The Role and Value of High-resolution Land Cover and Elevation Data within the Chesapeake Bay Program Partnership

To date, the Chesapeake Bay Program has relied on moderate-resolution (30 meter) land cover data produced by the U.S. Geological Survey (USGS) and National Oceanic and Atmospheric Administration (NOAA) to inform regional-scale policy decisions by incorporating such data in the Chesapeake Bay Program (CBP) Partners' suite of models and other decision support tools. Unfortunately, 30m-resolution data (quarter-acre cells) cannot accurately detect urban tree canopy, turf grass in small yards, narrow roads, and small buildings. Therefore, the CBP Partners have had to make broad inferences about the presence of these features based on U.S. Census Bureau and other sampled data.

Over the past decade, some local jurisdictions in the Bay watershed states have independently funded the development of high-resolution land cover data to establish tree-canopy restoration goals and to inform stormwater management and other natural resource decisions. These data can also be used to inform the Chesapeake Bay TMDL 2017 mid-point assessment. For the 2017 mid-point assessment, the CBP's Land Use Workgroup initiated an intensive effort to gather all available high-resolution land cover, land use, zoning, parcel, and sewer service data because the CBP watershed model relies on "land use" data to represent potential sources of nutrients and sediment. Land cover data are an essential but not exclusive component of the information needed to map land uses for the CBP's models. For example: planimetric data on roads are needed to differentiate impervious surfaces associated with roads from those associated with buildings and parking lots; residential and commercial land use, zoning, or parcel data are needed to identify and map developed open space, turf grass, and tree canopy, and to separate agriculture from developed areas. The role of high-resolution land cover in developing the Phase 6 Chesapeake Bay watershed model land uses is illustrated in Table 1.

The use of LiDAR-derived elevation data can greatly improve the accuracy of high-resolution land cover datasets. The USGS has inventoried the current availability of LiDAR data throughout the Chesapeake Bay watershed (Figure 1). The USGS' 3D Elevation Program is leading the effort to work with federal and state agencies to fill the current gaps in LiDAR-derived elevation data and to update existing coverages with higher-quality data. It is anticipated that current gaps in LiDAR coverage will be filled by May 2016. Improving the quality of existing LiDAR coverages will likely take several years.

Potential for High-Resolution Land Cover Monitoring

Restoration and conservation efforts in the Chesapeake Bay watershed would benefit greatly from the availability of high-resolution land cover and elevation data produced every 3-5 years. The data would inform goals outlined by all of the Partnership's Goal Implementation Teams and inform almost all of the outcomes specified in the 2014 Chesapeake Bay Watershed Agreement—particularly the vital habitats, healthy watersheds, and land conservation outcomes. Specific benefits include:

- Characterizing, mapping, and tracking of wetlands, riparian forest buffers, forests, and impervious surfaces;
- Characterizing, mapping, and tracking habitat conditions;
- Developing habitat suitability maps;
- Prioritizing and targeting restoration, conservation, education, and public access efforts;
- Understanding the effects of management actions on water quality;
- Verifying riparian buffer and urban tree canopy Best Management Practices;
- Identifying areas of bank erosion, channel incision, and floodplain sediment deposition;
- Improving the accuracy of nutrient and sediment load estimates; and
- Educating citizens on the value and location of high-functioning landscapes (e.g., landscapes providing ecological services such as nutrient uptake and transformation, sediment retention, and wildlife habitat).

Monitoring land surface change with high-resolution imagery presents some unique challenges. Differences in sun-angle and atmospheric conditions among multi-year images can lead to false-positive detections of change (e.g., interpreting areas in shadow or with sun-glint on the water as "change"). Moreover, some changes observable in multi-date high-resolution images are not relevant to land management and planning decisions (e.g., a truck parked in a yard, boats in a marina, or tree-fall gaps in a forest). The techniques for monitoring land surface change with high-resolution imagery are rapidly evolving and advancing such that it is not yet advisable to recommend one particular technique over another. Funders and users of high-resolution land cover products should focus their attention on specifying and understanding individual class accuracies and the rigor of the accuracy assessment protocol used to estimate those accuracies. Typically, the accuracy of land cover data products is expressed in terms of user's and producer's accuracies. For example, if the impervious surface class in a land cover map has a user's accuracy of 80% and a producer's accuracy of 90%, users of the data can be 80% sure that what is mapped as "impervious" actually is impervious. They can also be assured that 90% of what actually is impervious, has been mapped. High individual class accuracies are desirable for monitoring land change over 3-5 year intervals.

<u>Background Information on Land Cover and LiDAR Data in the Chesapeake Bay watershed</u>

The term "land cover[1]" refers to a wall-to-wall classification of land surface characteristics into categories such as impervious surfaces and tree canopy. Land cover classifications are derived from aerial and/or satellite spectral imagery collected from passive sensors (e.g., cameras). These classifications can be enhanced by incorporating data from active sensors (e.g., those emitting a pulse such as LiDAR). Since the late 1990s, the Chesapeake Bay Program Partners have relied on 30m-resolution Landsat satellite derived land cover data to provide a spatially consistent representation of Bay watershed conditions to inform the suite of models used for management purposes and for tracking changes on the landscape.

Throughout the 2000s and to the present, counties, states, and the USDA's Farm Service Agency have acquired high-resolution (<=2m) imagery to inform transportation, public works, and natural resource decisions. Initially, these data were acquired as natural color images and used as pictures rather than analyzed as data. This practice has gradually evolved through the development of object-based feature extraction software (e.g., Feature Analyst, ENVI, and eCognition) and the acquisition of imagery with a near-infrared spectral band in addition to the three visible bands. The near-infrared band enhances the ability to distinguish vegetation from non-vegetated areas.

At present, USDA-FSA collects 4-band leaf-on 1-meter resolution orthoimagery for each state as part of their National Agriculture Imagery Program (NAIP) every 1-3 years. Collection dates are cyclic and vary due to the availability of state cost-share funds and other factors (Figure 2). The Virginia Institute of Marine Sciences collects and manually classifies black and white aerial photographs along the near-shore areas of the Chesapeake and Coastal Bays to support their annual inventory of submerged aquatic vegetation (SAV) extent and density. In addition, some states and localities acquire sub-meter leaf-off imagery every 3-5 years to support transportation and planning needs. Leaf-on imagery is better for detecting vegetation and leaf-off imagery is better for detecting impervious surfaces and water features which may be obscured by the canopy during the growing season. Leaf-off imagery is mostly collected during the spring but the collection years often vary by state.

Complete or partial land cover information derived from classifying high-resolution imagery is available only for select counties in the Bay watershed. In 2015, tree canopy data will be developed for the states of Pennsylvania and Delaware through a recent NASA grant.

LiDAR (Light Detection and Ranging) refers to a high-resolution (<=2m) active airborne sensor that emits pulses of light in near-infrared (topographic LiDAR) and/or blue-green (topo/bathymetric LiDAR) wavelengths. These pulses are directed towards the ground, reflect off surfaces (i.e., buildings, leaves, branches, pavement, dirt), and return to the sensor. The

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[1] Land cover is not the same as land use. Residential land uses include impervious surface, herbaceous, scrub-shrub, and tree canopy cover types. Both land cover and land use data are needed to make inferences about land management. Even combined, however, they do not provide a complete perspective on how the land is managed to answer questions such as how often and how much fertilizer is applied.

time it takes for the pulses to be detected is recorded and correlated with the travel distance or “range” of each pulse. Because the exact location of the plane is known at all times, travel distances can be converted to elevations revealing a wealth of information about vegetation height, structure, biomass, and ground surface characteristics. LiDAR imagery has been collected on a county-by-county basis at least once (and seldom twice) for approximately three-quarters of the Bay watershed (Figure 1) with dates varying from 2004 - 2014.

There are different types of airborne LiDAR (e.g., waveform, discrete return, pulse width, and photon counting) which are not discussed here. The LiDAR data characteristics most relevant to the CBP needs are spatial accuracy, vertical accuracy, and penetration through water. Accuracies are influenced partly by the height and speed of the plane and frequency of pulses. The National Digital Elevation Program has developed a convention for characterizing the quality of elevation datasets. Almost all of the LiDAR elevation data currently available in the Chesapeake Bay watershed are classed as either Quality Level 2, QL-2 (2 points per m^2; 9.25 cm vertical RMSEz) or QL-3 (0.25 – 1 point per m^2; 18.5 cm vertical RMSEz). The QL-2 products have sufficient accuracy to produce a 1m resolution Digital Elevation Model (DEM) whereas the QL-3 products only support the production of a 2-3m resolution DEM. These LiDAR products have mostly been collected using laser pulses with near-infrared wavelengths that cannot penetrate through water. Surface waters are depicted as flat, constant elevation surfaces similar to some building and pavement surfaces. Bathymetric and topo-bathy LiDAR instruments emit pulses in the blue-green wavelength that can penetrate water surfaces up to depths of 1-10 meters depending on water clarity. Submerged surface elevations are also more accurate if the substrate is hardened (e.g., oyster bed) vs. soft (e.g., mud).

Coupling LiDAR data with high-resolution spectral imagery has proven useful for improving the accuracy of semi-automated land cover classifications (e.g., differentiating buildings from parking lots and forests from scrub-shrub vegetation). The more data informing a classification (e.g., # of spectral bands, elevation and biomass data, planimetric and land use information), the more automated the process can become to produce an accurate product. The costs of production are generally positively correlated with the degree of automation yet all products require some level of manual editing to increase the overall and individual class accuracies above 90%.

Table 1. Data Desired to Map Phase 6 Chesapeake Bay Watershed Model Land Uses (High-resolution land cover as primary dataset highlighted in red)

Phase 6 Land Use	Regional/National Moderate Resolution Data			County/State High-resolution or Permit data			
Impervious-roads	LC impervious	Road centerlines		**LC impervious**	Roads		
Impervious-other	LC impervious	Housing units		**LC impervious**	Buildings	Parking lots	Driveways
Tree canopy	LC tree canopy	Road centerlines	Developed area	**LC tree canopy**	LU Developed	Parcels	Zoning
Open space	LC herbaceous/ shrub	Developed area		**LC herbaceous/ shrub**	LU Developed	Parcels	Zoning
Turf grass	LC herbaceous	Road density	Developed area	**LC herbaceous**	LU Developed	Parcels	Zoning
Construction				Erosion and Sediment Control Permits (disturbed areas)			
Extractive				Mining, quarry, and gravel pit permits (active/disturbed areas)			
Commodity crops	LC commodity crops			LC herbaceous	LU agriculture	Parcels	Zoning
Specialty crops	LC specialty crops			LC herbaceous	LU agriculture	Parcels	Zoning
Pasture-Forage	LC pasture-forage			LC herbaceous	LU agriculture	Parcels	Zoning
Farmsteads	LC impervious/ farmstead			**LC impervious**	LU agriculture	Parcels	Zoning
Forest	LC tree canopy	Road centerlines		**LC tree canopy**	LU forest		
Harvested forest	LC transitions: forest- herbaceous – shrub- forest			Timber harvest permit areas			
Disturbed forest	LC monitoring of insect & fire damage						
Tidal wetlands	NWI	Bathymetry	Salinity/MHHW	State or county wetland inventory			
Floodplain wet.	NWI	FEMA	DEM; SSURGO	State or county wetland inventory			
Headwater wet.	NWI	NHD-H	DEM	State or county wetland inventory			
Depression wet.	NWI	DEM	SSURGO	State or county wetland inventory			
Water	NHD-H	DSWE	LC water	**LC water**	LU water	Streams	

Overlay	Regional/National Moderate Resolution Data			County/State High-resolution or Permit data
MS4 boundaries	2010 Census Urban Areas/Clusters			State or county regulated MS4 areas
Federal lands	US Protected Areas Database			Federal Facility Editor tool
Riparian zone	100-ft buffer of NHD-H streams			
Floodplain	FEMA	DEM	SSURGO	
Sewer service areas	1990 Census: % on public sewer			State, County, or Treatment Plant sewer service areas (polygons)
Fluvial erosion/deposition	DEM (LiDAR)	Storm sewer monitoring	Streamgage & Field monitoring	

Acronyms: Digital Elevation Model (DEM); Dynamic Surface Water Extent (DSWE); Federal Emergency Management Agency (FEMA); Land cover (LC); Land use (LU); Mean Higher High Water (MHHW); Municipal Separate Storm Sewer Systems (MS4); National Hydrography Dataset – High resolution 1:24,000 scale (NHD-H); National Wetlands Inventory (NWI); Soil Survey Geographic Database (SSURGO).

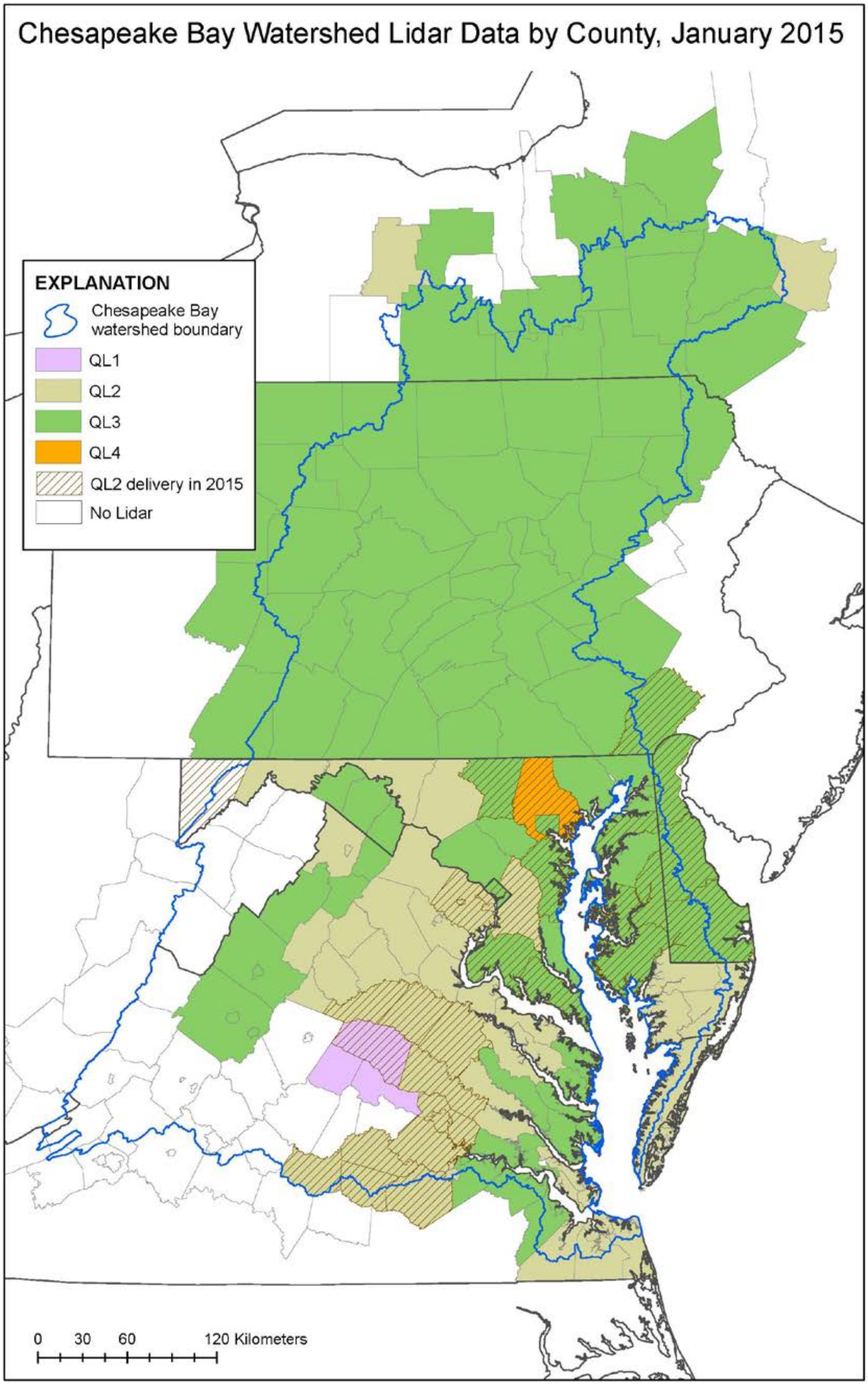

Figure 1. Existing LiDAR coverage in the Chesapeake Bay Watershed. Note that Baltimore County currently has QL-3 data- not QL-4.

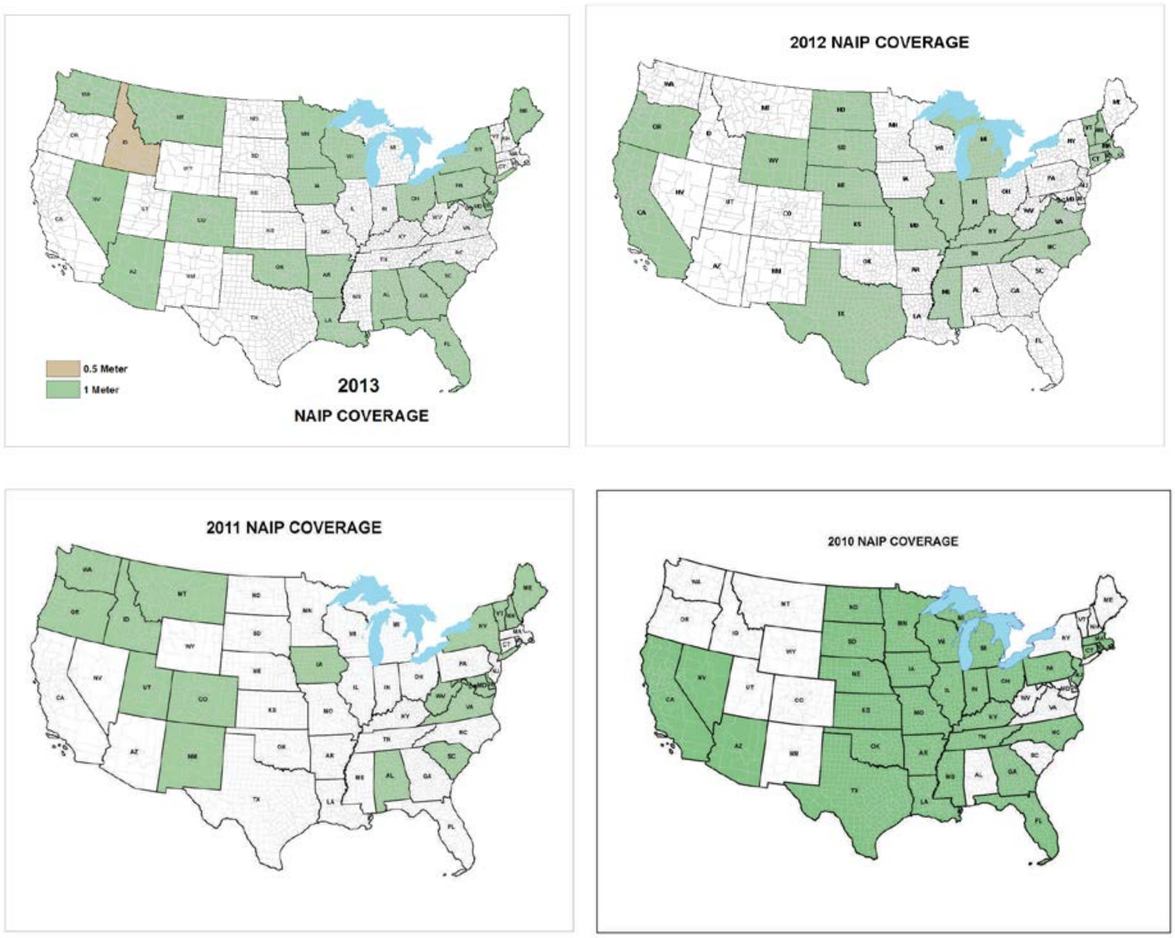

Figure 2. Status of NAIP imagery collection in the conterminous US, 2010 – 2013.