Thirty Years of the U.S. National Land Cover Database: Impacts and Future Direction

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Abstract

The National Land Cover Database (NLCD), developed through the Multi-Resolution Land Characteristics Consortium, was initiated 30 years ago and has continually provided critical, Landsat-based land-cover and land-change information for the United States. Originally launched to address the lack of national-scale, moderate-resolution land-cover data, NLCD has evolved from the pioneering 1992 dataset into a comprehensive, annually updated product suite. Key innovations include the introduction of impervious surface mapping, forest canopy mapping, standardized Landsat mosaics, national-scale accuracy assessments, continual evolution of deep learning and artificial intelligence methodologies, and a transition toward operational, change-focused monitoring. The NLCD has become an essential resource for scientific research, land management, and policy development, with extensive adoption across federal, state, and local agencies; academia; and the private sector. The NLCD data underpin a wide array of applications, including biodiversity conservation, urban planning, hydrology, human health studies, and natural hazard assessment. As new global and high-resolution commercial land-cover products emerge, the NLCD continues to distinguish itself through its temporal depth, federal backing, and thematic consistency. Moving forward, the NLCD will maintain its niche as the leading, moderate-resolution, long-term land-cover and land-change dataset for the United States, ensuring continued support for broad national applications while complementing higher-resolution and global-mapping efforts.

Introduction

Even before the first dedicated Earth observation satellite was launched, it was recognized that consistent, synoptic coverage of remote sensing data could be used to characterize the landscape. In the mid-1960s, Secretary of the Interior Steward Udall announced Project EROS (Earth Resources Observation Satellites), designed to "apply space technology towards the solution of many pressing natural resource problems" (U.S. DOI 1966). Before the launch of the first *Earth Resources Technology Satellite (ERTS-1)* in 1972, the development of a "thematic mapping system" was proposed where four themes were to be mapped (i.e., water, barren, infrared-reflective vegetation, massed works of man) using this new resource (EROS Program 1971). After launch of *ERTS-1*, later renamed as *Landsat 1*, the capability of the new system was apparent, with the science community noting that "ERTS could provide nothing less than a continuing, automated inventory of many of the world's resources" (Bylinsky 1975).

Over the 50 years of continuous Earth observation from the Landsat series of satellites, the mapping and monitoring of land cover has been a major derivative product of the data. Land-cover data in turn have been used for countless applications, including biodiversity, hydrology, carbon and greenhouse gases, and human health and safety, applied at scales from local to global (Table 1, *see next page*). However, for most of those 50 years, few institutions had the capability to produce broad regional- to national-scale land cover, as the "complexity of developing a land change monitoring system for large areas requires stable funding over long periods, considerable computing and storage capabilities, database management, and research to support continued production and product development" (Homer *et al.* 2020).

The U.S. National Land Cover Database (NLCD) began 30 years ago as a revolutionary attempt to use the consistent Landsat archive for national-scale mapping of land cover for the conterminous United States. The effect of NLCD on the scientific community, land and resource management, and health and human safety is difficult to overestimate; however, the field of land-cover mapping has undergone a revolution in the last several years. The original 1992 iteration of NLCD (Vogelmann *et al.* 1998a; Vogelmann *et al.* 2001) took several years to complete. With recent innovations the combination of cloud computing and freely available remote sensing data make it possible to create a national-scale land-cover map within days if not hours, although alternative products exhibit lower accuracy (Wang and Mountrakis 2023).

The NLCD is celebrating its 30th anniversary since initiation. It is no longer the only national-scale data available for the United States, but it remains the standard for validated, trusted land-cover data for the United States and is likely the most widely used land-cover data in the world. However, as technological innovation and new sources of data become available, NLCD must continue to evolve to maintain relevance. This article summarizes the history of the NLCD, the effect of NLCD in the scientific community and society aas a whole, and future directions and NLCD's long-term niche as science requirements and capabilities evolve.

NLCD History

Since the first Landsat launch, U.S. federal agencies developed applications based on Landsat data, taking advantage of Landsat's broad synoptic coverage, consistency of data, and long-term record. However, after the 1984 Land Remote Sensing Commercialization Act (Congress.gov, 1983–1984), costs for commercially distributed Landsat rose substantially. By 1992, total orders for Landsat products had

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dropped to only 4482 distributed scenes. To help overcome rising costs, the U.S. Geological Survey (USGS), U.S. Environmental Protection Agency (EPA), and the National Oceanic and Atmospheric Administration (NOAA) formed the Multi-Resolution Land Characteristics (MRLC) Consortium to pool agency resources and purchase complete coverage of Landsat data for the conterminous United States to meet individual agency needs. The consortium later expanded to include the U.S. Department of Agriculture (USDA), the Army Corps of Engineers, the U.S. Fish and Wildlife Service, the Bureau of Land Management, and the National Park Service. The MRLC purchased leaf-off and leaf-on Landsat Thematic Mapper scenes for the conterminous United States with dates from 1991 through 1993. The USGS EROS Center completed georectification and radiometric standardization of MRLC-purchased scenes in February 1996 (Campbell 1996).

Soon after the purchase of scenes, MRLC partners discussed the potential use of Landsat mosaics for mapping broad-area land cover using mosaics of Landsat data. The only national-scale land cover for the United States available at the time was the Land Use and Land Cover dataset, developed in the 1970s by interpreting and digitizing high-altitude aerial photography, and a 1-km resolution global land-cover dataset based on the Advanced Very High-Resolution Radiometer (USGS 1990; Loveland *et al.* 1991; Brown *et al.* 1993). By the 1990s, the 1970s Land Use and Land Cover data were outdated, and the Advanced Very High-Resolution Radiometer–based land cover was too coarse for many applications. A pilot investigation mapping regional land cover with Landsat was performed at USGS EROS, with the initial study completed for U.S. Federal Region 3 (U.S. states of Delaware, Maryland, Pennsylvania, Virginia, and West Virginia; Campbell 1996; Vogelmann *et al.* 1998a, 1998b). A successful proof of concept led to an agreement between USGS and EPA to develop a national land-cover dataset, leading to development and eventual completion of the 1992 NLCD (Vogelmann *et al.* 2001; Wickham *et al.* 2014).

The 1992 dataset was a revolutionary product. The development of large regional Landsat mosaics, the mapping by broad geographic zone instead of scene-based mapping, and methodologies for national-scale accuracy assessment were all unique developments (Stehman *et al.* 2003; Wickham *et al.* 2004). Given the exceptionally high cost of individual Landsat scenes and the practicality of Landsat-based national-scale mapping, the final 1992 NLCD product was a one-of-a-kind

Table 1. Applications of NLCD, represented by cited use of NLCD in peer-reviewed literature. Most applications have numerous references, indicating the standard use of NLCD for a wide variety of interdisciplinary applications.

Energy Development	
Biofuel development	Stoof *et al.* 2015; Baxter and Calvert 2017; Austin *et al.* 2022
Wind development and siting	Kiesecker *et al.* 2011; Fargione *et al.* 2012; Dai and Scown 2025
Hydropower potential at U.S. dams	Hadjerioua *et al.* 2012; Fergus *et al.* 2021; Rosenlieb *et al.* 2022
Power grid vulnerability	Alpay *et al.* 2020; Arora and Ceferino 2023; Watson *et al.* 2024
Post-operations reclamation	Ferrari *et al.* 2009; Gurung *et al.* 2018; Maigret *et al.* 2019
Human Health	
Mosquitoes and disease risk	Bowden *et al.* 2011; Wiese *et al.* 2019; Bondo *et al.* 2022
Lyme disease risk	Diuk-Wasser *et al.* 2012; Ballard and Bone 2021
COVID incidence	You and Pan 2020; Grima *et al.* 2021; Li and Managi 2023
Air-quality impacts	Cooter *et al.* 2012; Di *et al.* 2019a, 2019b; Rehman and Counts 2021
Natural Hazards	
Flooding vulnerability (inland)	Qiang *et al.* 2017; Tate *et al.* 2021; Banjara *et al.* 2024
Coastal storm surge	Bunya *et al.* 2010; Haddad *et al.* 2015; Yarveysi *et al.* 2025
Landslide vulnerability	He *et al.* 2014; Dahigamuwa *et al.* 2016; Meng *et al.* 2024
Fire management and risk	Alexandre *et al.* 2015; Radeloff *et al.* 2018; Gould *et al.* 2023
Biodiversity and Ecosystem Health	
Regional and national species richness	Pidgeon *et al.* 2007; Culbert *et al.* 2013; Dertien *et al.* 2020
Migratory corridors and behavior	Bonter *et al.* 2009; Guo *et al.* 2022; Mendgen *et al.* 2023
Pollinator health and abundance	Gallant *et al.* 2014; Ballare *et al.* 2019; Pardee *et al.* 2023
Species distribution models	Ferreira *et al.* 2011; Kreakie *et al.* 2012; Sohl 2014
Atmosphere and Land Interactions (Weather)	
Convective precipitation amounts	Carrio *et al.* 2010; Houser *et al.* 2019; Singh *et al.* 2020
Severe storm severity	Stueve *et al.* 2011; Liu and Li 2016; Frazier *et al.* 2019
Snow characteristics	Anderson *et al.* 2014; Foster *et al.* 2017; Linares and Ni-Meister 2024
Urban heat island	Conlon *et al.* 2020; Xian *et al.* 2021; Hasan *et al.* 2022
Hydrology	
Pollutant modeling	McMahon *et al.* 2019; Saby *et al.* 2021; Woznicki *et al.* 2023
Suspended sediment modeling	Renwick *et al.* 2005; Schwarz 2008; Dow *et al.* 2024
Harmful algal blooms	Iiames *et al.* 2021; Pelletier *et al.* 2024
Urban runoff	Chen *et al.* 2017; Kandel *et al.* 2022; Patton *et al.* 2022
Streamflow modeling	Eddy *et al.* 2017; Debbage and Shepherd 2018; Chordia *et al.* 2022
Economics and Policy	
National flood policy	Patterson and Doyle 2009; FEMA 2022
Clean Water Act analysis	Taylor and Druckenmiller 2022; Tomczyk *et al.* 2023
National land accounts	Sutton *et al.* 2019; Warnell *et al.* 2020; Wentland *et al.* 2020
Tourism economics, availability	Beeco *et al.* 2014; Browning *et al.* 2022
Conservation Reserve Program	Nielson *et al.* 2008; Riffell *et al.* 2010; Fleming 2013
Land Management	
Land use planning	Kovacs *et al.* 2013; Pennington *et al.* 2017; Bai *et al.* 2021
Soil erosion potential	Duan *et al.* 2008; Woznicki *et al.* 2020; Stribling 2024
Agricultural water use	Singh *et al.* 2014; LaHaye *et al.* 2021; Gedefaw *et al.* 2022
Watershed management	Ale *et al.* 2012; Vittorio and Ahiablame 2015; Yang and Best 2015
Ecosystem services valuation	Pickard *et al.* 2015; Narducci *et al.* 2019; Cochran *et al.* 2020

NLCD = National Land Cover Database.

map product for the conterminous United States, a status that largely stayed accurate for the next 20 years.

The 1992 NLCD may have been ground breaking, but the production process was time consuming, with final release of the data not occurring until late 1999. Given the dynamic U.S. landscape, production plans for a new, updated version of NLCD began almost immediately, with additional updates at increasingly smaller intervals to enable land-change monitoring and ensure that "recent" land-cover data were available. With each iteration of NLCD, improvements were implemented to expand the product line, improve the product quality, or reduce latency of delivery. Methodologies have continually evolved to meet those goals, moving from supervised classification and substantial manual interpretation with NLCD 1992, to classification and regression trees with NLCD 2001, to the series of linked deep learning models used with the latest iteration of NLCD. Figure 1 shows a timeline for NLCD, from initiation of the MRLC and the first 1992 NLCD, through the latest annual NLCD update release in 2025, with major innovations listed for each new delivered product.

Latest Annual NLCD

The Annual NLCD 1.0 product suite—including Land Cover, Land Cover Change, Land Cover Confidence, Fractional Impervious Surface, Impervious Descriptor, and Spectral Change products for the conterminous United States at 30-m resolution for 1985–2023—was released in late 2024. The new 2024 NLCD product suite (i.e., Annual NLCD Collection 1.1) was produced and added to existing land-cover data to complete four decades of land-cover and change monitoring and released in June 2025 (USGS 2024).

The overall method leveraged knowledge and experience from two projects at USGS EROS (i.e., legacy NLCD and Land Change Monitoring, Assessment, and Projection project) and included new innovations in image processing, training data modeling, deep machine-learning architecture design, and postprocessing (Brown *et al.* 2020). An automated compositing algorithm was developed to ingest Landsat Collection 2 Analysis Ready Data and output cloud-free and gap-free composite imagery, which can be directly used for land-cover classification. Composite imagery, synthetic imagery, and harmonic coefficients from continuous change detection, ancillary data, and multi-epoch legacy NLCD were hierarchically sampled and trained to produce regional and local models. A hybrid spatiotemporal deep-learning approach, which follows a two-track (land cover and impervious percentage), two-tier (U-nets and Transformer) methodology, was designed to produce one-to-one, land-cover, impervious descriptor and fractional impervious cover information (Fleckenstein 2025). The US Forest Service developed a new 1985-2023 NLCD Tree Canopy Cover as part of the new Annual NLCD, continuing a partnerhip committed to providing a comprehensive, multi-variable product suite (USDA Forest Service 2025).

Impacts of NLCD on the Scientific Community and Society

It is difficult to overestimate the effect NLCD has had on the scientific community, land and resources managers, health and human safety, and government policy. Here, the impacts of NLCD over the last three decades are summarized.

New Era of Interagency Collaboration

The NLCD was invaluable as a landscape monitoring project, but it also initiated a new era in cooperation on U.S. agency use and application of remote sensing data. With the formation of the MRLC, member agencies reduced duplication of effort, leveraged and shared research and development results, and provided a more comprehensive understanding of the U.S. landscape than any one agency could provide alone. The initial joint purchase of Landsat Thematic Mapper data resulted in a direct savings of $4 million across member agencies, with estimated joint savings for image processing and data management totaling an additional $26 million (Campbell 1996). Development of the NLCD database paradigm was cited by NOAA as facilitating a synergistic and cost-effective approach to collaboration, whereas EPA noted costs were a fraction of what they would spend independently on

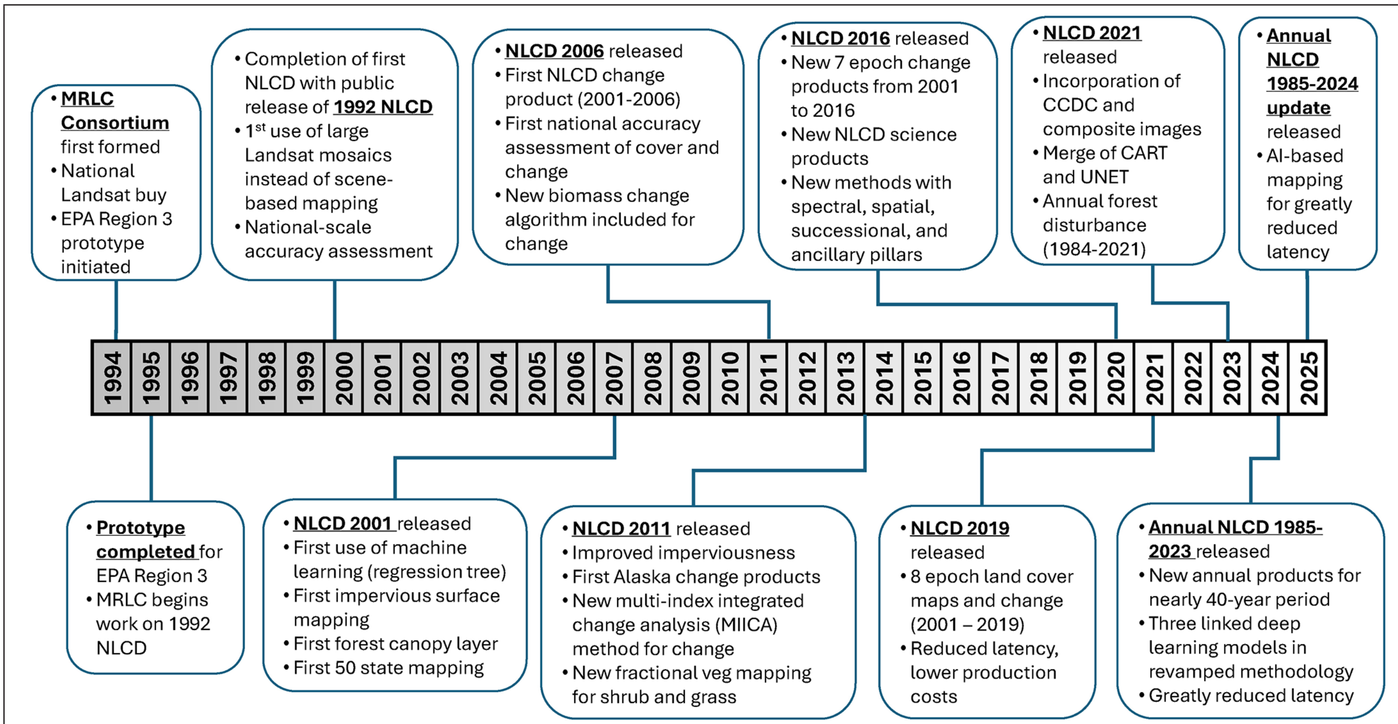

Figure 1. NLCD timeline, from initiation of the Multi-Resolution Land Characteristics Consortium, through the delivery of the latest annual NLCD products. Major innovations are provided for each new release, highlighting the continual evolution of NLCD (Vogelmann *et al.* 1998b; Vogelmann *et al.* 2001; Homer *et al.* 2004; Fry *et al.* 2011; Homer *et al.* 2015; Homer *et al.* 2020; Dewitz and USGS 2021; Dewitz 2023; USGS 2024; USGS 2024). NLCD = National Land Cover Database.

developing land cover and supporting their mission-related activities in air- and water-quality protection (Wickham *et al.* 2014).

As a consortium, the MRLC has developed a broad array of landscape monitoring data that complement NLCD and together provide a more thorough understanding of U.S. landscape change than any one agency could provide alone. The sister-product Coastal Change Analysis Program land-cover dataset, produced by NOAA, is focused on coastal areas and providing additional information on wetland habitats and other products with higher resolution than is provided by NLCD (NOAA 2022). The USDA produces the Cropland Data Layer (CDL), augmenting the NLCD cropland class with detailed mapping of thematic crop types for the United States (Johnson and Mueller 2010; Lark *et al.* 2017). The USDA Forest Service produces a forest canopy percentage dataset that is distributed with NLCD and complements discrete land-cover values (Coulston *et al.* 2012; USDA Forest Service 2025). These products and others are interlinked, with individual agency products often reliant on products from the MRLC partner agency. For example, NOAA has used NLCD-thematic land cover for value-added Coastal Change Analysis Program classifications in coastal areas, USDA CDL has used NLCD to map non-agricultural areas, and NLCD relies on CDL for training data of agricultural lands.

Conceptual and Methodological Shifts in Land-Cover Mapping

The 1992 NLCD was a pioneer effort in many ways, with subsequent iterations providing improvements that additionally altered the field of land-cover mapping.

Landsat for Broad Regional and National Mapping

For much of the NLCD timeline, the only comparable effort was the European Commission's Coordination of Information on the Environment Land Cover for Europe (Büttner 2014); however, this effort was based on manually interpreted, hard-copy, individual Landsat scenes. The 1992 NLCD was the first effort to digitally map Landsat-scale (30 m) land cover at broad, national scales requiring the mapping of parts of ~430 different Landsat scenes (Vogelmann *et al.* 2001).

Standardization of Landsat Data

For any land-cover mapping effort requiring coverage from more than one Landsat scene, scene-by-scene mapping and postclassification mosaicking dominated before 1992 NLCD (e.g., Fuller *et al.* 1994) but often resulted in seamlines between adjacent images. The 1992 NLCD attempted to minimize seamlines through mosaic-based mapping, with histogram equalization used to normalize each scene to an adjacent master scene (Vogelmann *et al.* 2001). The second iteration of NLCD (2001) furthered efforts to standardize and normalize Landsat data, with more rigorous radiometric calibration and conversion to at-sensor spectral radiance, top of atmosphere reflectance, and at-sensor brightness temperature prior to image classification (Chander *et al.* 2009). Standardizing Landsat data helps to eliminate seamlines and facilitates multi-date comparison of reflectance and assessment of land-surface change. More recent versions of NLCD are built on the use of Landsat Analysis Ready Data, a standardized set of surface reflectance products designed for time series analysis (Dwyer *et al.* 2018).

Semi-automated Classification at Broad Spatial Scales

Statistically based clustering methodologies for land-cover production, including initial attempts to use decision-tree methodologies, were beginning to be used in the 1990s, but computational and resource demands limited Landsat-scale applications to scene-based or local applications. The 1992 NLCD was the first application that mapped land cover for such a broad geographic extent at a Landsat pixel scale using a semi-automated, digital classification algorithm. Methodologies have continually evolved since then, with machine learning (classification and regression trees) being incorporated into the 2001 NLCD, and a series of three linked artificial intelligence (AI) based deep-learning models for the latest Annual NLCD release.

Imperviousness Mapping

Imperviousness was not recognized widely as a benchmark measure of land use until the early 1990s (Schueler 1994; Arnold and Gibbons 1996). National-scale imperviousness mapping was initially developed for the second NLCD iteration (2001) and has been a core product for all subsequent NLCD iterations. The 2001 NLCD imperviousness product marked the first national-scale impervious product produced and distributed at the Landsat scale and has served an invaluable role in supporting many broad regional- to national-scale applications (Endreny and Thomas 2009; Theobald *et al.* 2009; Zhang *et al.* 2014).

Forest Canopy Mapping

With the release of the 2001 NLCD, forest canopy was included as an additional variable to land cover, the first national, Landsat-scale data product of its kind (Homer *et al.* 2004). The USDA Forest Service continues to provide leadership and development of forest canopy products for NLCD, with widespread applications that augment the value of NLCD land-cover data (Ruefenacht *et al.* 2015, Houseman *et al.* 2023).

National-Scale Accuracy Assessment

The 1992 NLCD accuracy assessment represented the first attempt to evaluate the accuracy of a national land-cover map at 30-m pixel resolution (Stehman *et al.* 2003). Formal accuracy assessments have accompanied each subsequent NLCD iteration, including assessments of change across different NLCD epochs (Wickham *et al.* 2004, 2010, 2013, 2017, 2021, 2023). Along with papers describing statistical methodologies, citations for NLCD accuracy assessment publications number more than 1500, with NLCD accuracy assessment methodologies used for countless other remote sensing applications (Stehman *et al.* 2003, 2008; Huang *et al.* 2010; Song *et al.* 2016; Tsendbazar *et al.* 2018; Yin *et al.* 2018). The NLCD continues to address cutting edge issues in national-scale accuracy assessment, providing one of the first assessments of annual land cover over a long time period and examining the effect of interpreter consistency on accuracy assessment and land-cover area estimation (Pengra *et al.* 2020; Stehman *et al.* 2021, 2022; Xing and Stehman 2024).

National-Scale Change Data for the United States

Computational restrictions and data requirements limited Landsat-based change detection to smaller local or regional scales, until the 1992–2001 Retrofit product (Fry *et al.* 2009). The Retrofit product attempted to harmonize the newly released 2001 NLCD with the previously released 1992 data, providing more meaningful change data than can be provided through postclassification comparison of two independently created maps. The 1992 to 2001 Retrofit product set the standard for subsequent NLCD releases to a land-change monitoring framework rather than a more basic periodic data refresh. This established Landsat-based change monitoring as a feasible, operational paradigm for broad national application.

Every Pixel Counts

With the release of Annual NLCD 1.0 in October 2024, NLCD adopted the mapping paradigm from the USGS Land Change Monitoring, Assessment, and Projection project, including the Continuous Change Detection and Classification algorithm as part of the core strategy (USGS 2024). Continuous Change Detection and Classification is a pixel-based approach that uses every cloud-free pixel in the Landsat archive, a massive paradigm shift from the original 1992 NLCD that used one or two cloud free scenes for each Landsat path or row (Zhu and Woodcock 2014).

Appearances in Scientific Literature and Public Media

The broad use of NLCD in scientific and academic communities has resulted in a widespread presence in the scientific literature, with thousands of citations in the scholarly literature referring to NLCD and its use. More than 10,300 scientific publications refer to NLCD, including more than 9300 peer-reviewed journal articles covering more than 1100 different journal titles, more than 280 books and book chapters, and more than 600 conference papers representing more than 290 different conferences (Figure 2). To date, more than 970 emerging scientists have cited NLCD in their thesis and dissertation work. Figure 3 shows the breadth of topical areas and geographies touched on by manuscripts referencing NLCD, demonstrating the broad multidisciplinary impact.

Outside of academia and scientific literature, NLCD is heavily used in applied environmental work, including assessments conducted by federal and state agencies, non-governmental organizations, and local planning authorities. Governmental use of NLCD frequently influences policy decisions related to land conservation, zoning, and environmental compliance, such as supporting U.S. Fish and Wildlife Service habitat conservation planning (Soullierie *et al.* 2017), Federal Emergency Management Agency floodplain mapping (FEMA 2022), and drinking-water source assessments (New York State Department of Environmental Conservation 2025). The NLCD has been directly cited in more than 6000 policy documents, covering more than 130 different U.S. policy sources and 50 different broad topical areas, with additional references found in more than 1600 technical reports. The NLCD is also commonly referred to in popular media, highlighting the significance of the dataset to issues of overall societal interest and concern. Approximately 11,900 popular news stories have referred to NLCD in some way, representing more than 9800 different news outlets, including the New York Times, Washington Post, National Geographic, and National Public Radio (Figure 2).

U.S. Federal Impact

The original intent of the MRLC, and subsequently of the NLCD, was to serve the needs of the U.S. federal community for Landsat and derived land-cover data. Figure 4 (*see next page*) depicts the success of NLCD in supporting federal needs, linking one NLCD iteration (NLCD2011) with applications and federal agency (Homer *et al.* 2015). The breadth of applications across the U.S. federal government is vast and ranges from fire fuels to drought to honeybee habitat. The USGS National Land-Imaging Program Requirements, Capabilities, and Analysis for Earth Observation found that more than 70% of all U.S. federal use of Landsat in major sectors of agriculture, climate, and forestry were related to NLCD or NLCD derivatives (USGS 2025).

Impact on the Scientific and Resource Management Communities

The NLCD has had countless applications advancing scientific understanding and management of U.S. lands and resources. These impacts cross all public sectors, including federal, state, and local governments; academia; business and private sectors; and non-governmental organizations. The magnitude of NLCD in peer-reviewed literature, public news media articles, and policy documents is

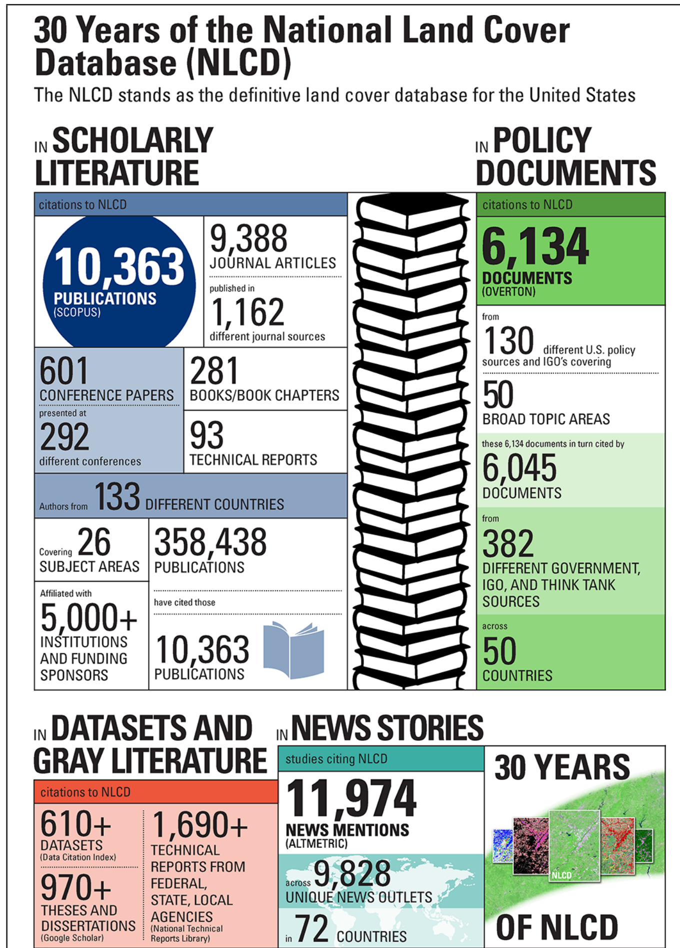

Figure 2. Summary statistics of the use of the National Land Cover Database in the scholarly literature and public media as of approximately February 2024 (USGS 2024).

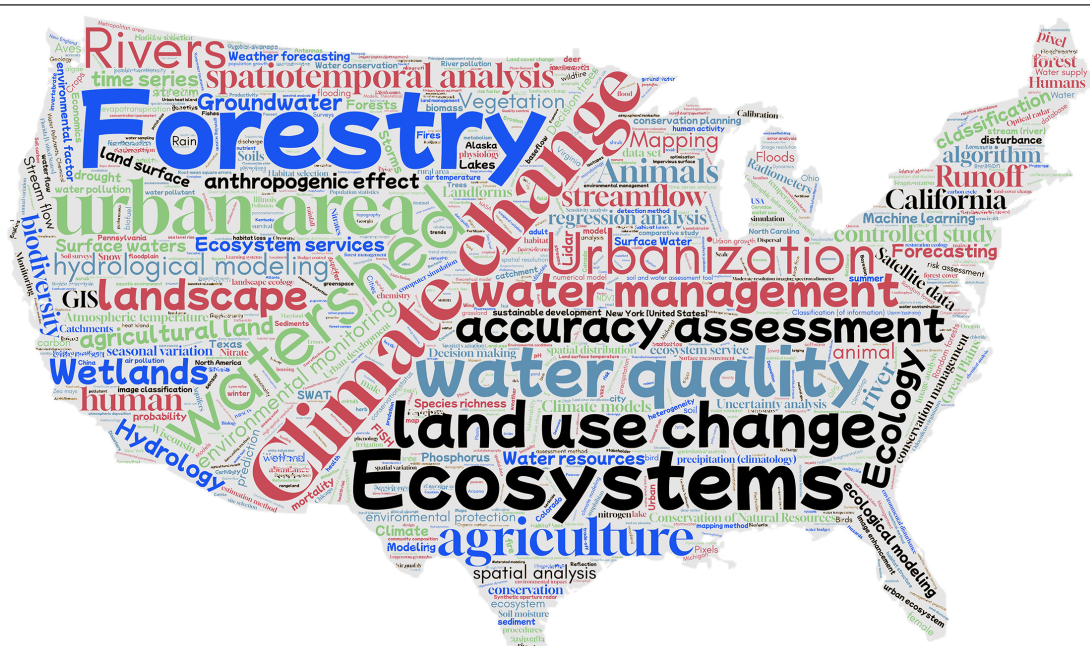

Figure 3. Word cloud depicting content of major journal abstracts that reference NLCD, highlighting the vast array of environmental, economic, policy, and other societal issues that NLCD touches. NLCD = National Land Cover Database.

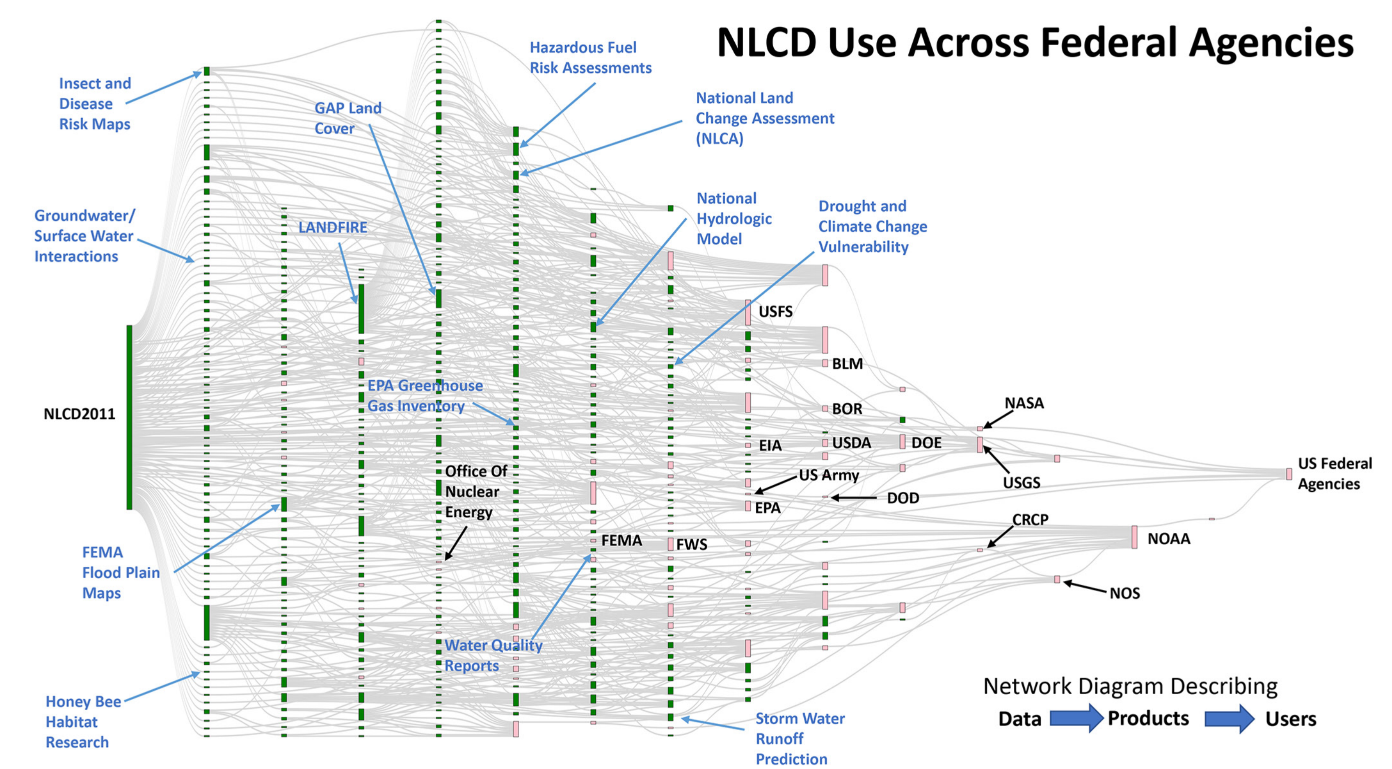

Figure 4. Sankey chart depicting use of NLCD within the federal community (NLCD 2011 in this depiction). NLCD is directly used by many federal agencies, but it also serves as primary data source for generating other needed federal data products. NLCD = National Land Cover Database.

astounding, yet it touches only on the most publicly accessible materials that demonstrate the use of the NLCD archive. Countless other applications likely use NLCD but are more difficult to characterize, particularly those in the private sector where peer-reviewed literature or other publicly available documentation describing the use of NLCD generally is not available.

Table 1 provides an overview of applications for which NLCD has been published in peer-reviewed literature. From environmental issues to land management and to policy and economics, NLCD informs many disciplines, yet the applications listed here indicate only a small fraction of on-the-ground applications of NLCD over the years. Uses are pervasive across many sectors at scales from national to local levels. Figure 5 depicts uses of NLCD for one relatively limited geographic area in the United States, the Lower Mississippi River Basin, which scratches only the surface of applications in the region.

Future Directions and Niche

The NLCD has been a revolutionary product, one that, for many years, was the only national-scale, Landsat-resolution product available for the United States. With new developments in cloud computing, deep learning and AI, and new data sources, land-cover products at regional, national, or even global scales are increasingly common. In just the past few years, national-scale coverage of land cover within the United States is also available through global land-cover products based on Sentinel-2 data, including the European Space Agency's WorldCover and Environmental Systems Research Institute's 10-m land cover (Karra *et al.* 2021; Zanaga *et al.* 2022). Commercial providers also increasingly provide high-resolution land cover on demand.

With the advent of new land-cover products, some with characteristics similar to NLCD, clarifying the niche of NLCD becomes increasingly valuable. The NLCD retains unique characteristics compared with other newly available land-cover data, including a long historical retrospective view of land-cover change (1985 through 2024), a focus on the characterization of change as opposed to representation of static land cover, the inclusion of complementary landscape variables including impervious surface and forest canopy cover, and perhaps most notably, a long-term U.S. federal commitment to a product that is a long-time staple in science, land management, and academic communities. In addition, independent analysis has demonstrated that NLCD outperforms other available land-cover products available for the United States both in terms of higher individual class accuracy and with accuracy variability across classes, which is not unexpected given generally anticipated higher performance for U.S. specific mapping compared with global maps with U.S. coverage (Wang and Mountrakis 2023). However, NLCD remains the most widely used source of land-cover data at moderate resolution for the United States.

Commercial entities are increasingly providing high-resolution (e.g., 1–5 m) land cover on demand, whereas NOAA has also begun to provide high-resolution land cover for select locations in the United States, with the goal of providing 1-m land cover for all United States coastal zones (NOAA 2025). With the rise of commercial interests in the production and dissemination of high-resolution land cover and the focus of NOAA on high-resolution land cover for U.S. coastal zones, it is not anticipated that NLCD will compete with high-resolution land-cover providers. However, freely available, moderate-resolution (Landsat-scale) land cover clearly remains an invaluable dataset for a wide variety of stakeholders. A multi-resolution paradigm to land cover likely defines NLCD's ongoing position, with operational, freely available, long-term monitoring of national-scale land cover for the United States provided through NLCD, whereas higher resolution land cover is provided by commercial or other federal entities as needed.

Developers and maintainers of NLCD continue to address the challenges and issues that exist with the product line. Creating a consistent, moderate-resolution product with national consistency and regional specificity is difficult. To counter issues with latency and temporal frequency, the new AI-based algorithms are now capable of producing annual updates with delivery measured in a handful of months from the mapping year. Other ongoing challenges include likely underestimation of low-density urban lands, user needs for greater thematic resolution, and a need for improved characterization of change (Wang *et al.* 2022; Wickham *et al.* 2023; Griffith 2025).

Figure 5. Sampling of the variety of applications of the National Land Cover Database in the Lower Mississippi River Basin.

The NLCD will continue to evolve under the mantra of faster, cheaper, better. Each new release is planned to provide more efficient and cost-effective mapping and increase accuracy over time. The newest annual NLCD 1985–2024 demonstrates this effort through innovative use of the latest in AI. Current NLCD research includes the use of transformer-based foundation models that can be trained once and then applied broadly. This potentially improves mapping efficiencies for NLCD and provides a potential platform for simultaneous co-production of other land-change variables produced by USGS EROS, resulting in an expanded land-change monitoring portfolio of nested, consistent products describing multiple aspects of U.S. landscape change.

Conclusions

The NLCD has had a transformative effect on land-cover mapping, scientific research, policy development, and resource management in the United States over the past 30 years. Its evolution from a ground-breaking 1992 product to today's sophisticated, annual land-change monitoring system corresponds with advances in satellite data processing, machine learning, and interagency collaboration. The NLCD has become a cornerstone dataset that is widely used across disciplines ranging from biodiversity and hydrology to human health, urban planning, and climate resilience.

Looking forward, although the availability of alternative land-cover products is rapidly expanding, NLCD maintains a unique and vital niche. Its strengths lie in its long-term historical record, detailed national change monitoring, and strong federal support for continuity, accuracy, and consistency. As the field shifts toward a multi-resolution, multi-source paradigm, NLCD will continue to provide essential, moderate-resolution, annual land-cover and change data for the United States and a trusted foundation for both scientific inquiry and practical decision-making well into the future.

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