Digital Elevation Model of Puget Sound, Washington: Procedures, Data Sources, and Analysis

Prepared for the National Tsunami Hazard Mitigation Program (NTHMP) by the NOAA National Geophysical Data Center (NGDC)
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Summary

In June of 2014, NOAA's National Geophysical Data Center (NGDC) developed an integrated bathymetric–topographic digital elevation model (DEM) of Puget Sound, Washington for the National Tsunami Hazard Mitigation Program (NTHMP). The DEM will be used to support modeling tsunami generation, propagation, and inundation. The DEM covers Puget Sound including the communities of Seattle, Tacoma, Everett, and Olympia and provides an updated model for the Tacoma DEM developed by NOAA's National Center for Tsunami Research in 2006. Extents of this DEM, procedures, data sources, and analysis are described below. The methodologies used by NGDC in developing DEM are described in the NOAA Technical Memorandum-52 for Central California and San Francisco Bay (Carignan et al., 2011).

DEM Specifications

The Puget Sound DEM was built to the specifications listed in Table 1. Figure 1 shows the new 1/3 arc-second Puget Sound DEM boundary in green and previously developed DEM boundaries in red.

Table 1. Specifications for the Puget Sound, Washington DEM.

Cell Size	1/3 arc-second
Coverage	122.16° to 123.18° W, 47.01° to 48.19° N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	NAVD 88
Vertical Units	Meters
Grid Format	ASCII raster grid

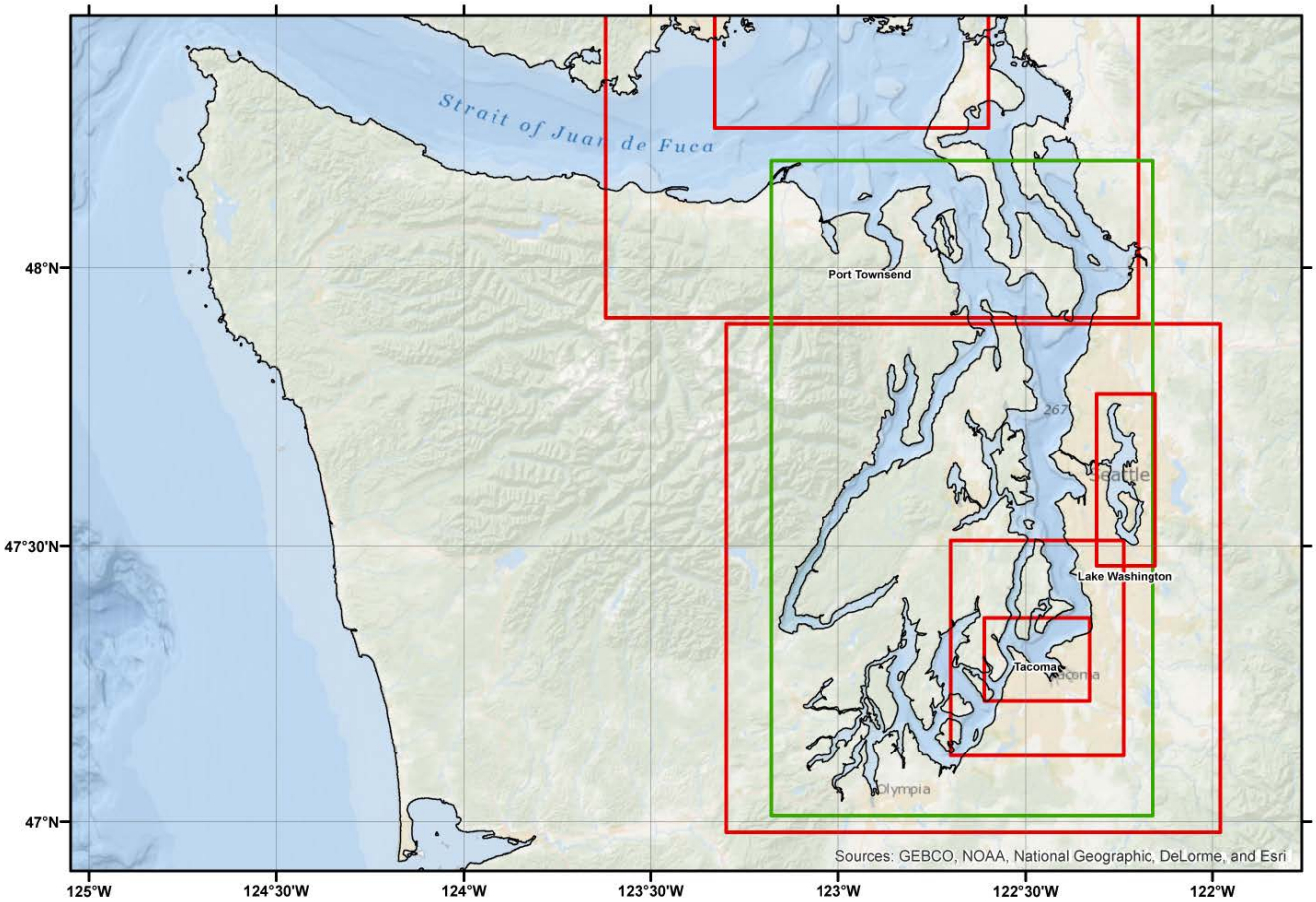

Figure 1. Map image of the boundaries for the 1/3 arc-second Puget Sound DEM in green and the previous DEMs in red.

Data Sources and Processing

A digital coastline was extracted from NOAA's Office of Coast Survey (OCS) ENC Direct to GIS online extraction service (http://nauticalcharts.noaa.gov/csdl/ctp/encdirect_new.htm). The coastline was edited to match either recently acquired high resolution lidar data or imagery available via Google Earth and ESRI's World Imagery map service (http://www.arcgis.com/features/maps/imagery.html). Figure 2 shows the source and coverage of the datasets used in developing the Puget Sound DEM.

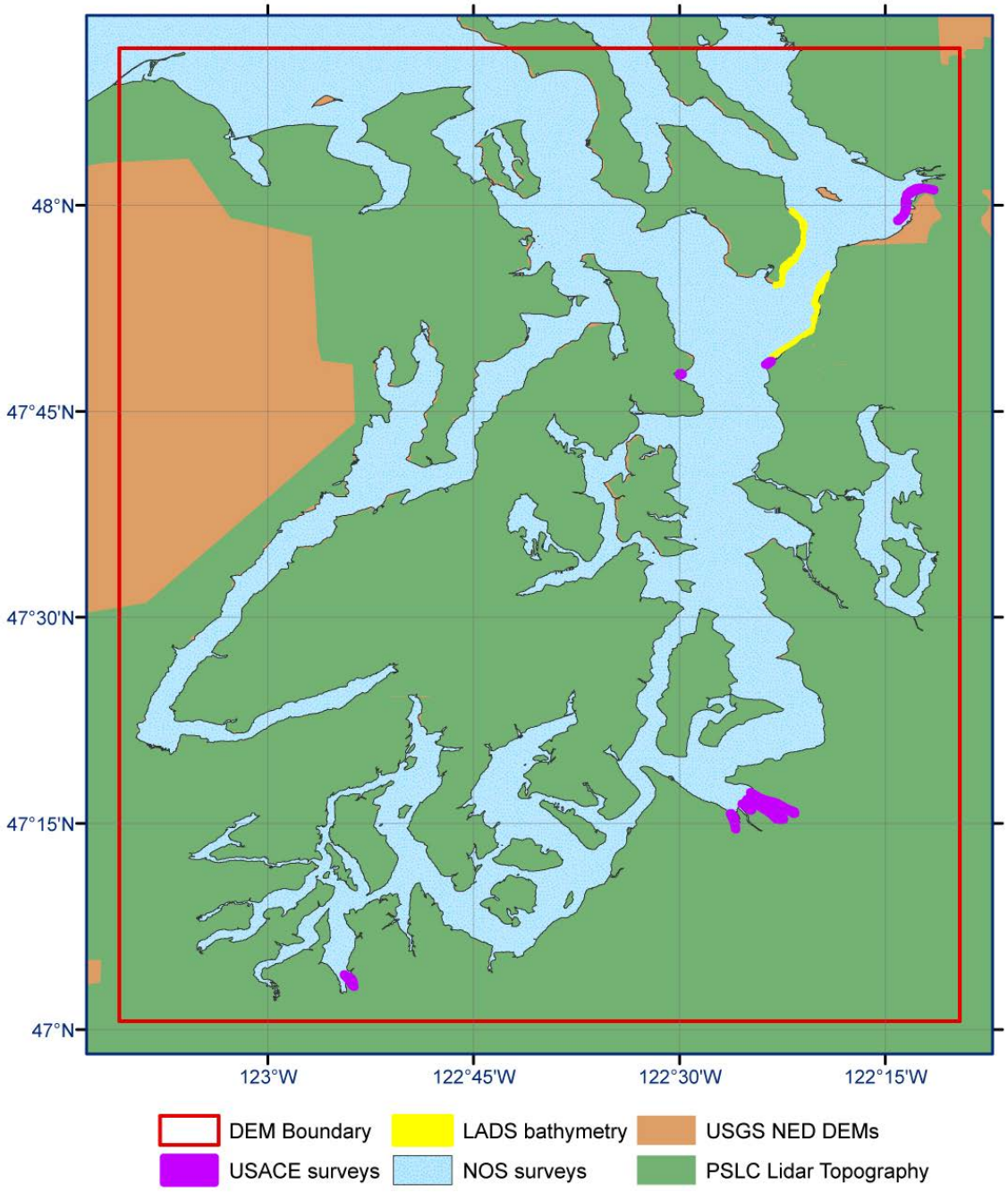

Figure 2. Source and coverage of the datasets used in compiling the Puget Sound DEM.

Table 2 lists the bathymetry data used in the compilation of the Puget Sound DEM including NOS hydrographic surveys (Appendix A), PSLC, and USACE harbor surveys. The USACE Seattle District provided NGDC with hydrographic condition survey data for several areas within the sound. NOS hydrographic survey data were downloaded from NGDC.

Table 2: Bathymetric data sources used in compiling the Puget Sound DEM.

Source	*Date*	*Data Type*	*Spatial Resolution*	*Horizontal Datum*	*Vertical Datum*
NOAA NOS	1894 to 2011	Hydrographic survey soundings	< 1 meter to several kilometers	Unknown, NAD 1927 geographic, NAD 83 geographic, or NAD 83 UTM Zone 10 North	Mean Lower Low Water (MLLW) or Lake Washington Low Water Datum
USACE	2008 to 2014	Hydrographic condition survey	meters	NAD 83 WA State Plane 4601 or 4602 (feet)	MLLW
PSLC – Tenix LADS	2001	Bathymetric Lidar	10,000	WGS 84 UTM Zone 10 North	MLLW

Bathymetric data were transformed to WGS 84 and NAVD 88 and where recent, higher resolution data exists, older data were superseded. Vertical datum transformations were completed using VDatum software. Outside VDatum boundaries, a constant value was applied based on extending the existing VDatum offsets. In Lake Washington a conversion value based on Lake Levels was used (Chamberlain, 2010). Table 3 illustrates the range of vertical datums within Puget Sound.

Table 3: Puget Sound datum information. Difference in vertical datums to MLLW in meters.

	Seattle	*Lake Washington*	*Lake Wash. Ship Canal*	*Tacoma*	*Pt. Townsend*	*Bremerton*	*Union, Hood Canal*	*Bangor*
Lake Wash. High Water (summer)		6.435						
Lake Wash. Low Water Datum		5.825						
Highest Observed Water Level	4.415			4.437	3.574			
MHHW	3.462			3.596	2.596	3.578	3.613	3.374
MHW	3.198			3.329	2.389	3.31	3.312	3.103
MTL	2.031			2.099	1.575	2.089	2.122	1.99
MSL	2.023			2.09	1.522	2.08	2.115	1.978
			1.696					
MLW	0.864			0.869	0.76	0.868	0.917	0.877
NAVD88	0.715			0.749	0.338	0.769	0.865	0.728
MLLW	0	0	0	0	0	0	0	0
Lowest Observed Water Level	-1.535			-1.434	-1.287			

The bathymetric data were converted to xyz format before combining with the coastline data to generate a bathymetric pre-surface at 1/3 arc-second. This bathymetric surface grid was converted to xyz format before incorporating in the final DEM.

Topographic data used in developing the Puget Sound DEM are listed in Table 4. Transformations to WGS 84 geographic were done using PROJ4. As all topographic data were delivered in NAVD 88, no vertical datum changes were necessary. All topographic data were converted to xyz format for the final gridding process. The converted xyz data files were clipped to the coastline to remove both NoData values and returns over water. Several breakwater features were not captured in either the lidar or NED data. NGDC manually digitized the Shilshole and Des Moines breakwaters based on elevation values from USACE or elevation data points along the feature. Additional data points were added to other breakwaters to ensure the feature was resolved at the 1/3 arc-second cell size.

Table 4: Topographic data sources used in compiling the Puget Sound DEM.

Source	*Date*	*Data Type*	*Spatial Resolution*	*Horizontal Datum*	*Vertical Datum*
PSLC	1996 to 2012	Bare-earth Lidar	< 1 meter	NAD 83 Washington State Plane North (feet) or NAD 83 Washington State Plane South (feet)	NAVD 88
USGS NED	1999 to 2012	Topographic DEM	1/9 and 1/3 arc second	NAD 83 geographic	NAVD 88

DEM Development

Development of the Puget Sound DEM followed procedures documented in NOAA Technical Memorandum NGDC-52 for Central California and San Francisco Bay (Carignan et al., 2011). Exceptions being the bathymetric pre-surface was generated at 1/3 arc-second. Gridding weight was modified to Table 5.

Table 5: Data hierarchy used to assign gridding weight in MB-System.

Dataset	*Relative Gridding Weight*
NOS hydrographic surveys (Lake Washington)	1000
USACE hydrographic survey	100
NGDC digitized breakwater	100
NOS BAG surveys	100
PSLC Jefferson-Clallam Co. 2012	100
PSLC Pierce Co. 2010	100

PSLC Snohomish 2010	100
PSLC Thurston 2010	100
PSLC 2005 Edmonds	10
PSLC 2005 Lynnwood	10
PSLC 2005 Marysville	10
PSLC 2005 Fischer-Susan	10
PSLC 2005 Mukilteo	10
PSLC Snohomish 2005-06	10
PSLC Snohomish 2003	10
PSLC VTMPJ 2002	10
PSLC Clallam 2001	10
PSLC Island-Jefferson Co. 2001	10
PSLC 2000	10
NOS hydrographic surveys (non-BAG)*	10
NOS hydrographic surveys (No VDatum)	10
1/3 arc-sec. bathymetric surface	10
PSLC Bainbridge Island	1
PSLC 2003 King County	1
USGS NED DEMs	1
PSLC LADS bathymetry	1
Coastline	1

***NOS hydrographic survey data collected pre NAD 1983 were only used in developing the bathymetric surface and not in the final grid.**

MHW DEM Development

The MHW Puget Sound DEM was developed by generated a conversion grid based on VDatum software. The completed conversion grid was then applied to the NAVD 88 DEM. Version 2 of the Strait of Juan de Fuca MHW VDatum conversion grid created an ~ 0.5 meter offset at latitude 48.10 N. Version 1 was used as the merged grid had no offset.

DEM Analysis

The completed Puget Sound DEM was compared to ENC sounding data, topographic benchmarks, and high resolution imagery. Inconsistencies were evaluated and resolved based on most current or reliable data available.

Acknowledgement

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Appendix A: NOS Surveys

Survey ID	*Date*	*Scale*	*Original Horizontal Datum*	*Original Vertical Datum*
F00236	1981	5000	North American Datum 1927	MLLW
F00427	1996	5000	North American Datum 1983	MLLW
F00468	2000	5000	North American Datum 1983 UTM 10	MLLW
F00479	2001	2500	North American Datum 1983 UTM 6	MLLW
F00541	2007	5000	North American Datum 1983 UTM 10	MLLW
F00568	2009	5000	North American Datum 1983 UTM 10	MLLW
F00589	2010	10000	North American Datum 1983 UTM 10	MLLW
H02211	1894	40000	Unknown	MLLW
H02608	1902	10000	Unknown	MLLW
H02609	1902	10000	Unknown	MLLW
H02610	1902	10000	Unknown	MLLW
H03998	1917	5000	Unknown	MLW
H05576	1934	10000	North American Datum 1927	MLLW
H05577	1936	10000	North American Datum 1927	MLLW
H05652	1934	10000	North American Datum 1927	MLLW
H05709	1935	20000	North American Datum 1927	MLLW
H05710	1934	10000	North American Datum 1927	MLLW
H05711	1936	10000	North American Datum 1927	MLLW
H05724	1936	10000	North American Datum 1927	MLLW
H05725	1936	20000	North American Datum 1927	MLLW
H05844	1935	5000	North American Datum 1927	MLLW
H05845	1935	5000	North American Datum 1927	MLLW
H05846	1935	5000	North American Datum 1927	MLLW
H05930	1935	10000	North American Datum 1927	MLLW
H05931	1935	10000	North American Datum 1927	MLLW
H05932	1935	10000	North American Datum 1927	MLLW
H05933	1935	10000	North American Datum 1927	MLLW
H06101	1935	20000	North American Datum 1927	MLLW
H06102	1936	10000	North American Datum 1927	MLLW
H06103	1936	10000	North American Datum 1927	MLLW
H06104	1935	10000	North American Datum 1927	MLLW
H06105	1935	20000	North American Datum 1927	MLLW
H06106	1935	10000	North American Datum 1927	MLLW
H06107	1935	20000	North American Datum 1927	MLLW
H06108	1936	10000	North American Datum 1927	MLLW
H06193	1937	5000	North American Datum 1927	MLLW
H06197	1936	10000	North American Datum 1927	MLLW
H06198	1936	10000	North American Datum 1927	MLLW
H06199	1936	5000	North American Datum 1927	MLLW
H06200	1936	5000	North American Datum 1927	MLLW
H06201	1936	5000	North American Datum 1927	MLLW
H06202	1936	10000	North American Datum 1927	MLLW
H06203	1936	10000	North American Datum 1927	MLLW
H06204	1936	10000	North American Datum 1927	MLLW
H06205	1936	10000	North American Datum 1927	MLLW

Survey ID	*Date*	*Scale*	*Original Horizontal Datum*	*Original Vertical Datum*
H06612	1941	20000	North American Datum 1927	MLLW
H06614	1941	10000	North American Datum 1927	MLLW
H06616	1941	10000	North American Datum 1927	MLLW
H06618	1940	5000	North American Datum 1927	MLLW
H06650	1940	10000	North American Datum 1927	MLLW
H06651	1941	10000	North American Datum 1927	MLLW
H06652	1941	20000	North American Datum 1927	MLLW
H06653	1943	40000	North American Datum 1927	MLLW
H06750	1941	10000	North American Datum 1927	MLLW
H06751	1942	5000	North American Datum 1927	MLLW
H06757	1942	5000	North American Datum 1927	MLLW
H06816	1943	10000	North American Datum 1927	MLLW
H06817	1943	10000	North American Datum 1927	MLLW
H07045	1945	20000	North American Datum 1927	MLLW
H07076	1946	1200	North American Datum 1927	MLLW
H07099	1947	10000	North American Datum 1927	MLLW
H07168	1946	600	North American Datum 1927	MLLW
H07613	1948	10000	North American Datum 1927	MLLW
H07929	1944	10000	North American Datum 1927	MLLW
H08173	1954	5000	North American Datum 1927	MLLW
H08174	1954	10000	North American Datum 1927	MLLW
H08199	1962	5000	North American Datum 1927	MLLW
H08211	1956	10000	North American Datum 1927	MLLW
H08542	1962	10000	North American Datum 1927	MLLW
H08543	1960	10000	North American Datum 1927	MLLW
H08544	1960	10000	North American Datum 1927	MLLW
H08609	1961	10000	North American Datum 1927	MLLW
H08699	1961	10000	North American Datum 1927	MLLW
H08700	1962	10000	North American Datum 1927	MLLW
H08701	1962	10000	North American Datum 1927	MLLW
H08753	1963	10000	North American Datum 1927	MLLW
H08754	1966	10000	North American Datum 1927	MLLW
H08894	1966	10000	North American Datum 1927	MLLW
H08895	1966	10000	North American Datum 1927	MLLW
H08910	1966	10000	North American Datum 1927	MLLW
H08911	1966	10000	North American Datum 1927	MLLW
H08912	1966	10000	North American Datum 1927	MLLW
H08914	1967	10000	North American Datum 1927	MLLW
H08915	1966	10000	North American Datum 1927	MLLW
H08916	1969	10000	North American Datum 1927	MLLW
H08927	1967	20000	North American Datum 1927	MLLW
H08928	1967	10000	North American Datum 1927	MLLW
H08929	1967	10000	North American Datum 1927	MLLW
H08930	1967	10000	North American Datum 1927	MLLW
H08933	1967	10000	North American Datum 1927	MLLW
H09035	1969	10000	North American Datum 1927	MLLW
H09036	1969	10000	North American Datum 1927	MLLW

Survey ID	*Date*	*Scale*	*Original Horizontal Datum*	*Original Vertical Datum*
H09038	1969	10000	North American Datum 1927	MLLW
H09167	1970	5000	North American Datum 1927	MLLW
H09168	1970	5000	North American Datum 1927	MLLW
H09169	1970	5000	North American Datum 1927	MLLW
H09319	1972	10000	North American Datum 1927	MLLW
H09320	1972	10000	North American Datum 1927	MLLW
H09337	1975	10000	North American Datum 1927	MLLW
H09345	1973	10000	North American Datum 1927	MLLW
H09372	1973	10000	North American Datum 1927	MLLW
H09410	1974	5000	North American Datum 1927	MLLW
H09411	1974	5000	North American Datum 1927	MLLW
H09412	1974	5000	North American Datum 1927	MLLW
H09417	1974	40000	North American Datum 1927	MLLW
H09682	1977	5000	North American Datum 1927	MLLW
H09742	1978	10000	North American Datum 1927	MLLW
H09743	1978	10000	North American Datum 1927	MLLW
H09744	1980	10000	North American Datum 1927	MLLW
H09747	1978	5000	North American Datum 1927	Lake Washington Low Water Datum
H09862	1980	5000	North American Datum 1927	MLLW
H09864	1980	10000	North American Datum 1927	MLLW
H10072	1983	10000	North American Datum 1927	MLLW
H10555	1994	10000	North American Datum 1983	MLLW
H10564	1995	10000	North American Datum 1983	MLLW
H10590	1995	5000	North American Datum 1983	MLLW
H10662	1996	5000	North American Datum 1983	MLLW
H10665	1996	10000	North American Datum 1983	MLLW
H10667	1996	10000	North American Datum 1983	MLLW
H10684	1996	10000	North American Datum 1983	MLLW
H10714	1996	10000	North American Datum 1983	MLLW
H10796	1998	5000	North American Datum 1983	MLLW
H10797	1999	10000	North American Datum 1983	MLLW
H10798	1998	5000	North American Datum 1983	MLLW
H10970	2000	5000	North American Datum 1983	MLLW
H11018	2001	1000000	North American Datum 1983 UTM 10	MLLW
H11025	2001	10000	North American Datum 1983	MLLW
H11038	2001	10000	North American Datum 1983	MLLW
H11039	2002	20000	North American Datum 1983	MLLW
H11040	2002	5000	North American Datum 1983	MLLW
H11041	2001	10000	North American Datum 1983	MLLW
H11042	2001	10000	North American Datum 1983	MLLW
H11188	2002	10000	North American Datum 1983 UTM 10	MLLW
H11190	2002	10000	North American Datum 1983	MLLW
H11292	2004	10000	North American Datum 1983	Lake Washington Low Water Datum
H11293	2004	10000	North American Datum 1983	Lake Washington Low Water Datum
H11317	2004	10000	North American Datum 1983	MLLW
H11370	2005	10000	North American Datum 1983 UTM 10	MLLW
H11371	2005	20000	North American Datum 1983 UTM 10	MLLW

Survey ID	*Date*	*Scale*	*Original Horizontal Datum*	*Original Vertical Datum*
H11376	2005	10000	North American Datum 1983 UTM 10	Lake Washington Low Water Datum
H11377	2005	10000	North American Datum 1983 UTM 10	Lake Washington Low Water Datum
H11458	2009	10000	North American Datum 1983 UTM 10	MLLW
H11548	2006	10000	North American Datum 1983 UTM 10	MLLW
H11549	2006	10000	North American Datum 1983 UTM 10	MLLW
H11550	2008	10000	North American Datum 1983 UTM 10	MLLW
H11551	2007	10000	North American Datum 1983 UTM 10	MLLW
H11556	2006	5000	North American Datum 1983 UTM 10	MLLW
H11605	2007	5000	North American Datum 1983 UTM 10	MLLW
H11642	2009	10000	North American Datum 1983 UTM 10	MLLW
H11646	2008	10000	North American Datum 1983 UTM 10	MLLW
H11749	2007	10000	North American Datum 1983 UTM 10	MLLW
H11750	2007	10000	North American Datum 1983 UTM 10	MLLW
H11810	2008	10000	North American Datum 1983 UTM 10	Lake Washington Low Water Datum
H11826	2008	10000	North American Datum 1983 UTM 10	MLLW
H11827	2008	10000	North American Datum 1983 UTM 10	MLLW
H12024	2009	5000	North American Datum 1983 UTM 10	MLLW
H12025	2009	5000	North American Datum 1983 UTM 10	MLLW
H12050	2009	10000	North American Datum 1983 UTM 10	MLLW
H12051	2009	10000	North American Datum 1983 UTM 10	MLLW
H12052	2009	10000	North American Datum 1983 UTM 10	MLLW
H12053	2009	10000	North American Datum 1983 UTM 10	MLLW
H12074	2009	12000	North American Datum 1983 UTM 10	MLLW
H12075	2009	10000	North American Datum 1983 UTM 10	MLLW
H12216	2010	5000	North American Datum 1983 UTM 10	MLLW
H12280	2011	10000	North American Datum 1983 UTM 10	MLLW
H12281	2011	10000	North American Datum 1983 UTM 10	MLLW
H12310	2011	10000	North American Datum 1983 UTM 10	MLLW
H12311	2011	10000	North American Datum 1983 UTM 10	MLLW
H12312	2011	10000	North American Datum 1983 UTM 10	MLLW
H12313	2011	10000	North American Datum 1983 UTM 10	MLLW