

December 10, 2007

This is a letter report to provide you with the methodology and results of the analysis performed by Woods Hole Group to determine tidal datums from tidal records obtained from gauges deployed by the New Jersey Meadowlands Commission (NJMC). As stated in our letter dated August 1, 2007, Woods Hole Group was to determine tidal datums, in reference to the superceded 1960-1978 and the current 1983-2001 National Tidal Datum Epochs (NTDEs), from the time series data provided by the NJMC. The tidal datums analyzed include: MHWS, MHHW, MTL, MLLW, and MLWS. The tidal datums were computed using both the observed data and reconstructed data that were synthesized from a harmonic analysis of the tidal records. This report will present an overview of the data, then summarize methods, and finally present the resultant datums.

Data

Woods Hole Group used data provided and proofed by the NJMC for eleven (11) water level gauges located within the Meadowlands district. The data were provided to Woods Hole Group in Excel spreadsheets. The provided data were retrieved from gauges by the NJMC for various time periods over the past ten years. The gauges recorded water elevation data at intervals ranging from 6 minutes to 1 hour. The eleven stations were numbered and are summarized in Table 1.

The tidal records obtained from the NJMC required minor pre-processing prior to the datum analysis. Station 4 (Mill Creek Point) showed data recorded in the "Mountain Daylight Time" time zone, which was converted to "Eastern Standard Time". Two data files were provided for Station 5 (Secaucus High School Creek), which were combined to provide a continuous dataset. Also, the data recorded at Station 7 was provided in reference to the NGVD92 vertical datum, which required conversion to the NAVD88 datum, as requested by the NJMC.

To verify the water elevation observations for amplitude and phase accuracy, Woods Hole Group visually compared the provided tidal records with NOAA/NOS data obtained for NOS Station 8518750, The Battery, New York Harbor, NY, which serves as a reference station. Figure 1 show the comparison between the water elevation time series recorded by NOAA at the Battery and Station 9 (Mill Creek, New and Current) for the period January 1 through April 20, 2007.

Table 1. NJMC Tidal Stations

Station Number	Station Name	Recording Period	Recording Interval	NJMC Filename
1	Mill Creek (Old)	5/28/98-09/25/98	30 min.	MCTG1998.xls
2	Berry's Creek Canal (Old)	6/23/99-06/27/00	15 min.	bcc041000.xls, BC062700.xls
3	Hackensack River (Riverbend)	6/23/99-09/13/00	15 min.	RB091300.xls
4	Mill Creek Point	4/03/03-12/22/03	15 min.	Mill Creek Point Tides.xls
5	Secaucus High School (SHS) Creek	6/07/05-9/22/05, 9/22/05-1/04/06	6 min.	SHS Creek(6-7-05 to 9-22-05).xls, SHS Creek test 2(9-22-05 to 1-4-06).xls
6	Harrier Meadow (Outer Bay)	11/18/02-09/24/03	15 min.	Harrier Outer Bay final(11-15-02 to 9-24-03).xls
7	Harrier Meadow Zone 1 (Impoundment)	2/23/05-5/12/05	15 min.	Zone1 (Impoundment) Final.xls
8	Harrier Meadow Zone 2 (Tidal)	2/23/05-6/01/05	15 min.	Zone2 (Tidal) Final.xls
9	Mill Creek (New and Current)	1/01/06-5/18/07	1 hr.	Mill Creek Tide Data Jan06 thu May 07.xls
10	Berry's Creek Canal (New and Current)	5/01/06-5/18/07	1 hr.	Berrys Creek Tide Data May06 thu May07.xls
11	Hackensack River (Kearny, New and Current)	3/01/06-9/02/06	1 hr.	Kearny Tide Data Mar06 thu Sept06.xls

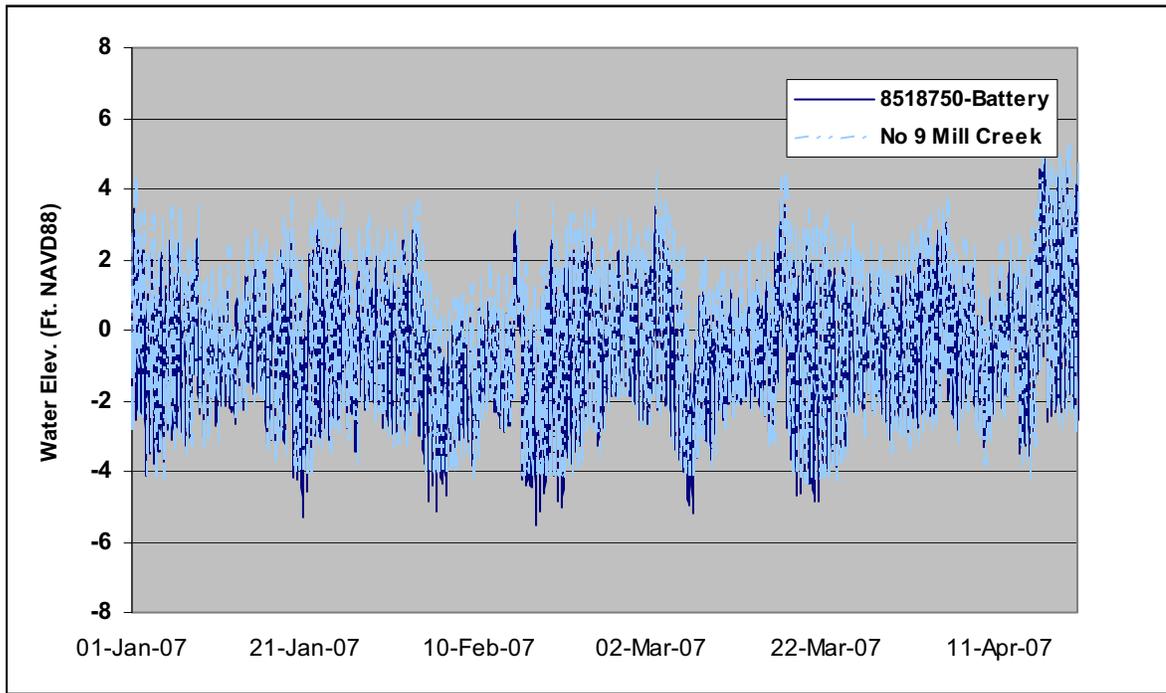


Figure 1. Comparison between Station 9 Mill Creek tide gauge and reference station 8518750-The Battery

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Procedures for Computation of Tidal Datums

Tidal datums were calculated relative to the North Atlantic Vertical Datum of 1998 (NAVD88) at the NJMC's request. The calculated tidal datums were:

- MHWS (Mean High Water Spring)
- MHHW (Mean Higher High Water)
- MHW (Mean High Water)
- MTL (Mean Tide Level)
- MLW (Mean Low Water)
- MLLW (Mean Lower Low Water)
- MLWS (Mean Low Water Spring)

Two numerical methods were used to compute the tidal datums. Datums were first computed using the observed data. Secondly, datums were computed using data reconstructed from harmonic constituents obtained from the observed tidal records that had sufficient, long term series data. Datums were evaluated for the 1960-1978 and 1983-2001 NTDEs using NOS Station 8518750, The Battery, as a control station. Tidal data was obtained for NOS Station 8518750 from <http://co-ops.nos.noaa.gov>.

The first numerical method involved processing the water level observations and using the observation data to determine the high and low tidal elevations for each day. Tidal datums were then computed by meaning values of the tidal parameters over the time period. The modified-range method detailed by NOAA¹ was employed to compute the datums. Once the tidal datums were computed from the tidal record for the period of measurement, the datums were referenced to the 1960-1978 and 1983-2001 NTDEs using the simultaneous comparison method.

The simultaneous comparison/modified-range method involved obtaining tidal datums at the control station for the periods of observation. The mean differences in the tidal parameters between the subordinate and control stations over the time periods were then computed. Accepted 1960-1978 and 1983-2001 NTDE values of the tidal datums at the control station were next obtained. The mean differences found between the subordinate and control stations for the period of observation were then applied to the accepted NTDE values at the control station to obtain the equivalent NTDE tidal datums for the subordinate stations. Using this comparison method, the MTL, diurnal tide level (DTL), mean range (Mn), and great diurnal range (Gt) datums are first determined. The MLLW, MLW, MHW, and MHHW datums are then computed using formulas involving the MTL, DTL, Mn, and Gt datums. The MLWS and MHWS tidal datums were determined using a method described by Marmer², which involves the use of the semi-diurnal principal solar harmonic constituent S_2 .

¹ National Oceanic and Atmospheric Administration (NOAA), Computational Techniques for Tidal Datums Handbook, National Ocean Service, Center for Operational Products and Services, Silver Spring, MD, 2003.

² Marmer, H.A., Tidal Datum Planes, NOAA National Ocean Service, Special Publication No. 135, U.S. Coast and Geodetic Survey, U.S. Govt. Printing Office, revised ed., 1951.

The second numerical method in determining the tidal datums involved using a tidal harmonic analysis technique introduced by Foreman in 1978 to obtain site-specific tidal constituents from the observed tidal record based on known tidal frequencies³. These tidal harmonic constituents were then used to reconstruct the tidal signal that would have been observed in the same region, assuming no morphological changes. Once the reconstructed tidal record was obtained, the same procedures used for the observed tidal records were employed to compute the tidal datums for the 1960-1978 and 1983-2001 NTDEs.

Results

Using the methods described above, tidal datums were computed for the 1960-1978 NTDE and 1983-2001 NTDE and are presented in Tables 2 through 12.

The results presented in Tables 2 through 12 show the tidal datums that were computed using both the observed data and the data reconstructed from harmonic constituents. The datums computed using the harmonic constituents as a quality control measure are shown for comparison purposes.

Table 2. Tidal datums for Station 1, in feet NAVD88

Datum	Observed			Reconstructed		
	Data	1960-1978 NTDE	1983-2001 NTDE	Data	1960-1978 NTDE	1983-2001 NTDE
MHWS	3.42	2.97	3.13	3.41	2.96	3.12
MHHW	3.29	2.89	3.02	3.26	2.86	3.00
MHW	3.04	2.59	2.74	3.03	2.57	2.73
MTL	0.34	-0.11	0.06	0.33	-0.12	0.05
MLW	-2.36	-2.81	-2.63	-2.37	-2.82	-2.64
MLLW	-2.58	-3.11	-2.90	-2.54	-3.06	-2.85
MLWS	-2.75	-3.20	-3.01	-2.75	-3.21	-3.02

Table 3. Tidal datums for Station 2 gauge, in feet NAVD88

Datum	Observed			Reconstructed		
	Data	1960-1978 NTDE	1983-2001 NTDE	Data	1960-1978 NTDE	1983-2001 NTDE
MHWS	3.05	2.84	3.00	3.02	2.81	2.97
MHHW	2.87	2.69	2.83	2.82	2.63	2.77
MHW	2.59	2.38	2.54	2.56	2.35	2.51
MTL	-0.26	-0.46	-0.29	-0.23	-0.42	-0.25
MLW	-3.12	-3.30	-3.11	-3.03	-3.20	-3.02
MLLW	-3.37	-3.54	-3.34	-3.16	-3.33	-3.13
MLWS	-3.58	-3.76	-3.57	-3.49	-3.66	-3.48

³ R. Pawlowicz, B. Beardsley, and S. Lentz, "Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE", Computers and Geosciences, 28, 929-937, 2002.

Table 4. Tidal datums for Station 3, in feet NAVD88

Datum	Observed			Reconstructed		
	Data	1960-1978 NTDE	1983-2001 NTDE	Data	1960-1978 NTDE	1983-2001 NTDE
MHWS	2.85	2.57	2.73	2.89	2.61	2.76
MHHW	2.68	2.44	2.57	2.70	2.46	2.59
MHW	2.40	2.12	2.28	2.43	2.16	2.31
MTL	-0.34	-0.59	-0.42	-0.26	-0.52	-0.35
MLW	-3.08	-3.31	-3.13	-2.96	-3.19	-3.00
MLLW	-3.32	-3.56	-3.36	-3.09	-3.33	-3.13
MLWS	-3.54	-3.76	-3.58	-3.41	-3.64	-3.45

Table 5. Tidal datums for Station 4, in feet NAVD88

Datum	Observed			Reconstructed		
	Data	1960-1978 NTDE	1983-2001 NTDE	Data	1960-1978 NTDE	1983-2001 NTDE
MHWS	3.42	3.13	3.28	3.34	3.05	3.20
MHHW	3.29	2.99	3.12	3.18	2.87	3.01
MHW	2.98	2.69	2.84	2.90	2.61	2.76
MTL	0.21	-0.16	0.01	0.21	-0.17	0.00
MLW	-2.57	-3.02	-2.83	-2.49	-2.94	-2.76
MLLW	-2.78	-3.24	-3.04	-2.63	-3.09	-2.89
MLWS	-3.00	-3.46	-3.27	-2.93	-3.38	-3.20

Table 6. Tidal datums for Station 5, in feet NAVD88

Datum	Observed			Reconstructed		
	Data	1960-1978 NTDE	1983-2001 NTDE	Data	1960-1978 NTDE	1983-2001 NTDE
MHWS	3.15	2.83	2.98	3.13	2.81	2.96
MHHW	3.07	2.72	2.85	3.03	2.68	2.82
MHW	2.71	2.39	2.54	2.68	2.36	2.52
MTL	0.08	-0.36	-0.19	0.11	-0.33	-0.16
MLW	-2.54	-3.10	-2.91	-2.47	-3.03	-2.84
MLLW	-2.70	-3.24	-3.04	-2.61	-3.16	-2.95
MLWS	-2.98	-3.54	-3.35	-2.92	-3.47	-3.28

Table 7. Tidal datums for Station 6, in feet NAVD88

Datum	Observed			Reconstructed		
	Data	1960-1978 NTDE	1983-2001 NTDE	Data	1960-1978 NTDE	1983-2001 NTDE
MHWS	2.54	2.38	2.53	2.01	1.85	2.00
MHHW	2.51	2.34	2.47	1.77	1.59	1.73
MHW	2.14	1.98	2.14	1.61	1.45	1.61
MTL	-0.29	-0.52	-0.35	-0.17	-0.39	-0.22
MLW	-2.73	-3.02	-2.83	-1.94	-2.23	-2.04
MLLW	-2.99	-3.28	-3.08	-2.05	-2.34	-2.13
MLWS	-3.13	-3.41	-3.23	-2.34	-2.62	-2.44

Table 8. Tidal datums for Station 7, in feet NAVD88

Datum	Observed			Reconstructed		
	Data	1960-1978 NTDE	1983-2001 NTDE	Data	1960-1978 NTDE	1983-2001 NTDE
MHWS	3.00	2.63	2.78	2.89	2.52	2.68
MHHW	3.04	2.71	2.85	2.89	2.56	2.70
MHW	2.76	2.39	2.55	2.65	2.29	2.44
MTL	1.21	0.73	0.90	1.23	0.75	0.92
MLW	-0.34	-0.93	-0.74	-0.19	-0.78	-0.59
MLLW	-0.47	-1.04	-0.84	-0.25	-0.83	-0.62
MLWS	-0.58	-1.16	-0.98	-0.43	-1.02	-0.83

Table 9. Tidal datums for Station 8, in feet NAVD88

Datum	Observed			Reconstructed		
	Data	1960-1978 NTDE	1983-2001 NTDE	Data	1960-1978 NTDE	1983-2001 NTDE
MHWS	3.50	3.13	3.29	3.46	3.10	3.25
MHHW	3.36	3.04	3.17	3.28	2.96	3.10
MHW	3.09	2.72	2.88	3.05	2.68	2.84
MTL	0.61	0.13	0.30	0.68	0.20	0.37
MLW	-1.87	-2.46	-2.27	-1.70	-2.29	-2.10
MLLW	-2.07	-2.65	-2.44	-1.85	-2.43	-2.23
MLWS	-2.28	-2.87	-2.68	-2.11	-2.70	-2.51

Table 10. Tidal datums for Station 9, in feet NAVD88

Datum	Observed			Reconstructed		
	Data	1960-1978 NTDE	1983-2001 NTDE	Data	1960-1978 NTDE	1983-2001 NTDE
MHWS	3.25	3.14	3.30	3.01	2.90	3.05
MHHW	3.15	3.01	3.14	2.87	2.74	2.87
MHW	2.82	2.71	2.86	2.58	2.47	2.62
MTL	0.10	-0.12	0.05	0.06	-0.16	0.01
MLW	-2.62	-2.95	-2.77	-2.45	-2.78	-2.60
MLLW	-2.87	-3.20	-3.00	-2.61	-2.94	-2.73
MLWS	-3.05	-3.39	-3.20	-2.88	-3.22	-3.03

Table 11. Tidal datums for Station 10, in feet NAVD88

Datum	Observed			Reconstructed		
	Data	1960-1978 NTDE	1983-2001 NTDE	Data	1960-1978 NTDE	1983-2001 NTDE
MHWS	3.42	3.29	3.45	3.20	3.07	3.22
MHHW	3.34	3.18	3.32	3.09	2.94	3.07
MHW	3.01	2.87	3.03	2.79	2.65	2.81
MTL	0.36	0.10	0.27	0.44	0.18	0.35
MLW	-2.29	-2.67	-2.48	-1.91	-2.29	-2.11
MLLW	-2.56	-2.94	-2.73	-2.08	-2.46	-2.26
MLWS	-2.70	-3.09	-2.90	-2.33	-2.71	-2.52

Table 12. Tidal datums for Station 11, in feet NAVD88

Datum	Observed			Reconstructed		
	Data	1960-1978 NTDE	1983-2001 NTDE	Data	1960-1978 NTDE	1983-2001 NTDE
MHWS	4.47	4.20	4.36	4.42	4.15	4.31
MHHW	4.32	4.05	4.19	4.26	4.00	4.13
MHW	4.03	3.76	3.92	3.98	3.71	3.86
MTL	1.53	1.14	1.31	1.55	1.16	1.33
MLW	-0.98	-1.48	-1.29	-0.88	-1.38	-1.20
MLLW	-1.21	-1.73	-1.53	-1.07	-1.59	-1.39
MLWS	-1.42	-1.92	-1.74	-1.33	-1.83	-1.64

Summary

Tidal datums were computed for 11 locations within the NJMC district where water level observations were made over the course of the past ten years. The water level data required minor pre-processing before the datums could be analyzed. The tidal record obtained from Station 9 (Mill Creek, New and Current) gauge required no pre-processing and compared well with a nearby NOS reference station. Tidal datums were computed for each station's period of observation and for the 1960-1978 and 1983-2001 NTDEs based on published algorithms. Tidal datums were computed using both the observed data and data reconstructed from a harmonic analysis of the observed tidal records.

The 1960-1978 and 1983-2001 NTDE tidal datums were computed based upon observations made at a control station, The Battery NOS Station 8518750 in New York Harbor, NY. Control tide stations are generally those that have operated for 19 or more years, are expected to continuously operate in the future, and are used to obtain a continuous record of the water levels in a locality. Differences seen at the control station between the datums computed for the period of observation and the accepted values for the tidal epoch were applied to the subordinate stations within the same locality.

The differences between the datums representing different time periods may be due to a variety of mechanisms, including sea level rise, subsidence, weather events, and seasonal fluctuations. The tidal datums based on recently observed data are best used to represent current physical processes. While the datums based on the 1960-1978 NTDE may less accurately represent present day tides, they are generally legally binding and may be used for legal delineation.

NOAA/NOS implemented the 1983-2001 NTDE in 2003 to reflect changes in mean sea level along the nation's coast. The 1983-2001 NTDE is the current epoch used in reporting datums for NOAA water level recording stations.

If you should have any questions, concerns or comments please feel free to give us a call at any time.

Sincerely,



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