC   Begin Date      End Date     In COCTT PID VID AID Data Type
------- - -- -- -------------- -------------- -- ----- --- --- --- ---------
8572271 1 A1 W3 20070101 00:00 20070131 23:54  6 01000 280 305      High/Low
```

Figure 4. Tabulated high and low, and monthly means for January, 2007. This tabulation shows the time and height of every high and low water level in relation to station datum (STND).

Oct 10 2013 18:52 GMT

HOURLY WATER LEVEL DATA
National Ocean Service (NOAA)

January, 2007

Station: 8572271
Name: Poplar Island, MD
Note: [] Inferred Water Level Value

T.M.: 0 W
Units: Meters
Datum: STND
Quality: Verified

Hour	Jan 1	Jan 2	Jan 3	Jan 4	Jan 5	Jan 6	Jan 7	Jan 8	Jan 9	Jan 10	Jan 11	Jan 12	Jan 13	Jan 14	Jan 15	Jan 16
0	0.220	0.521	0.179	0.372	0.324	0.447	0.532	0.425	0.382	0.473	-0.043	0.325	0.164	-0.037	0.194	0.444
1	0.198	0.441	0.126	0.286	0.240	0.371	0.463	0.419	0.338	0.460	-0.001	0.387	0.171	-0.021	0.195	0.410
2	0.208	0.380	0.089	0.199	0.157	0.315	0.373	0.349	0.243	0.433	0.050	0.427	0.171	0.015	0.240	0.396
3	0.282	0.377	0.089	0.121	0.092	0.246	0.270	0.287	0.189	0.357	0.041	0.453	0.168	0.050	0.290	0.419
4	0.371	0.371	0.149	0.091	0.036	0.189	0.190	0.244	0.116	0.263	0.023	0.434	0.143	0.079	0.345	0.440
5	0.457	0.412	0.220	0.097	0.036	0.179	0.122	0.216	0.041	0.170	-0.011	0.386	0.098	0.087	0.384	0.468
6	0.508	0.421	0.299	0.137	0.080	0.229	0.094	0.211	-0.009	0.079	-0.062	0.338	0.037	0.075	0.373	0.484
7	0.528	0.364	0.377	0.181	0.140	0.293	0.100	0.252	-0.054	-0.015	-0.098	0.266	-0.019	0.039	0.362	0.461
8	0.481	0.337	0.420	0.231	0.205	0.379	0.136	0.310	-0.043	-0.072	-0.116	0.205	-0.086	-0.008	0.314	0.428
9	0.424	0.251	0.408	0.244	0.256	0.458	0.203	0.366	-0.001	-0.157	-0.095	0.180	-0.125	-0.068	0.262	0.350
10	0.353	0.165	0.352	0.229	0.281	0.513	0.263	0.459	0.060	-0.176	-0.047	0.194	-0.146	-0.098	0.210	0.267
11	0.291	0.065	0.277	0.175	0.260	0.544	0.294	0.514	0.138	-0.199	0.020	0.235	-0.133	-0.097	0.185	0.170
12	0.253	-0.017	0.187	0.080	0.209	0.527	0.296	0.531	0.211	-0.196	0.110	0.298	-0.087	-0.065	0.218	0.115
13	0.320	-0.067	0.104	-0.008	0.136	0.436	0.250	0.539	0.268	-0.178	0.179	0.375	-0.012	0.010	0.267	0.120
14	0.377	-0.091	0.036	-0.069	0.064	0.368	0.182	0.494	0.299	-0.188	0.235	0.445	0.068	0.099	0.355	0.098
15	0.501	-0.074	0.039	-0.113	0.001	0.308	0.102	0.450	0.297	-0.207	0.269	0.489	0.133	0.195	0.463	0.121
16	0.631	-0.013	0.077	-0.105	-0.028	0.243	0.020	0.332	0.282	-0.235	0.274	0.511	0.197	0.278	0.562	0.197
17	0.725	0.078	0.163	-0.032	0.006	0.226	-0.032	0.300	0.249	-0.245	0.252	0.480	0.218	0.347	0.651	0.252
18	0.812	0.165	0.277	0.057	0.076	0.250	-0.035	0.262	0.240	-0.288	0.212	0.430	0.215	0.372	0.692	0.288
19	0.858	0.239	0.383	0.173	0.184	0.317	0.012	0.260	0.252	-0.285	0.197	0.361	0.175	0.370	0.710	0.297
20	0.833	0.283	0.462	0.283	0.308	0.396	0.095	0.278	0.272	-0.318	0.173	0.299	0.120	0.337	0.686	0.267
21	0.775	0.299	0.513	0.375	0.408	0.480	0.200	0.271	0.338	-0.260	0.179	0.242	0.061	0.287	0.628	0.210
22	0.689	0.278	0.509	0.405	0.483	0.544	0.299	0.322	0.383	-0.182	0.209	0.192	0.005	0.245	0.565	0.159
23	0.603	0.227	0.451	0.390	0.494	0.569	0.375	0.368	0.443	-0.119	0.265	0.163	-0.025	0.207	0.504	0.083
Mean	0.487	0.225	0.258	0.158	0.185	0.368	0.200	0.352	0.206	-0.045	0.092	0.338	0.063	0.112	0.402	0.289

Hour	Jan 17	Jan 18	Jan 19	Jan 20	Jan 21	Jan 22	Jan 23	Jan 24	Jan 25	Jan 26	Jan 27	Jan 28	Jan 29	Jan 30	Jan 31	
0	-0.003	0.119	0.363	0.341	0.003	0.250	0.558	0.464	0.429	0.333	0.109	0.175	0.224	-0.118	0.436	
1	-0.064	0.083	0.296	0.224	-0.088	0.213	0.536	0.475	0.462	0.421	0.194	0.209	0.224	-0.099	0.390	
2	-0.126	0.068	[0.237]	0.140	-0.186	0.150	0.474	0.443	0.451	0.388	0.270	0.244	0.282	-0.045	0.344	
3	-0.130	0.084	[0.216]	0.079	-0.247	0.087	0.404	0.382	0.398	0.355	0.325	0.288	0.316	0.034	0.353	Maximum
4	-0.132	0.138	[0.219]	0.037	-0.313	0.019	0.342	0.313	0.325	0.254	0.344	0.308	0.311	0.119	0.365	Day Hr
5	-0.114	0.218	[0.248]	0.035	-0.331	-0.020	0.279	0.246	0.254	0.154	0.320	0.302	0.304	0.202	0.391	1 19
6	-0.146	0.295	[0.295]	0.086	-0.313	-0.003	0.254	0.197	0.182	0.042	0.268	0.265	0.278	0.267	0.397	0.858
7	-0.107	0.356	0.345	0.147	-0.244	0.070	0.283	0.192	0.144	-0.026	0.213	0.191	0.186	0.291	0.383	
8	-0.132	0.390	0.399	0.201	-0.167	0.163	0.375	0.239	0.152	-0.138	0.163	0.117	0.095	0.280	0.333	
9	-0.184	0.376	0.417	0.256	-0.095	0.249	0.449	0.317	0.206	-0.203	0.127	0.059	0.005	0.241	0.249	
10	-0.239	0.325	0.391	0.260	-0.058	0.319	0.535	0.417	0.308	-0.202	0.143	0.021	-0.092	0.189	0.144	Minimum
11	-0.263	0.249	0.336	0.268	-0.034	0.357	0.569	0.506	0.410	-0.195	0.188	0.028	-0.138	0.134	0.022	Day Hr
12	-0.327	0.164	[0.272]	0.219	-0.060	0.342	0.575	0.551	0.487	-0.178	0.268	0.093	-0.169	0.116	-0.059	17 14
13	-0.390	0.107	[0.212]	0.075	-0.116	0.283	0.529	0.565	0.536	-0.143	0.356	0.188	-0.197	0.134	-0.139	-0.395
14	-0.395	0.062	[0.148]	0.064	-0.196	0.200	0.455	0.533	0.545	-0.118	0.441	0.309	-0.167	0.190	-0.189	
15	-0.338	0.071	[0.114]	-0.052	-0.261	0.121	0.355	0.452	0.525	-0.072	0.507	0.419	-0.115	0.286	-0.200	
16	-0.261	0.139	[0.122]	-0.140	-0.317	0.047	0.236	0.384	0.482	-0.062	0.521	0.479	-0.049	0.386	-0.172	
17	-0.155	0.231	0.236	-0.156	-0.318	0.011	0.145	0.313	0.370	-0.063	0.500	0.516	-0.008	0.479	-0.108	Monthly
18	-0.034	0.338	0.318	-0.125	-0.244	0.024	0.098	0.239	0.320	-0.059	0.449	0.507	0.012	0.558	-0.039	Mean WL
19	0.058	0.443	0.377	-0.103	-0.142	0.108	0.093	0.195	0.246	-0.080	0.381	0.469	0.042	0.597	0.022	0.205
20	0.130	0.493	0.435	-0.047	-0.016	0.244	0.136	0.181	0.215	-0.096	0.307	0.406	0.012	0.618	0.062	
21	0.184	0.511	0.495	0.018	0.098	0.365	0.216	0.214	0.184	-0.080	0.246	0.343	-0.028	0.594	0.085	
22	0.181	0.492	0.461	0.050	0.181	0.472	0.321	0.294	0.238	-0.035	0.196	0.283	-0.064	0.544	0.065	
23	0.160	0.437	0.416	0.034	0.241	0.536	0.405	0.362	0.317	0.031	0.167	0.246	-0.096	0.488	0.041	
Mean	-0.118	0.258	0.307	0.080	-0.134	0.192	0.359	0.353	0.341	0.009	0.292	0.269	0.049	0.270	0.132	

Figure 5. Tabulated hourly heights for January, 2007. This tabulation shows the hourly heights in relation to station datum (STND).

TIDAL DATUMS

Accepted tidal datums have been calculated for Poplar Island relative to the current 19-year National Tidal Datum Epoch (NTDE) of 1983-2001 using a standard NOAA simultaneous comparison procedure (CO-OPS, 2003) of three years of data (October 2006-February 2010) with the long-term control station at Annapolis, which has been continuously operating since 1928. For marine applications, a vertical datum is a base elevation used as a reference to determine heights and depths (NOAA, 2001). A vertical datum is referred to as a tidal datum when defined by a certain phase of the tide. It is determined by measurements from a water level station. For example, Mean High Water (MHW) is the mean elevation of all the high waters observed over the NTDE. Mean Lower Low Water (MLLW) is the mean elevation of all of the lower low waters observed each day over the NTDE and is the U.S. nautical chart reference datum (CO-OPS, 2001).

The tides at Poplar Island and Annapolis are classified as semi-diurnal (two high tides and two low tides per day with one high being slightly higher than the other and one low being lower than the other). The water levels in the Chesapeake Bay are influenced by atmospheric forcing (winds), as much as the astronomical tides. The mean range of tide (Mn), defined as the elevation difference between Mean High Water (MHW) and Mean Low Water (MLW), is 0.336 meters (1.102 feet) at Poplar Island. The Great Diurnal Range of Tide (GT) is 0.468 meters (1.535 feet) and is the elevation difference between Mean Higher High Water (MHHW) and Mean Lower Low Water (MLLW). Figure 6 shows the elevation relationships of tidal datums and ranges of tide for Poplar Island, MD.

GEODETIC ELEVATION REFERENCES TO TIDAL DATUMS

For land-based reference, a geodetic datum is a fixed reference that is developed and maintained by the National Geodetic Survey (www.ngs.noaa.gov). The North American Vertical Datum of 1988 (NAVD88) is the existing geodetic vertical reference datum for the United States and is the vertical reference for most modern topographic elevation sources such as the United States Geological Survey (USGS) National Elevation Database (NED) (NOAA, 2003). GPS surveys have been made at some of the tidal benchmarks on Poplar Island, but published NAVD88 elevations are not yet available. GPS surveys require occupying various tidal bench marks for several hours with a survey-grade static GPS receiver. Orthometric geodetic elevations, such as NAVD88 are obtained using the NGS OPUS software (http://www.ngs.noaa.gov/OPUS/). When available, relationships between tidal and geodetic datums can be determined; otherwise, geodetic datum relationships can be estimated using the NOAA VDatum tool (www.Vdatum.noaa.gov) with the Chesapeake Bay VDatum grid (Figure 7). Using VDatum for Poplar Island, NGVD29 was estimated to be 0.166 meters (0.545 feet) above station datum and NAVD88 was estimated to be 0.346 meters (1.135 feet) above station datum. This means NGVD29 was 0.150 meters (0.492 feet) below MSL and NAVD88 was 0.030 meters (0.098 feet) above MSL at Poplar Island.

Elevations on Station Datum

Station: 8572271, Poplar Island, MD
Status: Accepted (Jun 3 2011)
Units: Meters
T.M.: 75 W
Epoch: 1983-2001
Datum: STND

Datum	Value	Description
MHHW	0.549	Mean Higher-High Water
MHW	0.482	Mean High Water
MTL	0.313	Mean Tide Level
MSL	0.316	Mean Sea Level
DTL	0.315	Mean Diurnal Tide Level
MLW	0.145	Mean Low Water
MLLW	0.080	Mean Lower-Low Water
NAVD88		North American Vertical Datum of 1988
STND	0.000	Station Datum
GT	0.468	Great Diurnal Range
MN	0.336	Mean Range of Tide
DHQ	0.067	Mean Diurnal High Water Inequality
DLQ	0.065	Mean Diurnal Low Water Inequality
HWI	8.99	Greenwich High Water Interval (in hours)
LWI	3.01	Greenwich Low Water Interval (in hours)
Maximum	1.161	Highest Observed Water Level
Max Date & Time	12/26/2009 15:48	Highest Observed Water Level Date and Time
Minimum	-0.750	Lowest Observed Water Level
Min Date & Time	01/03/2008 10:54	Lowest Observed Water Level Date and Time
HAT	0.689	Highest Astronomical Tide
HAT Date & Time	06/14/1999 09:12	HAT Date and Time
LAT	-0.114	Lowest Astronomical Tide
LAT Date & Time	01/28/1983 14:18	LAT Date and Time

Tidal Datum Analysis Periods
03/01/2007 - 02/28/2010

Figure 6. Accepted tidal datum elevations (in meters) for Poplar Island, MD, relative to station datum based on the 1983-2001 NTDE. Accepted ranges of tide, maximum and minimum observed water levels, highest and lowest astronomical tides, and Greenwich time intervals have also been calculated. Although not shown, NAVD88 was estimated to be 0.346 meters (1.135 feet).

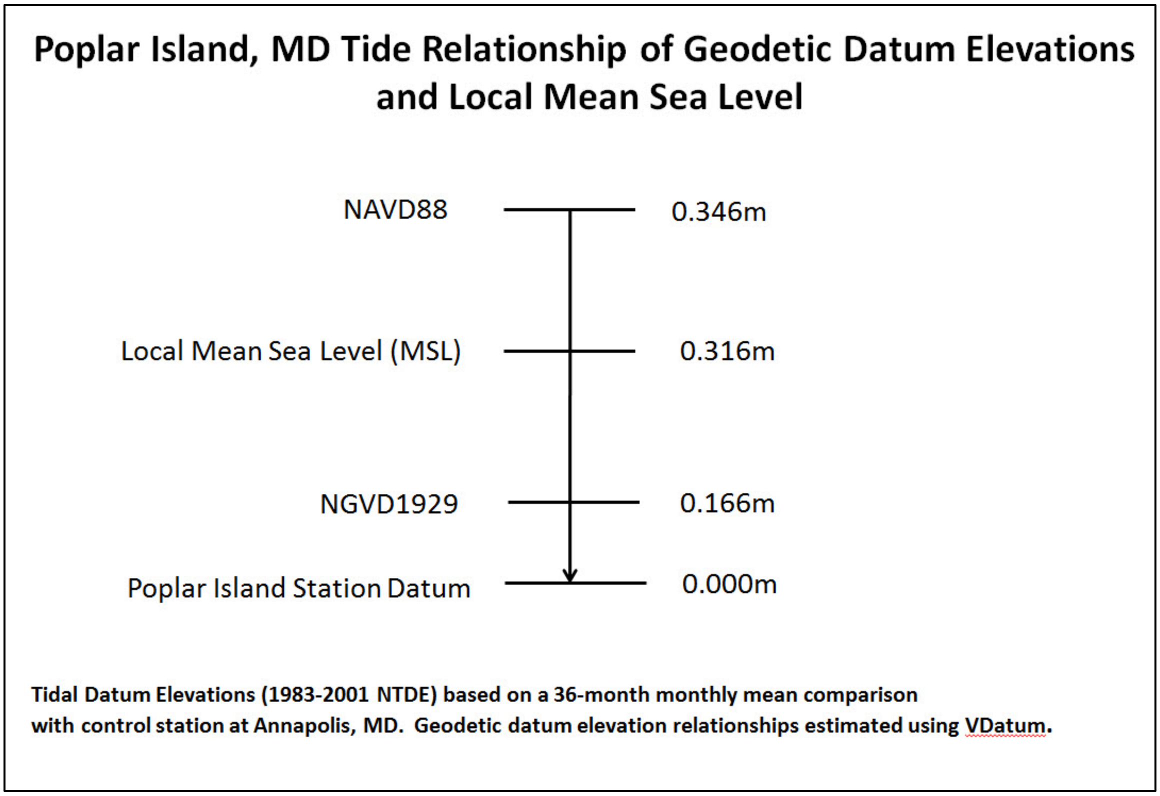


Figure 7. Relationship of geodetic datum elevations and local mean sea level at Poplar Island.

PREDICTED AND OBSERVED TIDE COMPARISON

Tidal predictions were generated for Poplar Island using the harmonic constants derived from a least-squares harmonic analysis for one-year of observed hourly heights (see Appendix 1). Figure 8 is a three year comparison plot of observed and predicted water levels that shows the large annual variations and the extent of the differences between observed and predicted high and low tides. There was a signficant amount of variability in the observations that was not present in the predictions due to the effects of atmospheric influences. Figure 9 shows the time series of the residual differences between observed versus predicted water levels. The standard deviation of these differences 0.17 meters (0.56 feet) was a signficant percentage of the observed mean range of tide 0.34 meters (1.12 feet). In this region of the Chesapeake Bay, the effects of the winds can have just as much influence on the water levels as the tidal forcing.

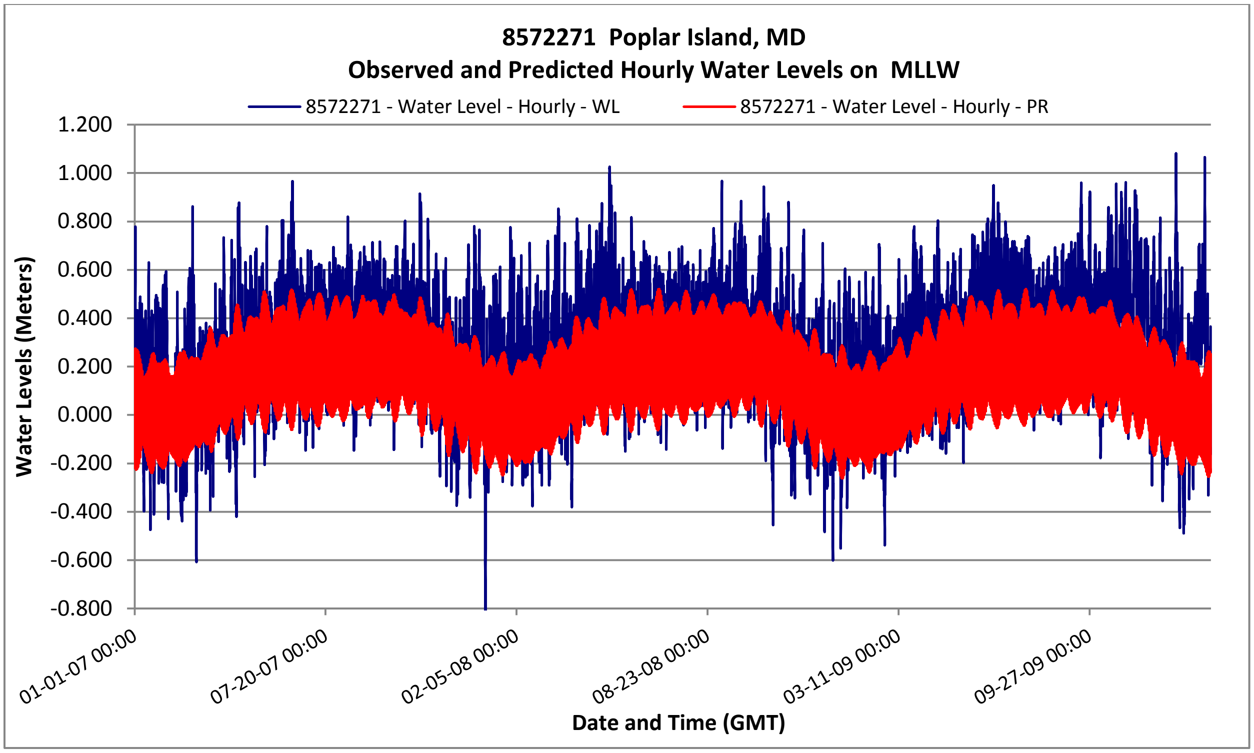


Figure 8. Plot of Poplar Island, MD observed (blue) and predicted (red) water levels.

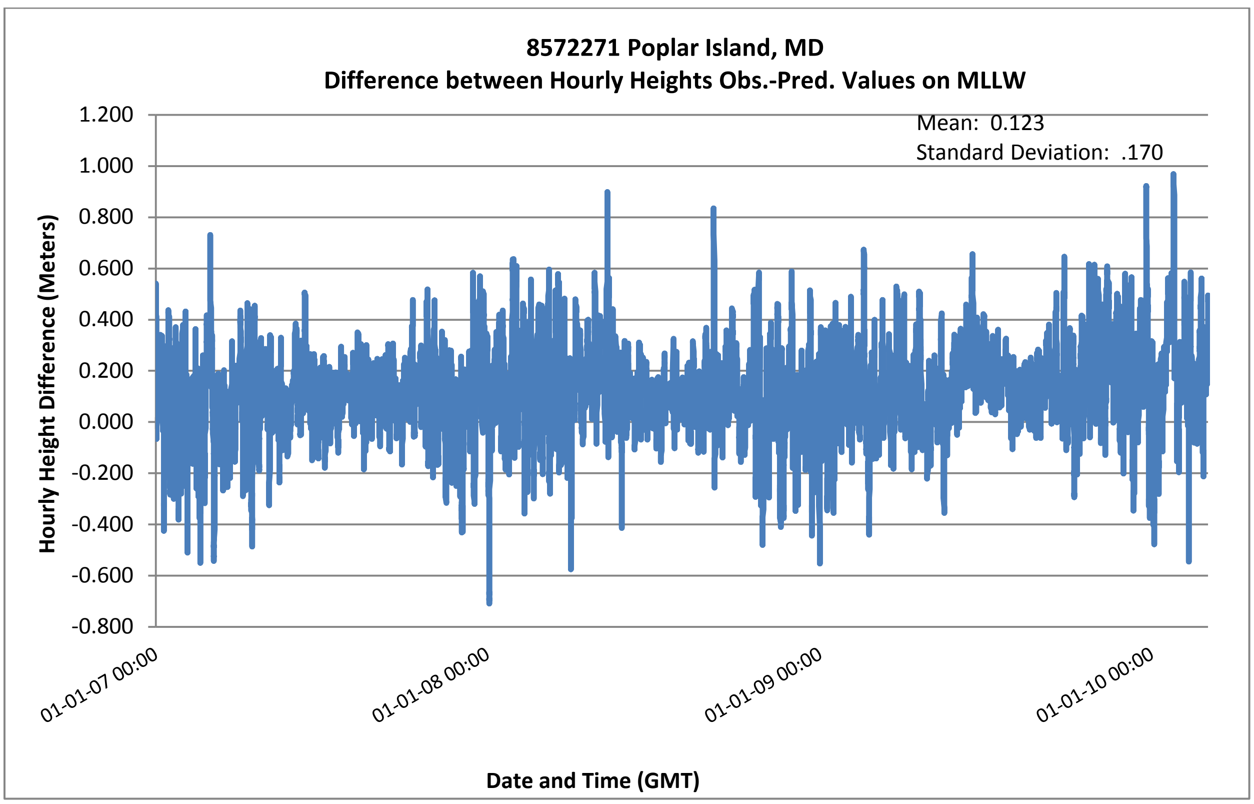


Figure 9. Difference of Poplar Island, MD observed and predicted water levels (residual).

FREQUENCY OF HIGH WATER ELEVATIONS AND DURATIONS OF INUNDATION

A frequency and duration of inundation analysis was used to generate statistics of the elapsed time the water elevation was at or above a user defined threshold for each tabulated high tide. Six-minute data above the defined threshold before and after the time of each tabulated high tide was used in this analysis. For this study, the frequency and duration of inundation of high water elevation relative to MHW for the Poplar Island and Annapolis water level gauges were analyzed. MHW is often used as a threshold for habitat restoration and inundation studies, as it often approximates the natural break in marsh vegetation between upland and lower marsh species. Sustained marsh health is also often dependent on the frequency and duration of inundation. Figure 10 is a histogram of the frequency of high water elevations above MHW at Poplar Island for all high waters measured during the operation of the station from October 2006-Feburary 2010. The histogram shows a decreasing distribution of tides, with 90% of the distribution being within 0.301 meters (0.988 feet) above MHW. The highest elevation was approximately 0.701 meters (2.299 feet) above MHW. The histogram in Figure 11 shows the histogram distribution for Poplar Island for the same time period. The distribution at Annapolis is very similar to Poplar Island, with the only difference being a slightly lower maximum elevation at Poplar Island due to their geographical locations on opposite sides of the bay.

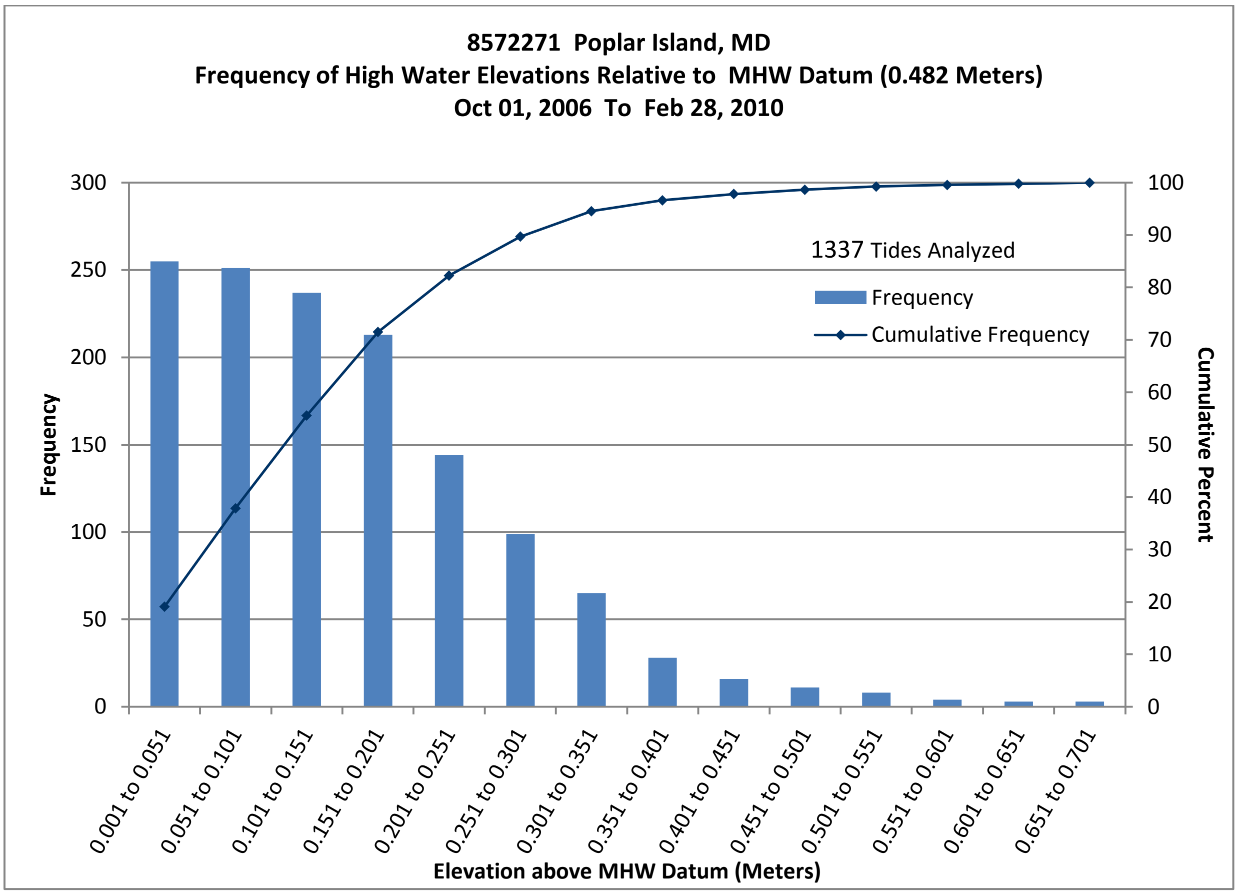


Figure 10. Frequency of high water elevation relative to MHW at Poplar Island, MD on station datum.

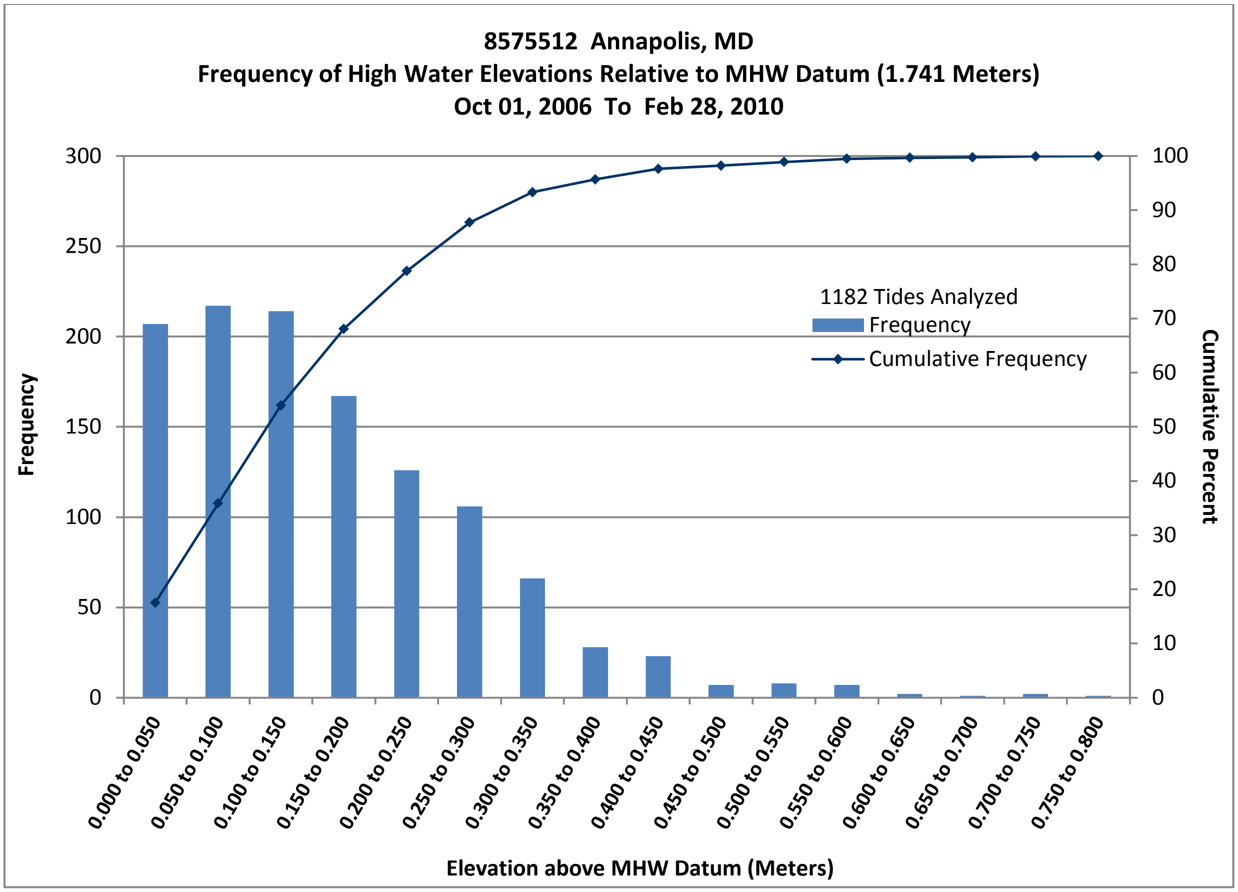


Figure 11. Frequency of high water elevation relative to MHW at Annapolis, MD on station datum.

The frequency of the duration of inundation above MHW at Poplar Island over the 2006 to 2010 time period is represented in Figure 12. The duration is defined as the length of time the 6-minute water level data is above the user threshold for each high water event, which is used to determine the total elapsed time the water level was at or above the threshold. Using MHW as the threshold elevation, the histogram was normally distributed, with 90% of the high waters having durations less than 10 hours. For the more extreme high storm tides, durations were over 15 hours.

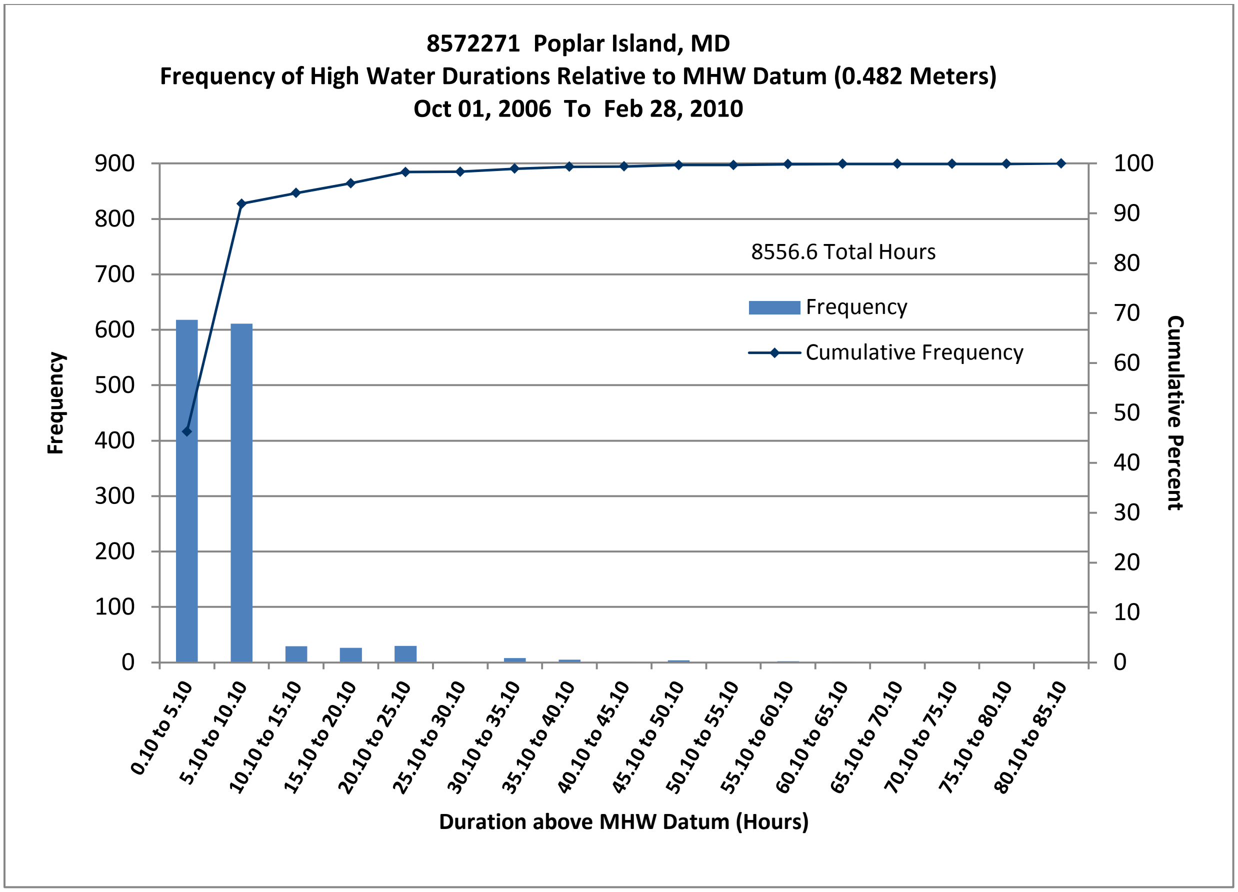


Figure 12. Frequency and duration of water at Poplar Island, MD above MHW on station datum.

Figure 13 illustrates a histogram of duration of inundation for the same time period observed at Annapolis. The distributions in these figures are similar to the distributions for the frequency of high water elevations. This agreement in the statistical distributions implies that the stations have similar tidal and nontidal signals. Statistical analyses from the long term record at Annapolis could therefore be used as a proxy for the long term statistics at the Poplar Island station location, which only has a three year record.

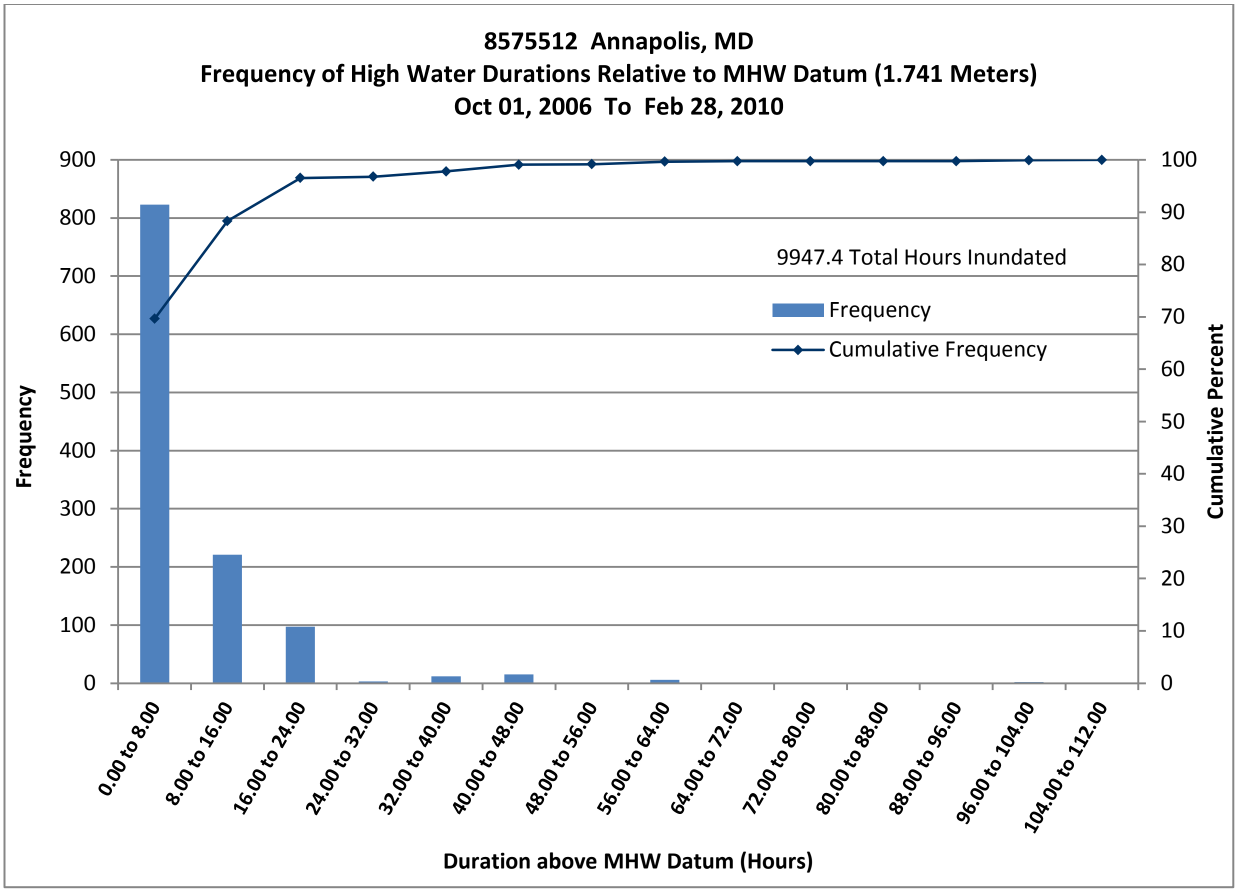


Figure 13. Frequency and duration of water at Annapolis, MD above MHW on station datum.

RELATIONSHIP OF DURATION OF INUNDATION VS. ELEVATION ABOVE MEAN HIGH WATER DATUM

The relationship of the frequency of elevation and frequency of duration can provide information that can be used to model and extrapolate the inundation statistics. In general, the higher the elevation of the tide above a threshold value, the longer the duration of inundation for that tide. However, as shown in Figures 14 and 15 for Poplar Island and Annapolis, it is not a linear relationship, but rather a complex multi-tiered curvilinear relationship which is not easily modeled. For instance, at Poplar Island (Figure 14), for elevations above 0.16 meters (0.52 feet) MHW, a second systematic tier of inundation durations centered around 20 hours occurs. This means that during these wind-driven events, the inundation above MHW lasts through two succesive high tides and the intervening low tide. Due to their close proximity, Poplar Island and Annapolis exhibit a similar response to these events. For extreme events, the events with the longest durations are not ncessarily those with the highest elevations.

A notable event that affected both Poplar Island and Annapolis was the Veteran's Day Nor'easter on November 10, 2009. The Veteran's Day storm was attributed to the remnants of Hurricane Ida which made landfall as a tropical storm along the U.S. Gulf Coast on Tuesday morning, November 10. Tropical Storm Ida weakened quickly into a remnant low which was located near the North Carolina coastal waters. The interaction between the low and a strong high pressure system located over eastern Canada produced an intense pressure gradient over the mid-Atlantic region, which persisted for several tide cycles. The Nor'easter generated a prolonged period of strong onshore winds of 39 miles per hour which persisted for more than 30 hours in some locations. The combination of the prolonged northeast flow, a long fetch over the bay, and the proximity of a new moon on November 16, produced large wave heights and strong wave action at the shore (NOAA, 2009). Moderate to severe tidal flooding also occurred along both the Atlantic coast and the back bays. Flooding on some barrier islands was worse on the bay side than on the ocean side because of the build up of water between tidal cycles. This extreme event resulted in Annapolis experiencing a duration of inundation of 103.7 hours at an elevation above datum equaling 0.506 meters (1.660 feet). The event was also observed at Poplar Island. Poplar Island experienced a duration of inundation of 81.8 hours at an elevation above datum equaling 0.529 meters (1.736 feet). Figure 16 captures this anomalous event and shows the deviation of water level observations from tide predictions at Poplar Island due to the landfall of the remnants of Hurricane Ida on November 10, 2009 to November 14, 2009. The elevation of the water levels remained above MHW for several tidal cycles.

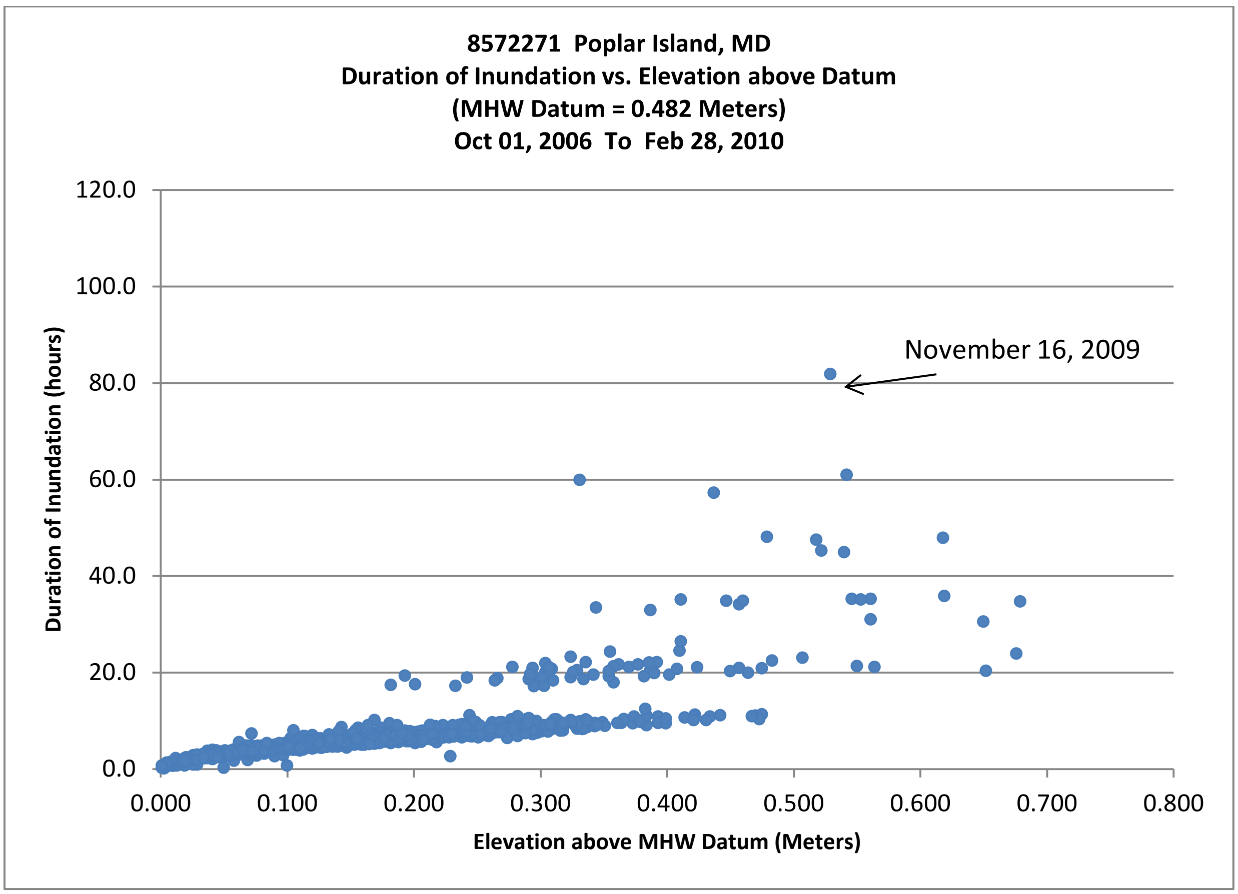


Figure 14. Poplar Island, MD duration of inundation.

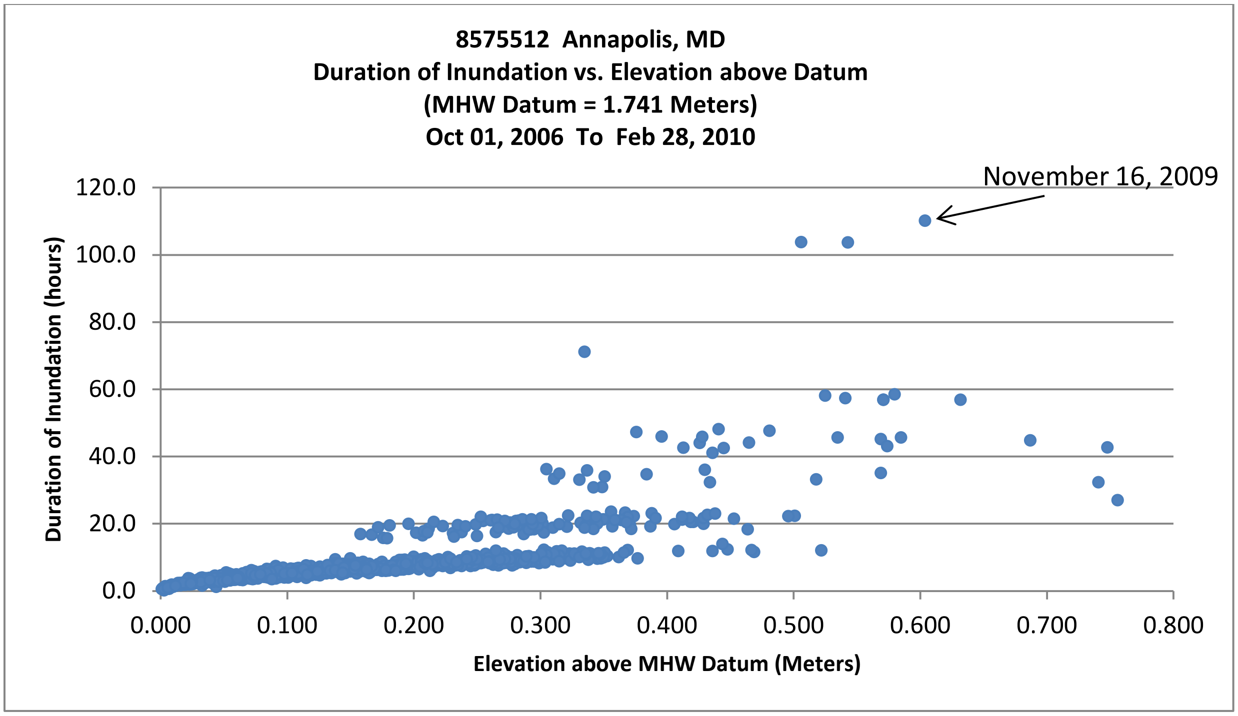


Figure 15. Annapolis, MD duration of inundation.

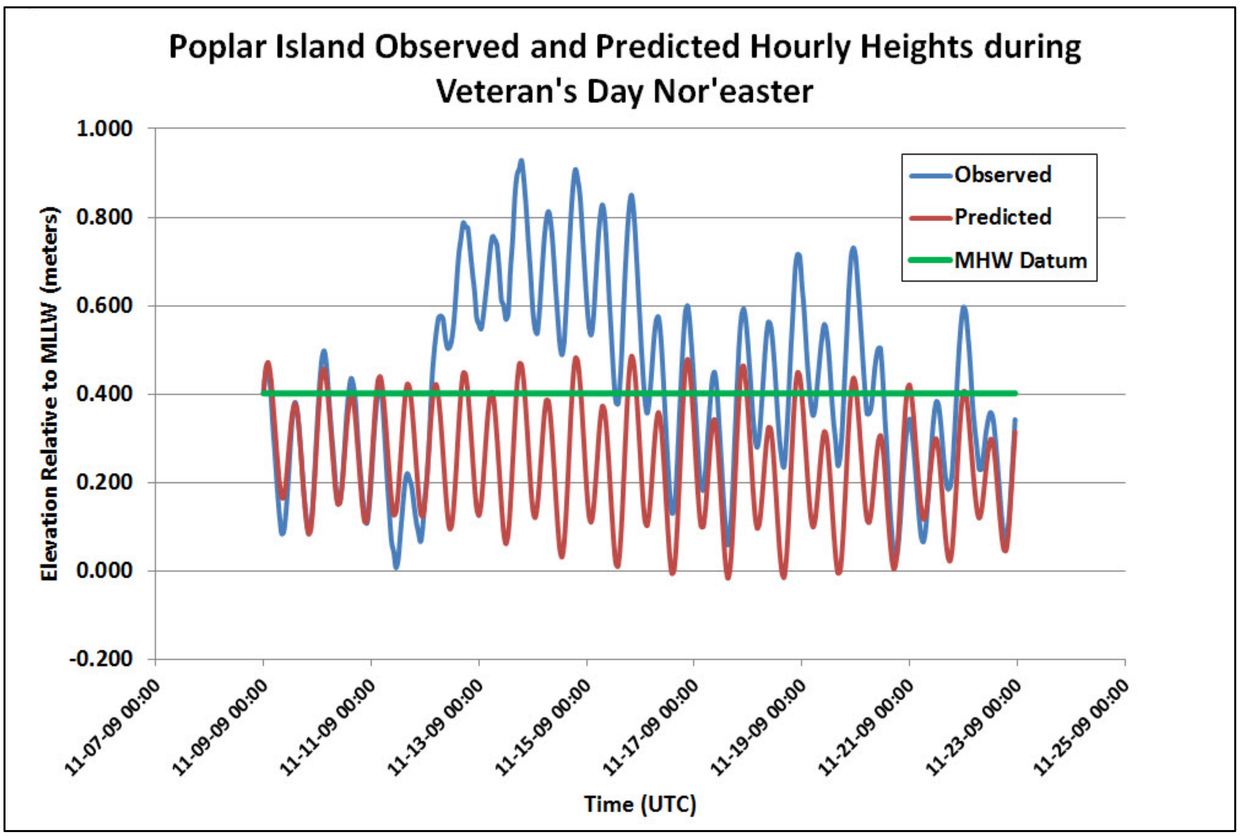


Figure 16. Poplar Island, MD tide predictions and observed hourly water levels relative to MLLW during the Veteran's Day Nor'easter.

COMPARISON OF MONTHLY MEANS

Figures 17, 18, and 19, show comparisons of the monthly means for MHW, MLLW, and Mean Sea Level (MSL) for the stations at Poplar Island, MD, Annapolis, MD, and Cambridge, MD relative to the long term MHW for the 1983-2001 NTDE. Over the period from 2006 thru 2010, the seasonal and annual variations are highly correlated, demonstrating similar regional response to seasonal weather patterns and longer periods of sea level change.

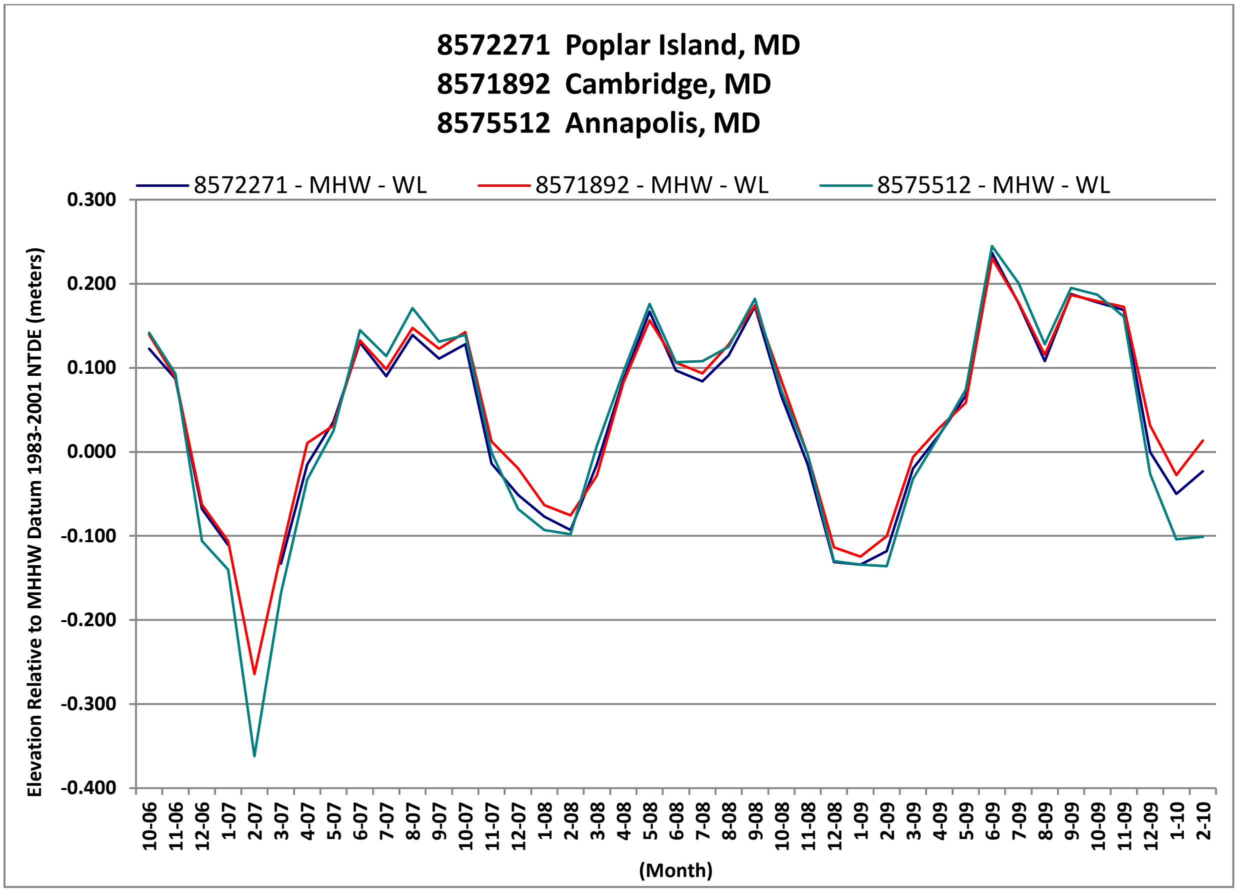


Figure 17. Regional comparison of monthly MHW relative to 1983-2001 NTDE MHW datum.

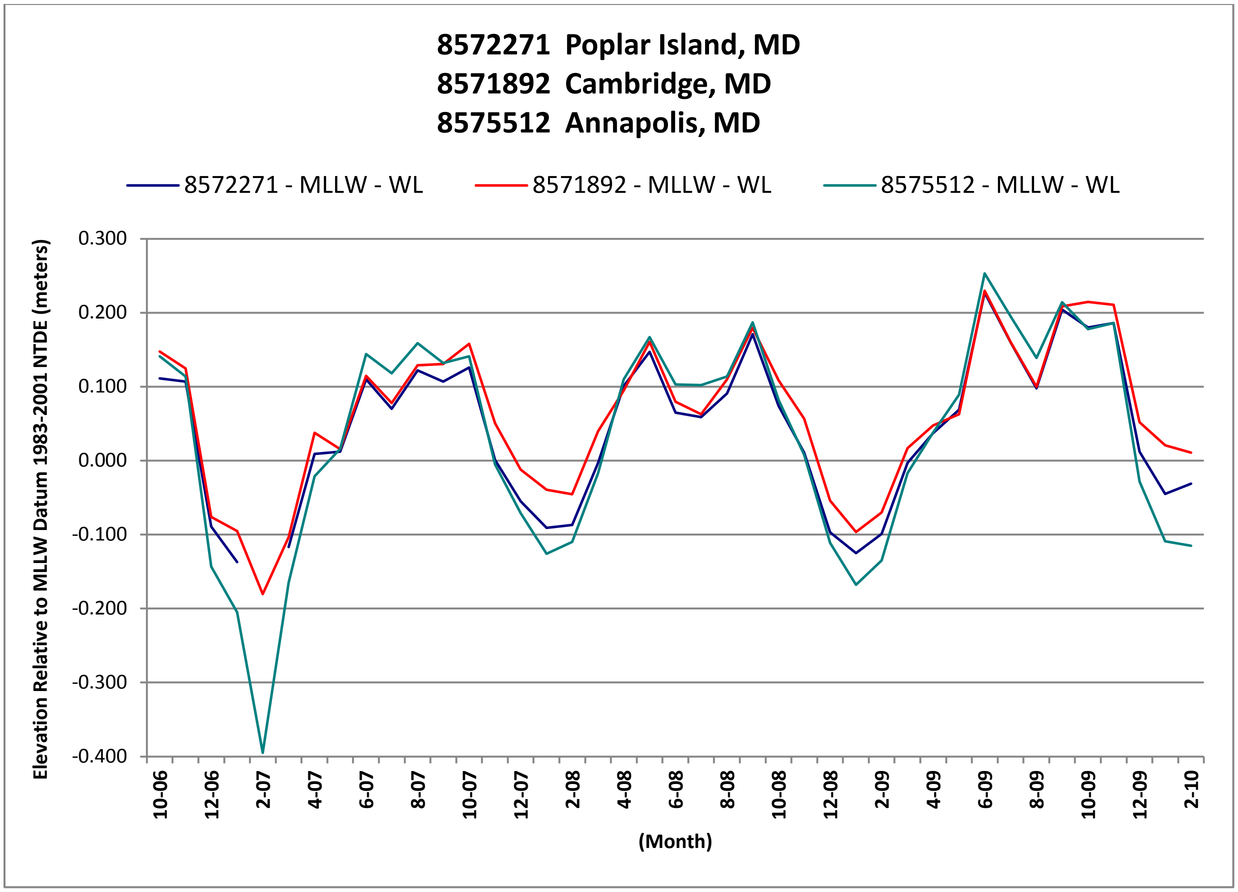


Figure 18. Regional comparison of monthly MLLW relative to 1983-2001 NTDE MLLW datum.

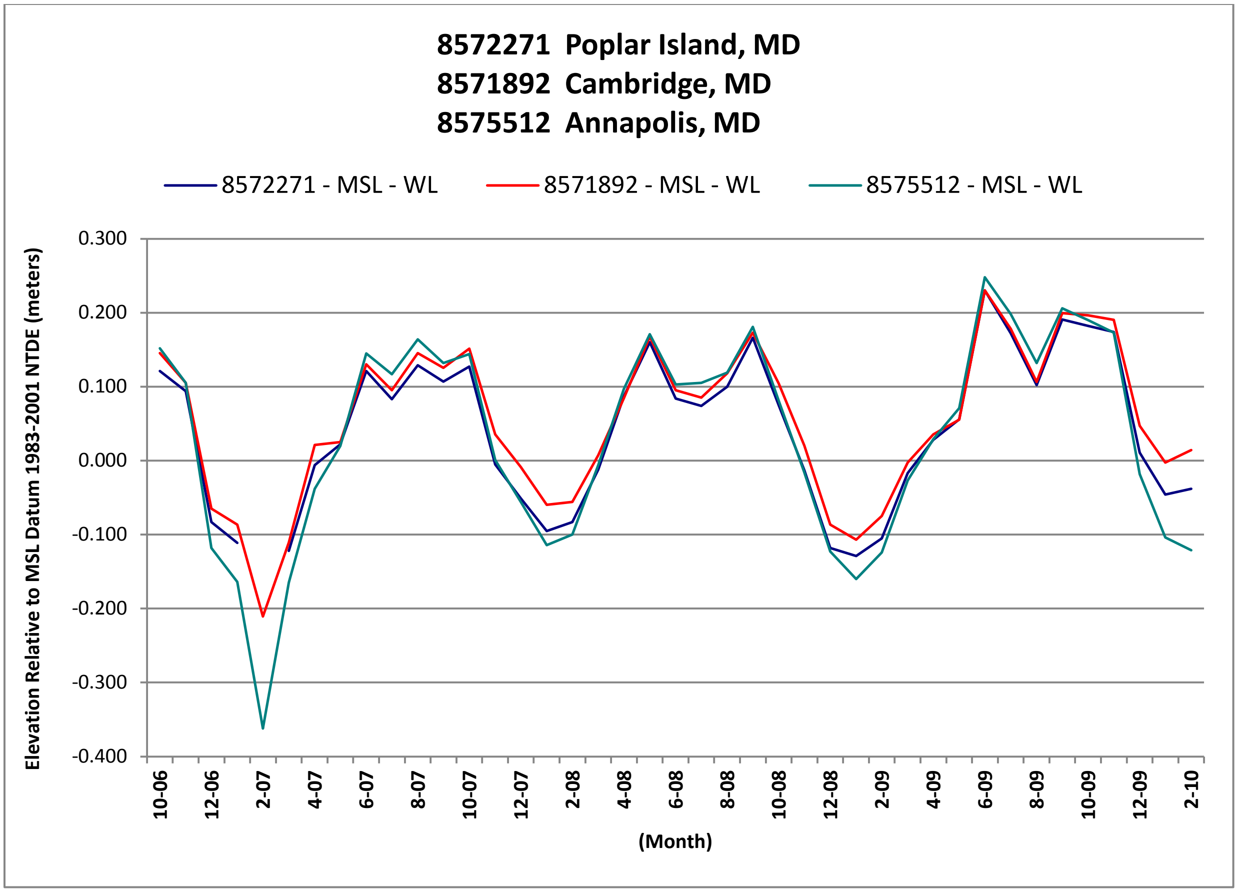


Figure 19. Regional comparison of monthly MSL relative to the 1983-2001 NTDE MSL datum.

LONG TERM SEA LEVEL TRENDS

Since the Poplar Island, Annapolis, and Cambridge water level station records exhibit similar monthly and seasonal variations over the five year period, it is reasonable to assume that the long term relative sea level trends for Annapolis and Cambridge can be used as guidelines for long term trends at Poplar Island. Relative sea level trends reflecting changes in local sea level over time are critical for many coastal applications. These sea level trends were computed from monthly averages of hourly water levels observed at Annapolis and Cambridge (Zervas, 2009). Annapolis' mean sea level trend is 3.44 millimeters/year (0.14 inches/year) with a 95% confidence interval of +/- 0.23 millimeters/year (0.01 inches/year) based on monthly mean sea level data from 1928-2013 which is equivalent to a change of 0.35 meters (1.15 feet) in 100 years (Figure 20). Cambridge's mean sea level trend (Figure 21**)** is 3.48 millimeters/year (0.14 inches/year) with a 95% confidence interval of +/- 0.39 millimeters/year (0.02 inches/year) based on monthly mean sea level data from 1943-2013 which is equivalent to a change of 0.37 meters (1.21 feet) in 100 years. It is likely that Poplar Island has experienced very similar mean sea level changes, although local changes in land motion (such as marsh subsidence) may create small local variations.

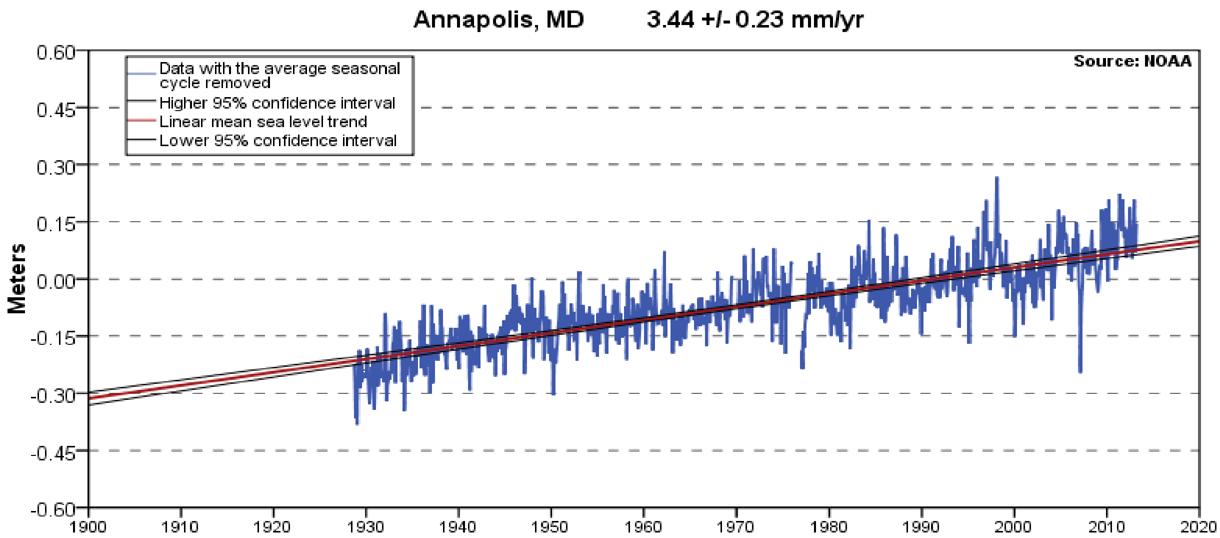


Figure 20. Mean sea level trend for Annapolis, MD.

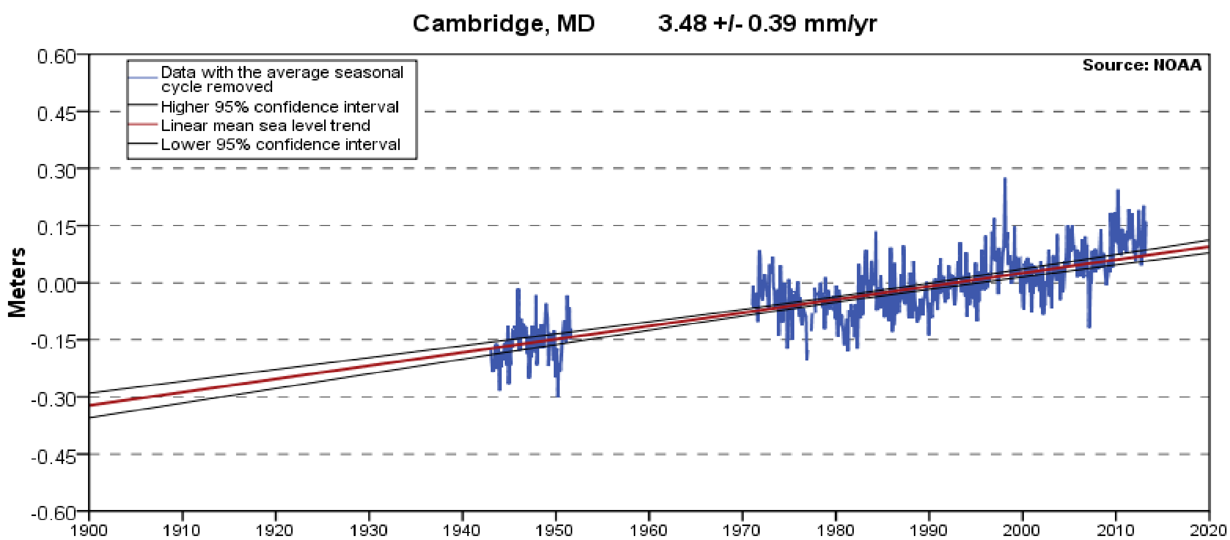


Figure 21. Mean sea level trend for Cambridge, MD.

EXTREME WATER LEVELS AND EXCEEDANCE PROBABILITY

CO-OPS has statistically analyzed the historical monthly and annual highest and lowest observed tides over the period of observation (Zervas, 2009). The results are a set of annual high and low exceedance probability levels relative to tidal datums and the geodetic North American Vertical Datum (NAVD88). The 1%, 10%, 50%, and 99% exceedance probability levels relative to Mean Sea Level (MSL) at the Annapolis and Cambridge stations are shown in Figure 22 and 23 (CO-OPS, 2015).

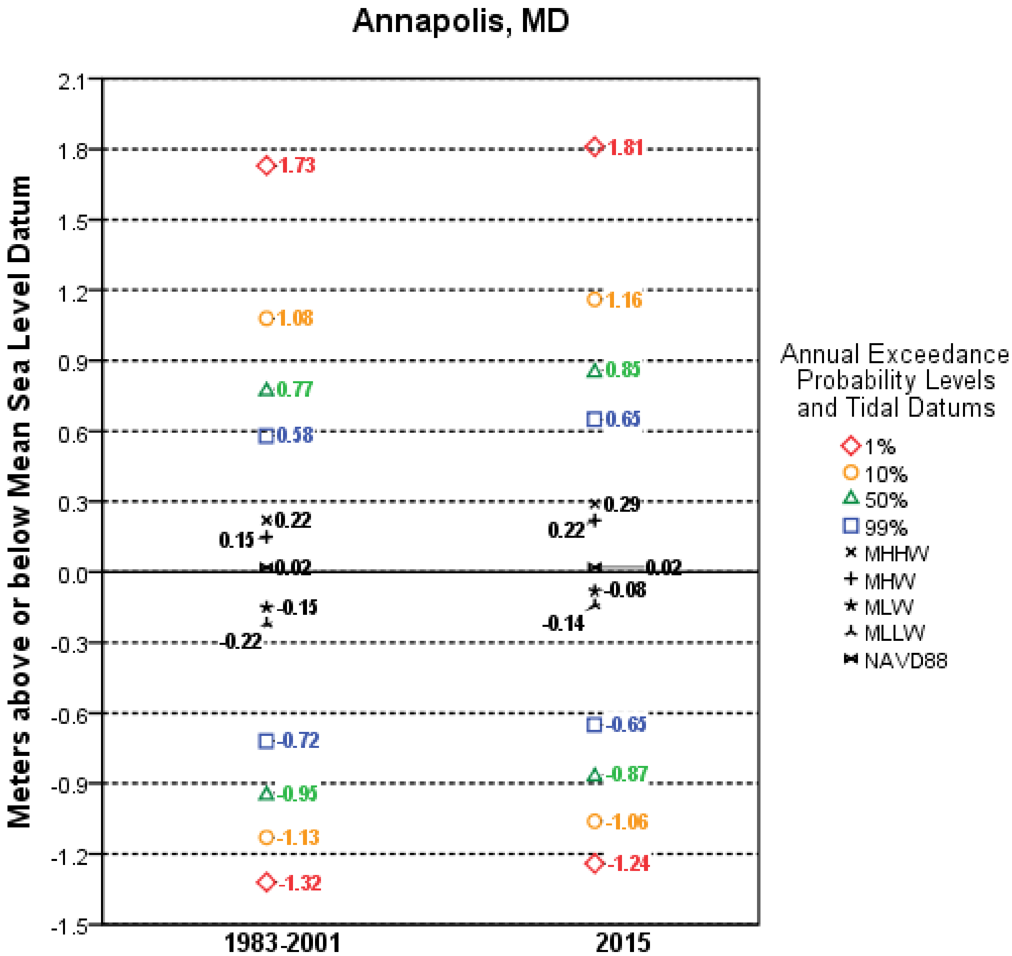


Figure 22. Exceedance probability for Annapolis, MD.

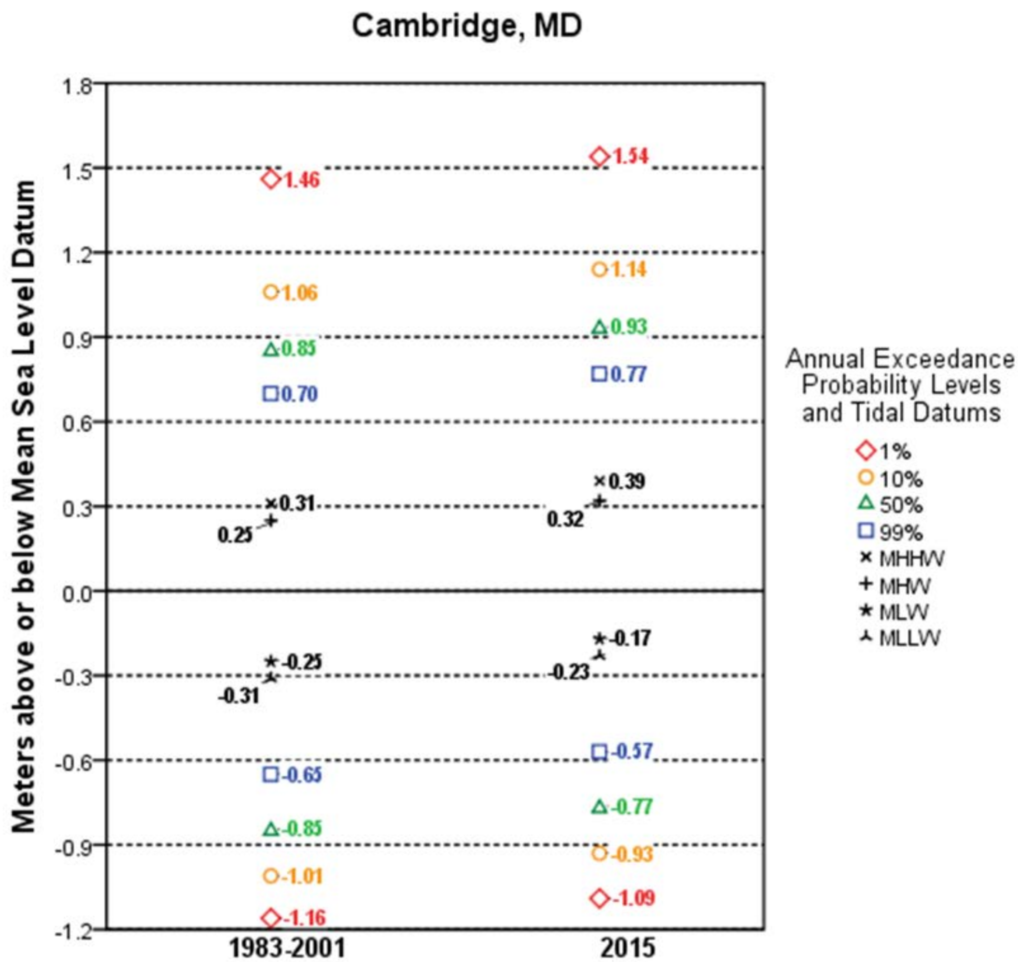


Figure 23. Exceedance probability for Cambridge, MD.

The probability levels are in meters relative to the National Tidal Datum Epoch (1983-2001) Mean Sea Level. The values in the left column are the exceedance probability levels for the mid-year (1992) of the current tidal epoch. In the right column, projected exceedance probability levels and tidal datums assuming continuation of the linear historic trend are provided. For instance, the 1% annual exceedance probability level for Annapolis increases from 1.73 meters (5.68 feet) above Mean Sea Level (MSL) to 1.81 meters (5.94 feet) above MSL based on the current trend. Similarly, the 1% annual exceedance probability level for Cambridge increases from 1.46 meters (4.79 feet) above Mean Sea Level (MSL) to 1.54 meters (5.05 feet) above MSL based on the current trend.

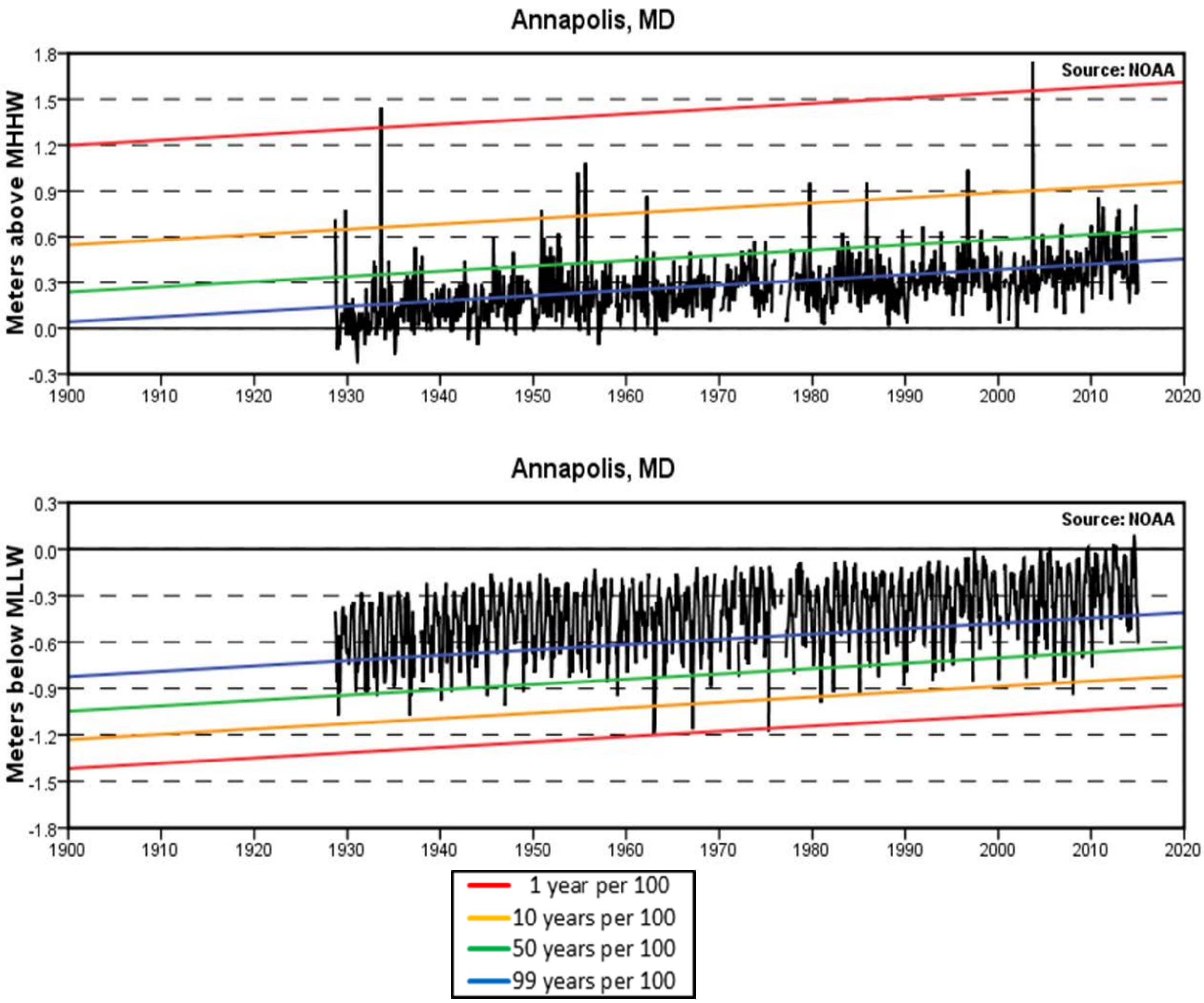


Figure 24. Extreme water levels at Annapolis, MD.

Figures 24 and 25 show exceedance probabilities above MHHW and below MLLW using the Generalized Extreme Value (GEV) probability distribution function applied to annual maximum or annual minimum data (Zervas, 2005). The monthly extreme water levels include a Mean Sea Level (MSL) trend of 3.44 millimeters (0.14 inches) (see earlier discussion of sea level trends). The figures show the monthly highest and lowest water levels with the 1%, 10%, 50%, and 99% annual exceedance probability levels shown in red, orange, green, and blue. The plotted values are in meters relative to the Mean Higher High Water (MHHW) or Mean Lower Low Water (MLLW) datums established by CO-OPS. On average, the 1% exceedance probability level (red) will be exceeded in only one year per century, the 10% level (orange) will be exceeded in ten years per century, and the 50% level (green) will be exceeded in fifty years per century. The 99% level (blue) will be exceeded in all but one year per century, and it is assumed that it could be exceeded more than once in any year. Of note in the top panel of Figure 24, the most extreme high water events that occurred during the period of record are the 1933 Hurricane and Hurricane Isabel in 2003. Both of these events exceeded the 1% level.

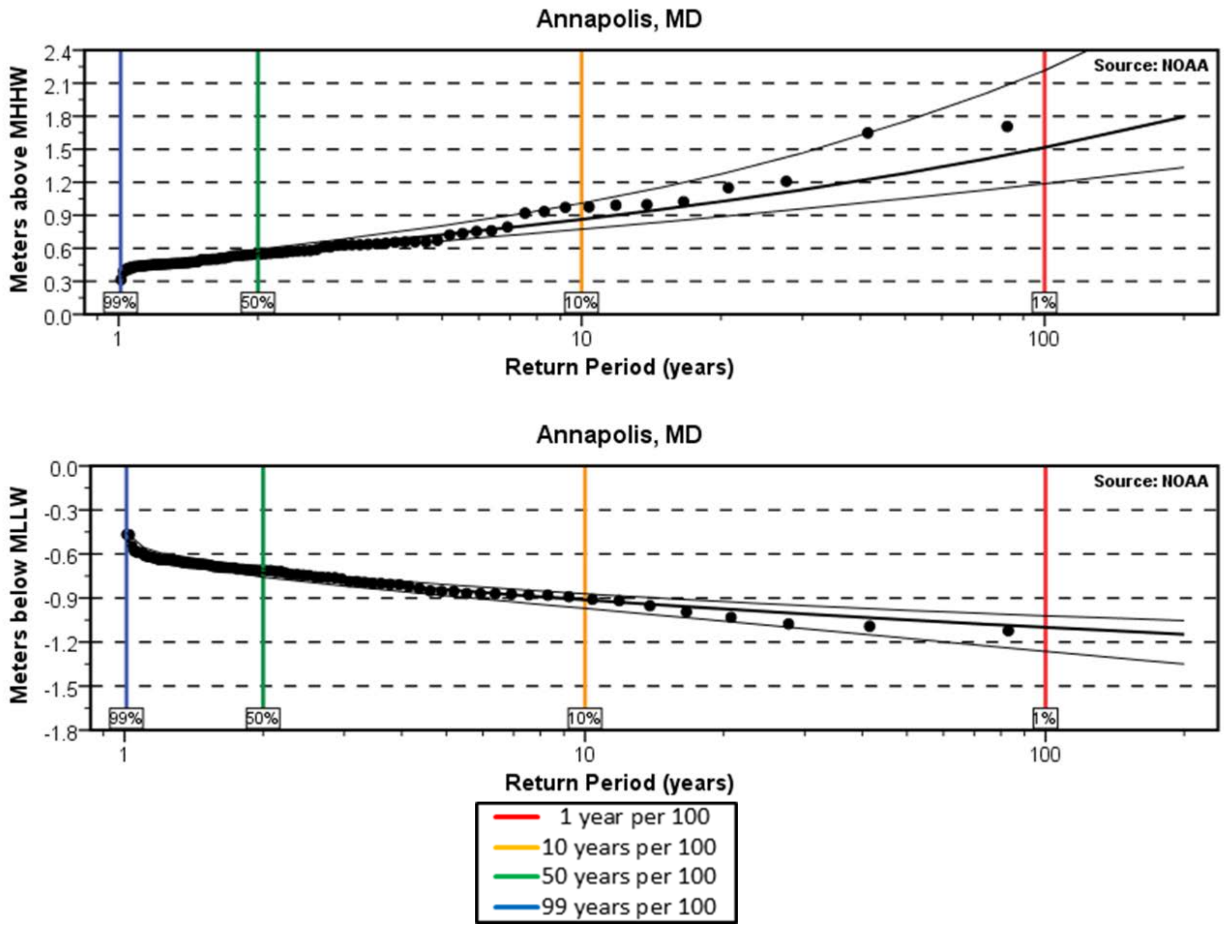


Figure 25. Annual exceedance probability curves for Annapolis, MD**.**

The 1% annual exceedance probability levels are 1.52 meters (4.99 feet) above Mean Higher High Water and 1.10 meters (3.61 feet) below Mean Lower Low Water for Annapolis. The curves were calculated using the CO-OPS Extremes Toolkit software package which fits the three parameters of the GEV probability distribution function to annual maximum or annual minimum data using an iterative maximum likelihood estimation. The spread of the 95% confidence intervals depends on the variability of the source data and the length of the series used. The level of confidence in the exceedance probability level decreases with longer return periods and should always be used in conjunction with the confidence interval in the application of these data. For instance, in the upper panel of Figure 25, the 95% confidence intervals have a large spread [approximately 1.0 meters (3.28 feet)] above and below the estimate for high water extremes and in the lower panel, the spread is approximately 0.600 meters (1.97 feet) for low water extremes. The estimated uncertainty in the elevation of the tidal datums (MHHW and MLLW) is less than 0.01 meters (0.03 feet). The annual exceedance probability curves and statistics at Annapolis are transferable to Poplar Island.

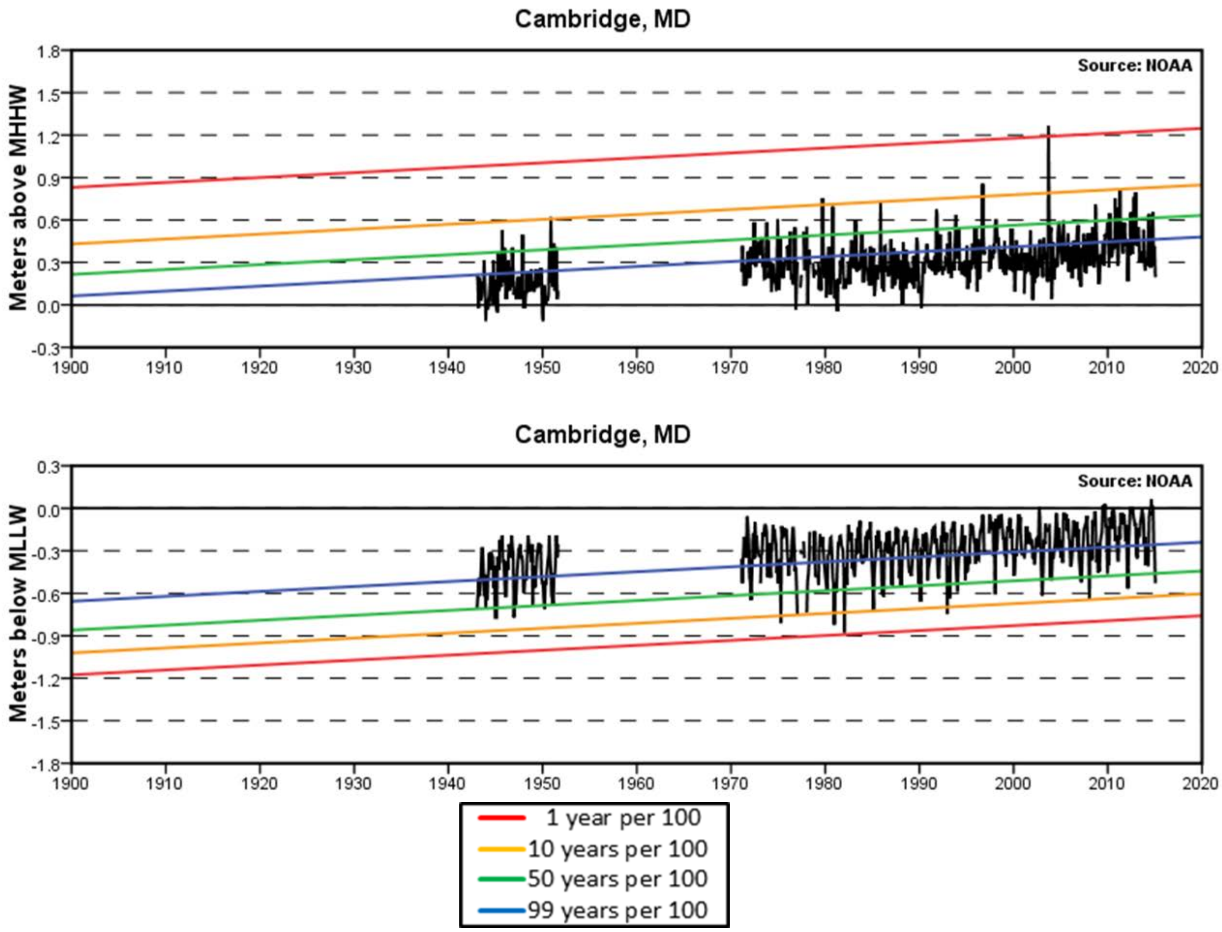


Figure 26. Extreme water levels at Cambridge, MD.

Similarly, Figures 26 and 27 show exceedance probabilities above MHHW and below MLLW for Cambridge using the GEV probability distribution function applied to annual maximum or annual minimum data using interactive maximum likelihood estimation. Due to the shorter record length and the presence of a multi-year gap, the annual exceedance probability curve and statistics determined at Cambridge are not transferable to Poplar Island. The monthly extreme water levels include a Mean Sea Level (MSL) trend of 3.48 millimeters/year (0.14 inches/year) with a 95% confidence interval of +/- 0.39 millimeters/year (0.02 inches/year) based on monthly MSL data from 1943 to 2006 which is equivalent to a change of 1.14 feet (0.35 meters) in 100 years. The top panel of Figure 26 (above), the most extreme high water event occurred during Hurricane Isabel in 2003. This event exceeded the 1% level.

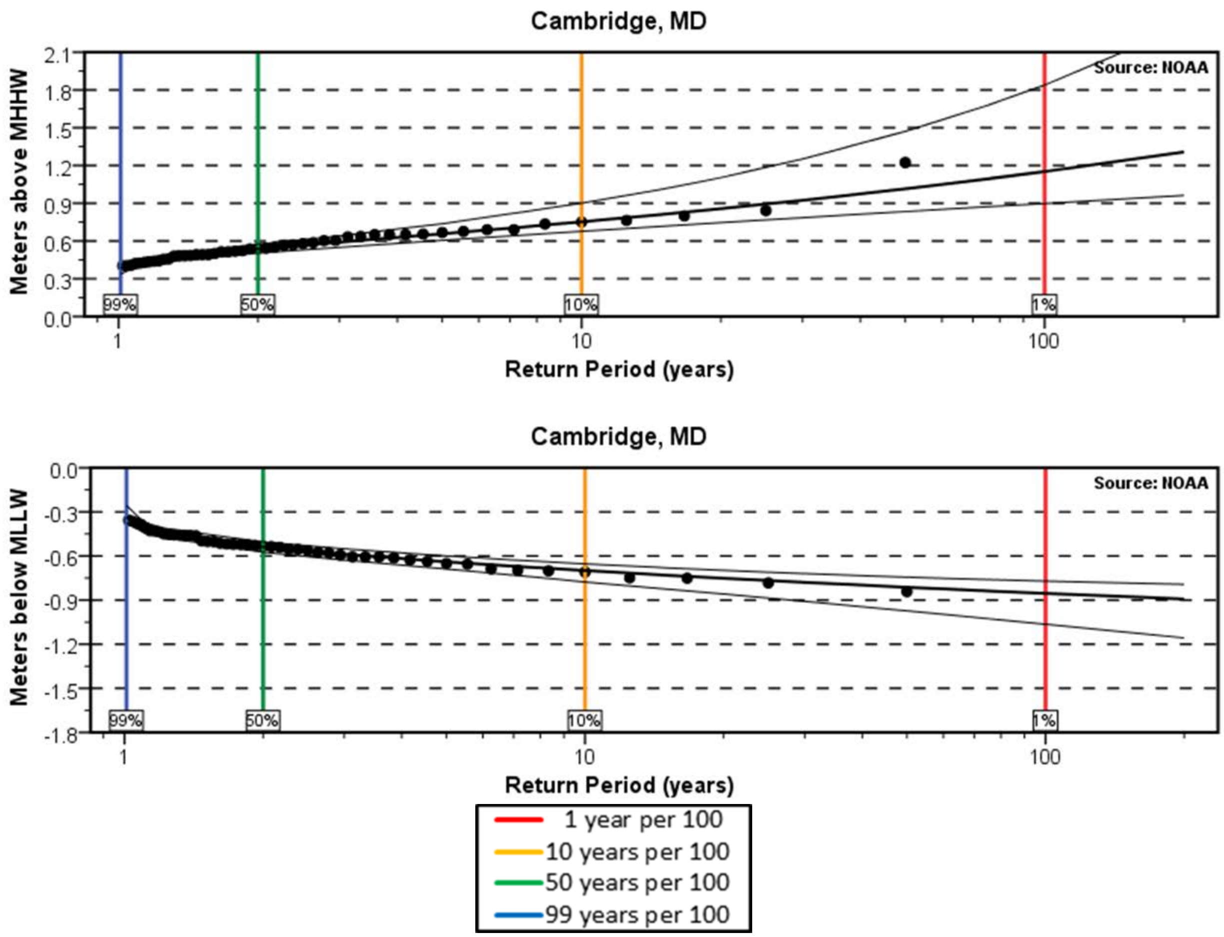


Figure 27. Annual exceedance probability curves for Cambridge, MD.

The 1% annual exceedance probability levels are 1.15 meters (3.77 feet) above Mean Higher High Water and 0.85 meters (2.79 feet) below Mean Lower Low Water for Cambridge. In the upper panel of Figure 27, the 95% confidence intervals have a large spread [approximately 1.2 meters (3.94 feet)] above and below the estimate for high water extremes and in the lower panel, the spread is approximately 0.30 meters (0.98 feet) for low water extremes. Estimated uncertainty in the elevation of the tidal datums (MHHW and MLLW) is 0.00 meters (0.00 feet).

SUMMARY

The water level station at Poplar Island, MD is a long term station established and operated by the USACE to support their project operations in building the island. CO-OPS analyzed approximately three years (October 2006-February 2010) of data for the purpose of establishing accepted NOAA tidal datums, publishing benchmark elevations, and performing frequency and duration of inundation analyses for use by USACE. The data and metadata were quality controlled and documented to meet NOAA standards. The observations at Poplar Island were compared with the two closest NOAA NWLON stations at Annapolis, MD and Cambridge, MD. Although they each have slightly different ranges of tide and times of high and low waters, the water levels at all three locations have very similar responses to regional atmospheric forcing due to changes in wind and barometric pressure. The statistical distributions of the frequency and duration of inundation above MHW are very similar at all three locations. Based on these comparisons, it is recommended that the longer term sea level trends and statistical distribution for inundation and for extreme water levels observed at Annapolis and Cambridge can be used as a proxy for Poplar Island.

USACE's goal was to ensure that all elevations on the island could be accurately related to elevations of surrounding land masses, as well as tidal characteristics derived from nearby water level stations. This information is critical because the frequency and duration of flooding are both dependent upon elevation. The tidal datum elevations and the frequency and duration statistics are specifically being used to design the wetlands and marsh surfaces in specified project areas on the island. This information is also essential for monitoring the impacts of change (in land elevation or water level) over time and projecting the long term sustainability of the restoration project. NOAA products and services will help inform wetland restoration in the face of rising sea levels in this area.

ACKNOWLEDGEMENTS

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APPENDIX 1. Benchmark Sheet

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service

Station ID: 8572271 **PUBLICATION DATE: 03/09/2012**
Name: POPLAR ISLAND
MARYLAND
NOAA Chart: 12270 **Latitude: 38° 45.5' N**
USGS Quad: CLAIRBORNE **Longitude: 76° 22.5' W**

This station was installed in support of a project with the U.S. Army Corp of Engineers (USACE). Due to the special nature of this project, the bench mark are described in terms specific to the project. To reach the tidal bench mark from Lowes Wharf in Sherwood, MD, proceed west by boat for 4.3 km (2.7 miles) to the personnel pier at Poplar Island. The bench mark are located along the islands perimeter road and cross dikes. The tide gauge is located at the SE end of the personnel pier T-section.

T I D A L B E N C H M A R K S

PRIMARY BENCH MARK STAMPING: USACE CM3 2004
DESIGNATION: CM-3 TRUE

MONUMENTATION: Bench Mark disk VM#: 19749
AGENCY: USACE PID:
SETTING CLASSIFICATION: Aluminum rod driven to the ground

The primary bench mark is a disk at the NE corner of cell 4D, 15.68 m (51.4 ft) east of the east corner of the Murden Memorial monument stone, 10.62 m (34.8 ft) WSW of the west corner of the landing craft ramp, and 1.02 m (3.3 ft) NNW of a wooden bollard. The bench mark is set 15 cm (0.5 ft) below ground, crimped to an aluminum rod driven to an unknown depth to substantial resistance, and encased in a 5-inch logo cap.

BENCH MARK STAMPING: NONE
DESIGNATION: SP-6

MONUMENTATION: Pipe Cap VM#: 19750
AGENCY: USACE PID:
SETTING CLASSIFICATION: Driven to the ground

The bench mark is a 2-inch capped pipe at the NE corner of cell 3A, 12.20 m (40.0 ft) ENE of the SE sluice gate operator for spillway #6, 5.55 m (18.2 ft) SE of the SE railing of the gangway for spillway #6, and 3.47 m (11.4 ft) SW of the centerline of the perimeter road. The bench mark is set 30 cm (1.0 ft) below the road grade, driven to an unknown depth to substantial resistance, and encased in a 12-inch steel casing.

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National Ocean Service

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NOAA Chart:	**12270**	**Latitude:**	**38° 45.5' N**
USGS Quad:	**CLAIRBORNE**	**Longitude:**	**76° 22.5' W**

T I D A L   B E N C H   M A R K S

BENCH MARK STAMPING: USACE CM1 2004
DESIGNATION: CM-1

MONUMENTATION:	Bench Mark disk	VM#:	19751
AGENCY:	USACE	PID:	
SETTING CLASSIFICATION:	Aluminum rod driven to the ground		

The bench mark is a disk at the NE corner of cell 3C, 9.99 m (32.8 ft) ESE of the south sluice gate operator for spillway #5, 4.55 m (14.9 ft) south of the south railing of the gangway for spillway #5, and 5.03 m (16.5 ft) west of the centerline of the perimeter road. The bench mark is set 15 cm (0.5 ft) below ground, crimped to an aluminum rod driven to an unknown depth to substantial resistance, and encased in a 5-inch logo cap.

BENCH MARK STAMPING: NONE
DESIGNATION: SP-8

MONUMENTATION:	Pipe Cap	VM#:	19752
AGENCY:	USACE	PID:	
SETTING CLASSIFICATION:	Driven to the ground		

The bench mark is a 2-inch capped pipe at the approximate midpoint of the cross dike, 3.66 m (12.0 ft) NE of the centerline of the cell 1A-3D cross dike, 0.93 m (3.1 ft) SE of the northernmost of two wooden bollards, and 0.91 m (3.0 ft) NNE of the other wooden bollard. The bench mark is set 9 cm (0.3 ft) below ground, driven to an unknown depth to substantial resistance, and encased in a 12-inch steel casing.

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	MARYLAND		
NOAA Chart:	**12270**	**Latitude:**	**38° 45.5' N**
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T I D A L   B E N C H   M A R K S

BENCH MARK STAMPING: PIP 1 2002
DESIGNATION: PIP-1

MONUMENTATION:	Bench Mark disk	VM#:	19753
AGENCY:	USACE	PID:	
SETTING CLASSIFICATION:	Aluminum rod driven to the ground		

The bench mark is a disk at the south edge of cell 3A, 20.12 m (66.0 ft) NNE of the NE corner of a metal shed, 7.94 m (26.0 ft) NW of the center of an abandoned electric box, and 3.93 m (12.9 ft) ENE of the island's well. The bench mark is set 6 cm (0.2 ft) below ground, crimped to an aluminum rod driven to an unknown depth to substantial resistance, and encased in a 4-inch PVC pipe with concrete kickblock.

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USGS Quad: CLAIRBORNE **Longitude: 76° 22.5' W**

T I D A L D A T U M S

Tidal datums at POPLAR ISLAND based on:

LENGTH OF SERIES:	3 YEARS
TIME PERIOD:	March 2007 - February 2010
TIDAL EPOCH:	1983-2001
CONTROL TIDE STATION:	8575512 U.S. NAVAL ACADEMY, SEVERN R., CHES. BAY

Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in METERS:

HIGHEST OBSERVED WATER LEVEL (12/26/2009)		=	1.081
MEAN HIGHER HIGH WATER	MHHW	=	0.469
MEAN HIGH WATER	MHW	=	0.402
MEAN SEA LEVEL	MSL	=	0.236
MEAN TIDE LEVEL	MTL	=	0.233
MEAN LOW WATER	MLW	=	0.065
MEAN LOWER LOW WATER	MLLW	=	0.000
LOWEST OBSERVED WATER LEVEL (01/03/2008)		=	-0.830

Bench Mark Elevation Information In METERS above:

Stamping or Designation	MLLW	MHW
USACE CM3 2004	1.508	1.106
NONE	2.042	1.640
USACE CM1 2004	2.064	1.662
NONE	2.215	1.813
PIP 1 2002	2.773	2.371

Foot Notes:

Bench mark PIP 1 2002 is based on one differential leveling connection and does not meet the quality control standards of the NOS. Therefore, caution should be used when deriving elevations for this mark.

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	MARYLAND		
NOAA Chart:	**12270**	**Latitude:**	**38° 45.5' N**
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D E F I N I T I O N S

Mean Sea Level (MSL) is a tidal datum determined over a 19-year National Tidal Datum Epoch. It pertains to local mean sea level and should not be confused with the fixed datums of North American Vertical Datum of 1988 (NAVD88).

NAVD88 is a fixed datum derived from a simultaneous, least squares, minimum constraint adjustment of Canadian/Mexican/United States leveling observations. Local mean sea level observed at Father Point/Rimouski, Canada was held fixed as the single initial constraint. NAVD88 replaces NGVD29 as the national standard geodetic reference for heights. Bench mark elevations relative to NAVD88 are available from NGS through the World Wide Web at National Geodetic Survey.

NGVD29 is a fixed datum adopted as a national standard geodetic reference for heights but is now considered superseded. NGVD29 is sometimes referred to as Sea Level Datum of 1929 or as Mean Sea Level on some early issues of Geological Survey Topographic Quads. NGVD29 was originally derived from a general adjustment of the first-order leveling networks of the U.S. and Canada after holding mean sea level observed at 26 long term tide stations as fixed. Numerous local and wide-spread adjustments have been made since establishment in 1929. Bench mark elevations relative to NGVD29 are available from the National Geodetic Survey (NGS) data base via the World Wide Web at National Geodetic Survey.

NAVD88 and NGVD29 are fixed geodetic datums whose elevation relationships to local MSL and other tidal datums may not be consistent from one location to another.

The Vertical Mark Number (VM#) and PID# shown on the bench mark sheet are unique identifiers for bench mark in the tidal and geodetic databases, respectively. Each bench mark in either database has a single, unique VM# and/or PID# assigned. Where both VM# and PID# are indicated, both tidal and geodetic elevations are available for the bench mark listed.

The NAVD88 elevation is shown on the Elevations of Tidal Datums Table Referred to MLLW only when two or more of the bench mark listed have NAVD88 elevations. The NAVD88 elevation relationship shown in the table is derived from an average of several bench mark elevations relative to tide station datum. As a result of this averaging, NAVD88 bench mark elevations computed indirectly from the tidal datums elevation table may differ slightly from NAVD88 elevations listed for each bench mark in the NGS database.

APPENDIX 2. Harmonic Constants from Poplar Island, MD

Station Metadata		
Station Id	:	8572271
Station Name	:	Poplar Island
State	:	MD
Latitude	:	38.7583
Longitude	:	-76.375
Time Zone	:	LST
Unit	:	Meters

Center for Operational Oceanographic Products and Services

Name	**--**	**Description**
Cst#	--	Constituent Number Order in which NOS lists the constituents
Name	--	Common name used to refer to a particular constituent, subscript refers to the number of cycles per day
Amplitude Phase	--	One-half the range of a tidal constituent
	--	The phase lag of the observed tidal constituent relative to the theoretical equilibrium tide
Speed	--	The rate change in the phase of a constituent, expressed in degrees per hour. The speed is equal to 360 degrees divided by the constituent period expressed in hours

Cst#	**Name**	**Amplitude**	**Phase**	**Speed**
1	M2	0.156	117.1	28.9841042
2	S2	0.024	142.9	30.0000000
3	N2	0.031	94.9	28.4397295
4	K1	0.053	269.3	15.0410686
5	M4	0.004	135.3	57.9682084
6	O1	0.041	285.3	13.9430356
7	M6	0.002	13.5	86.9523127
8	MK3	0.003	227.9	44.0251729
9	S4	0.000	0.0	60.0000000
10	MN4	0.002	103.8	57.4238337
11	NU2	0.007	102.2	28.5125831
12	S6	0.000	0.0	90.0000000
13	MU2	0.001	190.4	27.9682084
14	2N2	0.004	51.4	27.8953548
15	OO1	0.002	257.9	16.1391017
16	LAM2	0.004	137.7	29.4556253
17	S1	0.017	226.6	15.0000000
18	M1	0.002	316.5	14.4966939
19	J1	0.002	241.0	15.5854433
20	MM	0.010	49.2	0.5443747
21	SSA	0.037	61.7	0.0821373
22	SA	0.113	134.0	0.0410686
23	MSF	0.006	236.0	1.0158958
24	MF	0.009	330.3	1.0980331
25	RHO	0.004	280.9	13.4715145
26	Q1	0.009	267.2	13.3986609
27	T2	0.002	121.1	29.9589333
28	R2	0.002	315.1	30.0410667
29	2Q1	0.003	260.8	12.8542862
30	P1	0.018	255.1	14.9589314
31	2SM2	0.001	85.8	31.0158958
32	M3	0.001	189.1	43.4761563
33	L2	0.010	142.0	29.5284789
34	2MK3	0.003	221.1	42.9271398
35	K2	0.006	137.6	30.0821373
36	M8	0.000	0.0	115.9364166
37	MS4	0.001	185.4	58.9841042