**Technical Summary: Development of dWind Customer Locations and Allowable Turbine Height Ranges**

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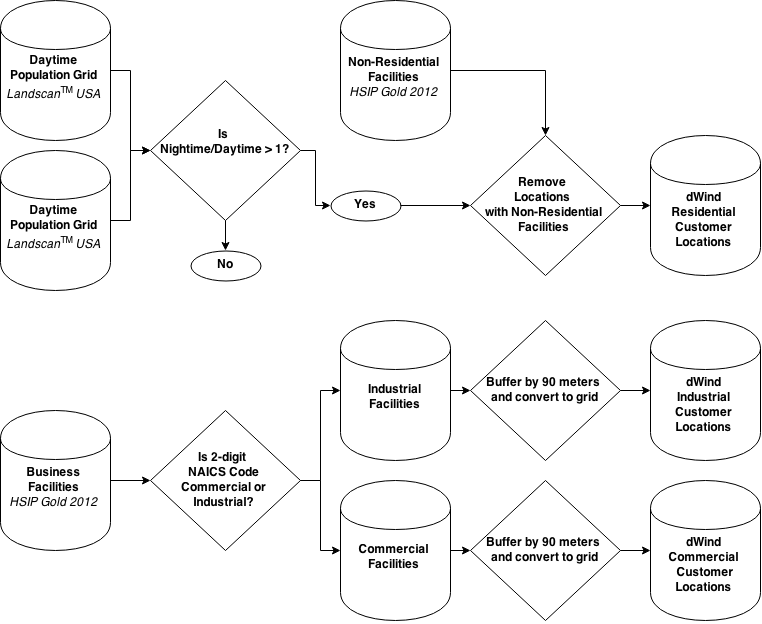
**Introduction**

The dWind Model evaluates the economic value of distributed wind systems at potential customer locations within each county of the contiguous United States. The set of potential customer locations are represented in the model by a national geospatial grid, derived by the dWind team, that indicates which grid cells are likely to be used by each of the three customer sectors (residential, commercial, and industrial). Each square cell in this grid is 200 m by 200 m in size, which is a sufficiently high degree of spatial resolution to allow customer locations to be attributed with local characteristics critical to evaluating the local economics of distributed wind. One of most important characteristics attributed to each customer location is a set of factors that constrain the allowable system size and turbine height that can be built at the location. These factors include parcel size and degree of existing development at the site, which determine the maximum allowable turbine height at each location, and tree height and cover, which determine the minimum required turbine height. This document provides a summary of the analysis methods used to derive the customer location grids for each sector, as well as the turbine height factors for each customer location.

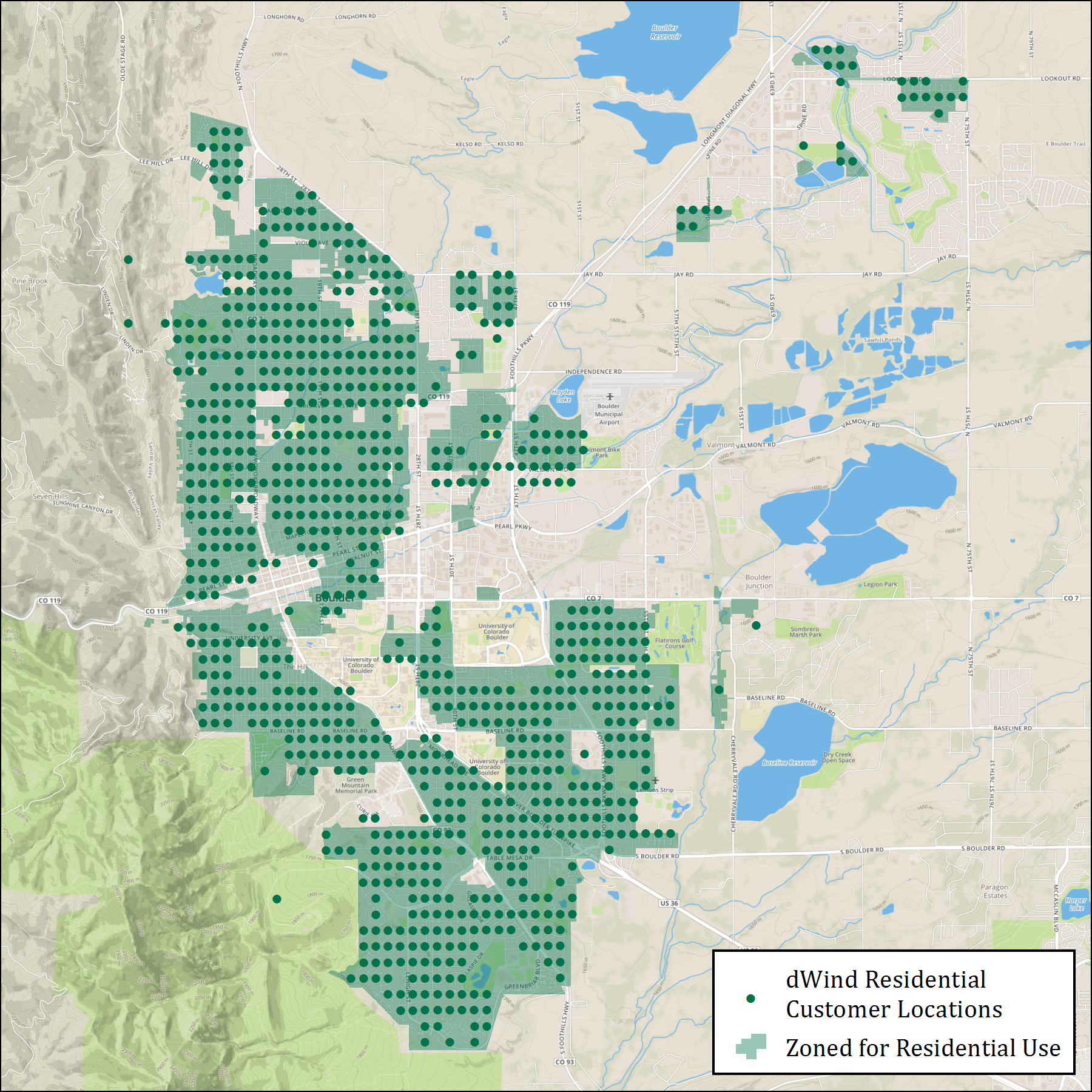
**Customer Locations**

Figure 1 provides an overview of the analysis process used to identify customer locations for each of the three customer sectors. Customer locations for the residential sector were developed primarily using an analysis of the LandScan™ USA geospatial grids, which provide a fine-resolution estimate of daytime and nighttime population (ORNL 2011). These population grids were overlaid and combined to determine the ratio of nighttime to daytime population, and areas where the ratio exceeded a value of 1 were classified as residential. To complete the residential customer location grid, a second analysis was conducted to remove grid cells coinciding with known locations of non-residential facilities with high nighttime populations, including prisons, hotels, motels, college campuses, and industrial complexes (HSIP Gold 2012). For the commercial and industrial sectors, the customer location grids were derived using a dataset of known business facility locations. These locations were separated into commercial and industrial groups based on two digit codes from the North American Industry Classification System (NAICS), then each point location was expanded by a 90 m radius, and the resulting areas were overlaid on the grid to identify grid cells occupied by facilities of each sector. These analyses produces a total of 5,751,859, 1,603,958, and 1,145,187 customer locations for the residential, commercial, and industrial sectors, respectively. Based on a qualitative evaluation against select city or county zoning maps, the customer locations were determined to be of sufficient fidelity for use in the dWind model (see Figure 2).

**Figure 1.** Graphical workflow illustrating the analysis used to develop customer locations for the dWind model.



**Figure 2.** A comparison of the derived dWind residential customer locations to land that is legally zoned for residential use in the City of Boulder, CO.



**Turbine Height Criteria**

For each customer location, the dWind model determines the range of feasible turbine heights that can be constructed. This turbine height range is based on three local factors: the average residential parcel size, the amount of existing highly developed land, and the amount and height of existing tree canopy. Together, these three factors are used to provide a nationwide approximation of the legal (i.e., zoning, safety) and operational constraints affecting distributed wind development.

The average residential parcel size was selected as an important constraint because, in discussions between NREL and representatives from DWEA, parcel size was highlight as an important first order indicator for the feasibility of installing different height turbines. Nationwide parcel datasets are not freely available; therefore, as an alternative, the dWind model uses estimates of acres per of housing unitderived from the Census 2010 at the block-level. Blocks are the smallest available “region” for Census data. Commonly, they are city blocks in the colloquial sense – small areas bounded by streets on all sides; however, in rural areas, they may be bounded by other physical, manmade, or cultural features (e.g., railroads, streams, etc.) and tend to be slightly larger (U.S. Bureau of the Census 1994). Due to their fine spatial resolution, blocks allow for capturing sufficient spatial heterogeneity to differentiate patterns in parcel size between customer locations. The maximum allowable turbine height allowed at each customer location is based on the average residential parcel size for the intersecting block, and a user-defined table that defines minimum required parcel size for each of the turbine hub heights evaluated in the model (see Table 1). The current default values shown in Table 1 are based on preliminary feedback from DWEA representatives.

**Table 1.** User input table defining minimum parcel size required for each turbine hub height, populated with current default values.

|  |  |
| --- | --- |
| **Turbine Hub Height (m)** | **Minimum Parcel Size (acres)** |
| **20 m** | 0.50 |
| **30 m** | 1.00 |
| **40 m** | 2.00 |
| **50 m** | 3.00 |
| **80 m** | 4.00 |

Because the Census block data only accounts for residential development, a secondary dataset was used to assign an overall degree of all developed land to each customer location. This data was derived from the high resolution (30 m by 30m) National Land Cover Dataset 2011 (NLCD) (Jin et al. 2013), which includes a “High Intensity” land class, defined as “highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover” (MRLC 2014). Given the intensity of development associated with this land class, the dWind model assumes that portions of customer sites occupied by this land class cannot be developed for wind. The percent of each 200 m by 200 m customer location occupied by this land class was derived from the finer resolution NLCD grid. The dWind model allows the user to define the maximum percentage of heavily developed land at a customer site for each of the turbine hub heights evaluated in the model (see Table 2). The current default values shown in Table 2 were derived by NREL analysts based on the assumption that a turbine of hub height HH requires a minimum area of undeveloped land equal to (2\*HH)2 , and that the undeveloped land within each customer location is optimally configured in a contiguous square area.

**Table 2.** User input table defining the maximum allowable percent of heavily developed land at each customer site for each turbine hub height, populated with current default values.

|  |  |
| --- | --- |
| **Turbine Hub Height (m)** | **Maximum % Heavily Developed Land** |
| **20 m** | 96% |
| **30 m** | 91% |
| **40 m** | 84% |
| **50 m** | 75% |
| **80 m** | 26% |

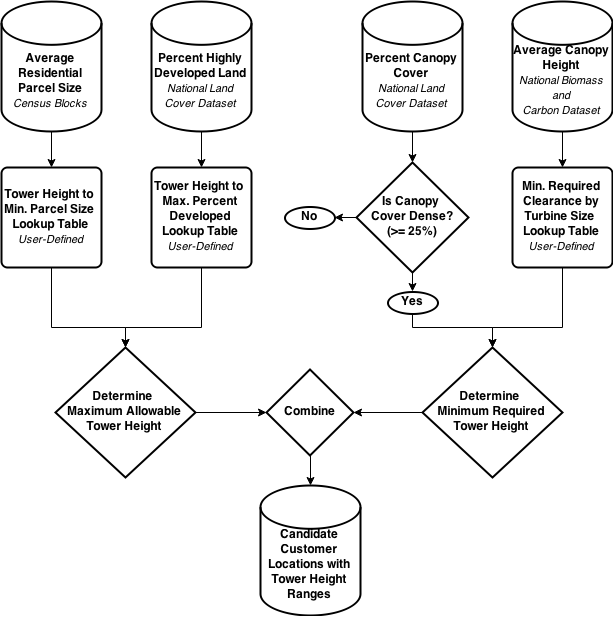
The third factor that contributes to the range of allowable turbine heights in the dWind model is the density and height of the tree canopy around each customer location. The density of the canopy cover is determine using a high-resolution (30 m by 30 m) grid of percent canopy created as part of the NLCD (2011) (Jin et al. 2013). Customer locations with an average canopy cover less than 25 percent are considered to have low density canopy, and are not assigned any turbine height requirements. Locations with canopy coverage above this threshold are further evaluated by determining the average canopy height, which is derived from the high-resolution (30 m by 30 m) National Biomass and Carbon Dataset (Kellndorfer et al. 2012). At such locations, the canopy height is combined with a user-defined minimum required clearance above tree cover for each turbine size (e.g., 20 m clearance for a 10 kw turbine) (see Table 3) to constrain the range of allowable turbines at each customer location. The current default values for minimum required canopy clearances shown in Table 3 were derived by NREL analysts based on a static clearance of 15 m for all turbines, plus a scalar factor of 1.1 times the approximate turbine radius.

**Table 3.** User input table defining the canopy clearance required for each turbine size (i.e., rated capacity), populated with current default values.

|  |  |  |
| --- | --- | --- |
| **Turbine Size (kW)** | **Approx. Rotor Radius (m)** | **Required Clearance (m)** |
| **2.5 kW** | **2.2** | 17.40 |
| **5 kW** | **3.1** | 18.40 |
| **10 kW** | **4.4** | 19.80 |
| **20 kW** | **6.2** | 21.80 |
| **50 kW** | **9.8** | 25.70 |
| **100 kW** | **13.8** | 30.20 |
| **250 kW** | **21.9** | 39.00 |
| **500 kW** | **30.9** | 49.00 |
| **750 kW** | **37.8** | 56.60 |
| **1000 kW** | **43.7** | 63.10 |
| **1500 kW** | **53.5** | 73.9 |

At each customer location, the three factors of residential parcel size, percent of highly developed land, and tree canopy characteristics are combined within the dWind model to determine the allowable range of turbine hub heights at each customer location. Figure 3 provides an overview of the processes described above that are used to analyze each factor, and the way in which they are combined to determine the range of allowable turbine heights at each site.

**Figure 3.** Graphical workflow illustrating the analysis used to develop and combine each of the factors that affect the range of developed turbine hub heights at each customer location.



**References Cited**

Homeland Security Infrastructure Program (HSIP) (2012). “HSIP Gold 2012 Infrastructure ArcGIS 9.3 Filebase Geodatabases”.

Jin, S., Yang, L., Danielson, P., Homer, C., Fry, J., and Xian, G (2013). “A comprehensive change detection method for updating the National Land Cover Database to circa 2011”. *Remote Sensing of Environment*, 132: 159 – 175.

Kellndorfer, J., Walker, W., LaPoint, E., Bishop, J., Cormier, T., Fiske, G., Hoppus, M., Kirsch, K., and Westfall, J. (2012). “NACP Aboveground Biomass and Carbon Baseline Data (NBCD 2000), U.S.A., 2000”. Available on-line at http://daac.ornl.gov from ORNL DAAC, Oak Ridge, Tennessee, U.S.A.

Multi-Resolution Land Characteristics Consortium (MRLC) (2014). “National Land Cover Database 2011 Product Legend”. Accessed May 1, 2015: http://www.mrlc.gov/nlcd11\_leg.php.

Oak Ridge National Laboratory (ORNL) (2011). “Landscan USA™ Raster Datasets (2011‑Prerelease)”.

U.S. Bureau of the Census (1994). *Geographic Areas Reference Manual*. U.S. Dept. of Commerce, Economics and Statistics Administration, Bureau of the Census. Accessed May 1, 2015: https://www.census.gov/geo/reference/garm.html.