American Farmland Trust

Revision to American Farmland Trust's *Farms Under Threat: The State of America's Farmland*: Improved data products enable more accurate estimates of urban conversion

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Executive Summary

Overview

In May 2018, American Farmland Trust (AFT) and Conservation Science Partners (CSP) released *Farms Under Threat: The State of America's Farmland (FUTv1)*, a national spatial analysis of farmland conversion between 1992 and 2012. Based on the best data available at that time, *FUTv1* estimated that 18 million acres of agricultural land had been converted to urban development and 12.7 million acres had been converted to low-density residential land use over the 20-year period—a total of nearly 31 million acres.

Recent updates to a key federal dataset, the 2016 USGS National Land Cover Database (NLCD) have allowed us to greatly refine our estimate of urban development on agricultural land between 1992 and 2002, the first half of the *FUTv1* time period. While *FUTv1* estimated there were 16.3 million acres of urban conversion during this period, our refined analysis indicates it was probably closer to 6.5 million acres, so urban development was overestimated by roughly 10 million acres. This refinement was not possible until the release of the new NLCD 2016 data. The *FUTv1* estimate used the best data available at the time and benefited from a correction that we applied to avoid a much larger overestimate.

Mapping challenges and how we addressed them

Farms Under Threat spatial data are based on the NLCD, so our urban development totals are directly linked to NLCD mapping methods. While NLCD is the best available land cover database for the United States, NLCD's methods have changed over time, so there are known challenges with using NLCD datasets to map land cover/use change. NLCD was used to map agricultural land conversion between 1992 and 2012[2] in *FUTv1.* However, due to a methodological change, roads are vastly underestimated in the 1992 NLCD and vastly overestimated in the post-2000 NLCD datasets. Since roads are mapped as urban cover, this methodology change can cause large artifacts of urban conversion on agricultural land. We addressed this issue in *FUTv1* by removing rural roads from the 2001 and 2011 data, greatly improving our ability to map and estimate urban conversion. Without the rural road correction, the *FUTv1* estimate of urban conversion would have been over twice as high.

In May of 2019, NLCD released new data for 2016 based on a new methodology. NLCD also released updated maps back to 2001 that were generated with this same methodology, providing more consistent land cover mapping products through time (Yang et. al. 2018). These new maps also include a new data layer that makes it possible to more precisely identify and separate

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[2] *FUTv1* used 2012 as the end year for the analysis to be consistent with the NRI data, but the spatial mapping was based on the 2011 NLCD map.

impervious surfaces associated with roads from other urban built-up areas. This significantly improves our ability to map urban conversion over time and to remove artifacts caused by NLCD's over-mapping of road areas as urban land cover.

Refining the *FUTv1* estimates

AFT's subsequent analysis (*FUTv2, State of the States*) uses these updated NLCD datasets (2001-2016). This new analysis shows a much lower rate of urban development than was found in *FUTv1.* While the *FUTv2* analysis covers a later time period than *FUTv1*, this difference does not fully explain why urban conversion rates between *FUTv1* and *FUTv2* were so dissimilar. The most likely reason for the difference is that urban conversion was inflated in *FUTv1* due to the inconsistent mapping of roads between the 1992 and post-2000 NLCD versions, despite our best efforts to account for this.

Since the recent NLCD update allows us to remove roads completely in 2001 and 2011, we are now able to avoid all urban conversion artifacts due to over-mapping of roads. Therefore, we used the new data to reanalyze urban conversion between 1992 and 2012. This reanalysis revealed that *FUTv1* overestimated urban conversion in the decade between 1992 and 2002. (The 2001 and 2011 maps were relatively consistent, so most of the overestimate occurred in the first decade of the analysis period.) Instead of 16.3 million acres, it was probably closer to 6.5 million acres, so urban development was overestimated by roughly 10 million acres.

This refinement was not possible until the release of the new NLCD 2016 data. The *FUTv1* estimate used the best data available at the time, and the original correction to this estimate helped avoid a much larger overestimate. (In contrast to the urban conversion issue, the *FUTv1* analysis of low-density residential land use was not impacted by the issues with the NLCD, since this analysis relies on housing density data from the U.S. census, not NLCD data.)

Full Discussion

Introduction to *Farms Under Threat*

In May 2018, American Farmland Trust (AFT) and Conservation Science Partners (CSP) released *Farms Under Threat: The State of America's Farmland* (*FUTv1*), a national spatial analysis of farmland conversion between 1992 and 2012. Our goal was to document development threats and offer policy solutions to ensure the long-term protection of agricultural land in the United States. Based on the best data available at that time, *FUTv1* estimated that 18 million acres of agricultural land had been converted to urban development and 12.7 million acres had been converted to low-density residential land use over the 20-year period—a total of nearly 31 million acres.

Mapping approach and challenges

To quantify the amount and quality of farmland lost to urban development, *Farms Under Threat* relied on the USGS National Land Cover Database (NLCD) for mapping land cover and land cover change. The NLCD dates back to 1992, is based on satellite imagery, and has become the definitive land cover database for national high-resolution mapping (Wickham et al. 2014). We also had access to the USDA NRCS National Resources Inventory (NRI) data, which uses

periodic ground-based observations of roughly 800,000 fixed sites around the country to track changes over time at a national and state level (Schnepf and Flanagan 2016). *FUTv1* used the NLCD as the primary input source for mapping land cover and used the NRI estimates at the county level to more accurately map different agricultural land cover types (crop, pasture, range) and help us track the conversion of agricultural land.

FUTv1 used 1992 NLCD for the baseline year. The subsequent timepoints were based on the 2001 and 2011 land cover data from the 2011 NLCD release. *FUTv1* referred to the end year of the analysis as 2012, not 2011, to be consistent with the NRI data.

Going into the analysis, we knew that mapping land cover change from 1992 to 2012 would be difficult because: 1) USGS had cautioned against direct comparisons between NLCD 1992 and NLCD 2001/2011 due to changes in methodology, input data, and land cover classification schema; and 2) NLCD 2001/2011 was more inclusive in identifying urban development than NLCD 1992.

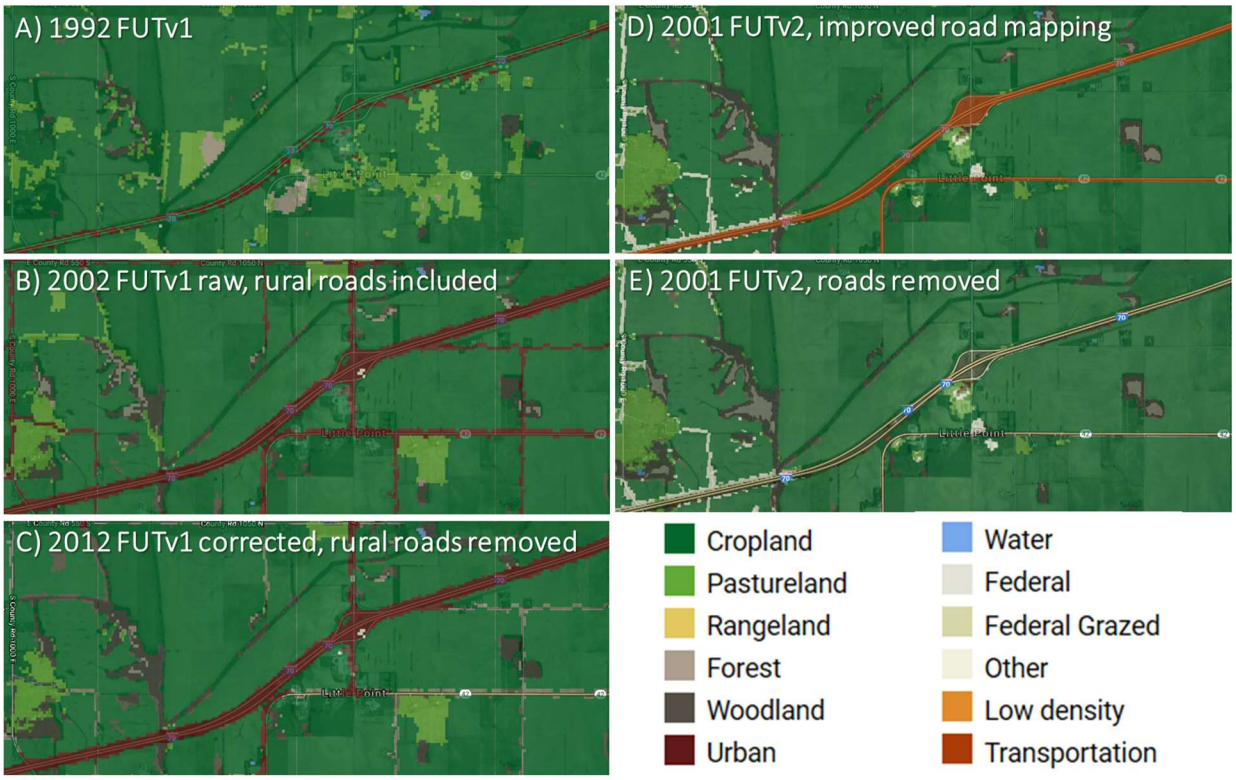

Figure 1. A comparison of *Farms Under Threat* land cover versions to highlight differences in mapping road area, near the town of Little Point, Indiana. A) The 1992 *FUTv1* data layer, showing how little road cover is mapped in 1992 NLCD. B) The raw version of the 2002 *FUTv1* layer, showing how roads are over-mapped in 2001 NLCD. C) The 2012 *FUTv1* layer with rural roads removed, showing the results of the correction used in *FUTv1* to remove rural roads. Note that this image is from 2012, but the land cover is substantially the same in this area between the two time points. D) The 2001 *FUTv2* land cover layer, showing rural roads removed and major roads mapped at 10 m using a more precise methodology. E) The 2001 *FUTv2* land cover layer

with all roads removed, which was used in the reanalysis of agricultural land conversion between 1992 and 2001.

How we addressed the most significant challenge

Ultimately, the most challenging issue was that NLCD 1992 used unsupervised classification methods to map urban areas, resulting in roads being under-represented in NLCD 1992 (Fig. 1A). For NLCD 2001 and subsequent NLCD releases, roads are mapped from U.S. Census TIGER/Line data at 30-meters resolution and co-mingled with other developed land cover (Fig. 1B). This leads to overestimation of road area mapped as urban land cover, especially in rural areas where roads are typically less than 10 meters wide (Lark et al. 2017). As a result, NLCD overestimated the amount of urban land in its post-2000 releases (Soulard and Acevedo 2017).

To adjust for over-mapping of roads in 2001 and 2011 NLCD, *FUTv1* used a morphological filter on the 2001 and 2011 NLCD v3 datasets to identify smaller, more rural roads (Theobald 2013; Soulard et al. 2018) and replace them with the nearest non-urban cover type (Fig 1C). A similar analysis that removed rural roads and small patches of development in rural areas from the NLCD developed class ultimately removed almost 57 million acres of rural roads (Soulard and Acevedo 2017).

After this rural road removal step, *FUTv1* estimated that urban development converted 18 million acres of agricultural land between 1992 and 2012. This figure was compared to the NRI estimate from the same time period, which found that almost 16 million acres of land were converted to "developed." Since the NRI has been the definitive source of information about farmland conversion, and these numbers are relatively close given the complexities of national land cover assessments, the *FUTv1* team concluded that the correction for rural roads had been sufficient.

Improved mapping methods: *FUTv2 State of the States*

AFT and CSP are now undertaking an update to *FUTv1*, called *Farms Under Threat: State of the States* (*FUTv2*). In *FUT*v2, we circumvent the NLCD roads problem and inconsistencies in how NLCD mapped urban use over time by using the NLCD 2016 products that were released in May of 2019. This release only includes updated products back to 2001. It's important to note that the producers of NLCD did not attempt to update NLCD 1992 and no longer make this data readily available, stating that NLCD 1992 "is not directly comparable to any later editions of NLCD" (MRLC 2019). To our knowledge this represents a change in MRLC policy that occurred sometime during the development and possibly after the release of *FUTv1*.

The 2016 NLCD release includes a new impervious surface descriptor layer, which allows us to separate the impervious surface areas of roads from other development types like houses and parking lots. Using the impervious descriptor layer, we are able to remove the overestimated road footprint in NLCD and replace it with major roads mapped at 10-meter resolution from the 2016 TIGER/Line data (Fig. 1D). It is important to note that we use the same 2016 road data for mapping land cover in both 2001 and 2016 in order to reduce false mapping of conversion. We chose to use a static road layer for the *FUT* analysis because consistent and spatially accurate road data for 2001 is not available. Using the earliest available TIGER/Line data (for 2007) is not advisable due to issues of spatial misalignment, mapping precision, and attribute quality

compared to the 2016 road data. Thus, we are not able to account for actual conversion of agricultural land due to the expansion of roads.

Our initial analyses of the *FUTv2* results revealed very different rates of land cover/use change in agricultural areas than we had reported in *FUTv1*. While the overall rate of conversion was 1.5M acres/year in *FUTv1*, it was only 730K acres/year in *FUTv2*. Likewise, urban conversion comprised 61 percent of the total agricultural land conversion in *FUTv1*, but only 38 percent in *FUTv2* (the remainder is due to conversion to low-density residential land use). These findings led us to reevaluate the findings from *FUTv1*.

Revisiting our estimates of urban development between 1992 and 2012/2016

Our initial review of the data indicated that the majority of the overestimate occurred between 1992 and 2001 and was primarily driven by the difference in methodology for 1992 vs 2001 NLCD. Based on *FUTv2* mapping, we estimated that urban conversion in *FUTv1* from 1992-2001 was ~16.3 million acres[3] (row A in Table 1). Since this represents the vast majority of the 1992-2012 urban conversion in *FUTv1* (18 million acres, row A in Table 1), we hypothesized that development was inflated during this period due to remaining issues with road mapping.

To evaluate this hypothesis, we used the new mapping capabilities provided by the release of NLCD 2016 to remove roads entirely from the updated 2001 and newly available 2016 NLCD (Fig. 1E). Since the 1992 map already had very few roads represented, these new roadless maps provided a relatively consistent comparison to 1992 (compare Figs. 1A and 1E). Our goal with this reanalysis was not to definitively map urban development on agricultural land from 1992 to 2001 or 2016. Instead, our goal was to get an illustrative estimate of how much agricultural land was truly converted to urban development over this longer time period to better understand the limitations of the *FUTv1* analysis compared to *FUTv2*. We conducted two analyses to reassess *FUTv1* urban development conversion estimates.

Analysis #1: First, we compared the *FUTv1* land cover/use layer for 1992 to the *FUTv2* roadless layer for 2001 and 2016. Areas that were under agricultural cover in 1992 and then under urban cover in 2001 or 2016 were classified as converted to urban. These results are reported in row B of Table 1.

However, our land cover/use map for 1992 classified 62.3 million acres of land identified as low-density residential land use. These areas were considered developed, and further land cover change within them (e.g. conversion to urban) was not assessed. Since some acres of agricultural land remain in these areas and may be vulnerable to development, we wanted to estimate how much of that agricultural land had been converted, without having to recreate the 1992 land cover/use layer without the LDR masking.

Analysis #2: Our second analysis compared the agricultural land base mapped directly from the 1992 NLCD to the *FUTv2* mapping of urban land cover/use (with roads removed) for 2001 and 2016. The following NLCD land cover classes were used to map the agricultural land base,

[3] Since the *FUTv2* maps are based on updated data, they are not directly comparable to *FUTv1* maps. Therefore, this figure may be over- or under-estimated and should not be understood as an official *FUT* estimate of urban conversion of agricultural land from 1992-2002.

including rangelands, in 1992: Shrub/Scrub, Grassland/Herbaceous, Pasture/Hay, Cultivated Crops. This analysis does not benefit from *FUT's* detailed mapping of the location of agricultural lands, but it provides a helpful upper bound of urban conversion of agricultural lands, including agriculture in LDR areas in 1992. These results are reported in row D of Table 1.

Table 1. Conversion of agricultural land to developed land covers and land uses.

		1992-2001/2	1992-2012	1992-2015/6	2001-2015/6
		Millions of acres			
	NOT including agriculture under LDR				
A	*FUTv1*	16.3[1]	18.0	-	-
B	Reanalysis (based on *FUT* land cover maps)	6.5	-	9.3	-
C	*FUTv2*	-	-	-	2.6
	Including agriculture under LDR				
D	Reanalysis (based on NLCD roads removed)	10.4	-	13.8	-
E	*FUTv2*	-	-	-	4.1
	NRI conversion to "developed"				
F	Including rural transportation	10.6	15.7	16.6	5.9
G	Margin of error	0.8	1.2	1.3	.5

Comparing urban conversion estimates

To provide context for these numbers, we are reporting two additional sources of data on urban conversion of agricultural land. First, the preliminary results from *FUTv2* for 2001-2016 are reported on rows C and E in Table 1. This enables a direct comparison of total urban conversion of agricultural land (row E) against urban conversion outside of areas classed as LDR in 2001 (row C).

Second, NRI estimates of conversion of agricultural land to "developed" uses are included in row F (USDA 2018). These estimates include conversion from NRI crop, pasture, and range land cover classes.[4] The margins of error for these estimates are listed in row G. Note that these estimates are aggregated from the 2012 and 2015 NRI Summary Reports by summing results from each 3-5 year period and may not exactly match estimates for specific time periods provided by NRI.

There are important differences—both definitional and methodological—between *FUT* estimates of agricultural land conversion to urban and NRI estimates of conversion to "developed." First, the *FUT* urban category, which encompasses all NLCD developed classes, is defined more narrowly than the NRI developed category. Second, NLCD identification of developed land is based on remoted sensing of impervious surfaces, which can be obscured by tree cover in built-up areas, causing an underestimate. Since NRI data is based on ground observations, it is not subject to this error. Third, NLCD identifies developed land pixel-by-pixel, so there is little extrapolation involved, whereas NRI calculates a multiplier based on the percentage of the land surface that each sample point represents, which is sensitive to the number of sample locations in a given area, resulting in margins of error around NRI acreage estimates for each state or county (row G). Finally, the NRI developed class includes transportation, which the *FUTv1* re-analyses

[4] Note that the dates of the NRI analyses used here are 1992, 2002, 2015. *FUTv2* analyses are referred to by NLCD dates—2001 and 2016—even though NRI data is a fundamental input to *FUT*, dates based on NLCD correspond best to the bulk of the datasets used in *FUTv2*.

and *FUTv2* explicitly exclude. Therefore, it is expected that *FUT* estimates of urban development on agricultural land are lower than NRI estimates.

Refined estimates of urban conversion from 1992-2002 and 1992-2016

Our analyses indicate that *FUTv1* overestimated urban development from 1992-2002 by about 10 million acres. Note that the 1992-2002 estimate (16.3 million acres) is illustrative but may not be accurate because it was derived from a comparison of two mapping products that are not directly comparable. Based on a review of the spatial data layers, we concluded that the over-estimate of urban conversion was largely an artifact of the change in mapping methodology between 1992 and 2001/2011 NLCD products. While the effort in *FUTv1* to remove rural roads greatly improved our estimate, the updated data release with NLCD 2016 enabled a more accurate assessment.

We estimate between 6.5 and 10.4 million acres of agricultural land were converted to urban land cover/use from 1992- 2002. The upper estimate includes agricultural land converted to urban within existing LDR areas. Corresponding estimates for 1992-2016 are 9.3 and 13.8 million acres. Due to the inconsistencies between NLCD data layers for 1992 and later years, which extend beyond the road mapping issues, it may not be feasible to improve upon these estimates.

Comparing FUT and NRI estimates

As expected, based on definitional and methodological differences between *FUT* and NRI, both the reanalysis of *FUTv1* and *FUTv2* provide lower estimates of urban conversion of agricultural land than NRI. Results for *FUTv2* (2001-2016) urban conversion are about two-thirds of the urban conversion that NRI estimates for the corresponding timeframe (2002-2015), not including the margin of error. In addition, these NRI estimates include conversion to rural transportation, which makes up 10-15% of the urban conversion (P. Flanagan, pers. comm.). When this conversion is removed, the *FUTv2* estimate is 70-80% of the NRI estimate.

Since we have the greatest confidence in *FUTv2* conversion estimates, we expect that this is roughly the correct ratio between *FUT* and NRI estimates of urban conversion. The totals are much closer for 1992-2001/2 when comparing the reanalysis using NLCD with roads removed (10.4 million acres, row D) to NRI (10.6 million acres, row F). This indicates that 1992-2001/2 conversion may still be somewhat overestimated in the reanalysis, likely due to remaining inconsistencies between NLCD 1992 and NLCD 2001 with roads removed.

The threat to farmland extends beyond the areas included in the NRI “developed” class, to areas of even lower-density residential development that nevertheless impact agriculture. The *FUT* analysis of low-density residential (LDR) land use is a pioneering effort to spatially map and quantify these threats. The LDR data layer encompasses rural lands that are experiencing an increase in housing density but may not yet be experiencing widespread land cover change. This layer may overlap agricultural land conversion estimated by NRI but not mapped by NLCD. Data on conversion to LDR land use are not included here because they are undergoing peer review and they are not critical to this discussion.

With the increased spatial resolution in *FUTv2*, these maps can help guide farmland protection efforts and other agricultural decision making at the state, county, and perhaps sub-county levels.

FUTv2 also establishes a baseline for agricultural land cover and a consistent method for mapping conversion that can be leveraged in tracking and forecasting future threats.

Glossary of Terms

Conversion refers to a change in land cover and/or land use. *Farms Under Threat (FUT)* is focused on the conversion of agricultural land to a) urban land cover and b) low density residential land use.

Development is the conversion of agricultural land and other open space to land uses that are dominated by intensive human activity. The development footprint can range from being relatively dispersed to highly concentrated. Examples of dispersed development include large-lot housing and distributed energy production (e.g., well pads or wind turbines). Examples of concentrated development include contiguous urban blocks, dense housing, and large solar panel fields.

Low-density residential land use is a new land use class developed in *FUT* to identify agricultural lands in areas threatened by increased housing density. It is the first nationwide attempt to spatially identify low-density residential land. This land use is concentrated in areas where developed and undeveloped land are interspersed, often on the edges of cities and towns. Low-density residential land use can include a mix of land covers, including cropland, pasture, rangeland, woodland, or forest. Although agricultural production may still occur in low-density residential areas, increased housing density reduces the available land base, limits management options, and may also affect the economic viability of remaining farms. In addition, unless the agricultural land comingled with low-density development is protected, it is more likely to be lost to urban development in the future.

Urban land cover/use (urbanization) occurs when the land cover is made highly impermeable, typically by constructing buildings and paving over the ground. Urbanization can occur anywhere on the landscape, from large cities to isolated rural areas. In urbanized areas, most of the land has been converted into commercial, industrial, or high-density residential uses and is no longer available for agriculture, though opportunities exist for urban agriculture. *FUT* maps urban development using data provided by the National Land Cover Dataset. *FUT* combines data from all four NLCD developed classes (21-24) (Theobald et al. 2018). Typically, urban areas do not include less-dense residential development.

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