Supplementary

Table S1. LULC Class definitions and reclassification IDs (source: https://www.mrlc.gov/data, accessed on 27 February 2021)

Land cover class	NLCD class	Modified ID	Definition
Water	11	1	All areas of open water, generally with less than 25% vegetation or soil cover.
Urban	21 22 23 24	2	All areas of low, medium, and intense development with a mixture of constructed materials and vegetation, such as lawn grasses as large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes, multifamily housing units, and areas of retail, commercial, and industrial uses. with a mixture of some constructed materials.
Barren Land	31	3	Areas of bedrock, pavement, scarps, talus, slides, glacial debris, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Deciduous & Mixed Forests	41 43	4	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change (41: Deciduous Forest), or neither deciduous nor evergreen species are greater than 75% of total tree cover (43: Mixed Forest).
Evergreen Forest	42	5	Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
Shrub/Scrub & Herbaceous	52 71	6	Grassland areas dominated by graminoid or herbaceous vegetation (52) and shrub/scrub (71) areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation, including true shrubs, young trees in an early successional stage, or trees stunted due to harsh environmental conditions.
Hay/Pasture	81	7	All actively tilled land for planting grasses, legumes, or grass-legume mixtures for livestock grazing or the production of seed or hay crops, typically on a perennial cycle.
Cultivated Crops	82	8	Areas used to produce annual crops, such as corn, soybeans, and cotton, and also perennial woody crops such as orchards and vineyards.
Forested and Open Wetlands	90 95	9	Areas with forests or shrublands (90), or perennial herbaceous covers (95) and the soil or substrate is periodically covered or saturated with water.

1. S1. Incorporating driving factors to CI layer

Table S1 shows the reclassification of LULC categories based on the NLCD. These reclassified categories were used in our analysis. Population change is often closely linked to residential and commercial development, and both are associated with changes to transportation infrastructure [83]. Although a map of roads, highways and railroads was used in extracting change potentials and previous LULC change trends, population change was not directly incorporated in the Land Change Modeler module in TerrSet

software. This is despite the fact that population change is one of the most important factors dictating future LULC changes, and inclusion of a population growth rate helps to not only anticipate future trends of urban expansions but also to make informed decisions about infrastructure investments [84]. Thus, in this study we included a population growth rate layer generated by the US Census Bureau at the census tract level (https://data.census.gov/cedsci, Accessed on 24 September 2022) as one of the contributing factors to our CI layer. For the sake of simplicity and consistency, this factor is considered constant over time in our model.

Income is another socio-economic factor suggested to have a significant impact on future urbanization patterns [10,85,86]. Previous research on urbanization trends showed a considerable growth in the suburbs during the mid-20th century when middle- and upper-class residents fled the urban center to the suburbs while the poor settled in urban cores [20]. We concluded that there is a higher chance of forest conversion to urban areas in the outlying areas of counties with higher median household income. We extracted information on population median household income at the census tract level in our study area from the https://data.census.gov/cedsci, (Accessed on 24 September 2022) Website. As discounting Median Household Income would be a linear transformation with no effect on the model, it is considered constant over time in our model for simplicity.

Information and communication technologies play an increasingly important role in the planning, management and use of urban physical infrastructure in the areas of transport systems, power supply, sewage and waste treatment and water supply and management [87]. Rapid technology development in the area of digital network and telecommunications on the one hand, and post COVID-19 social norms such as remote work and education opportunities on the other, represent a considerable impact on contemporary urbanization process [64]. Therefore, we added a broadband coverage map downloaded from the https://data.census.gov/cedsci (Accessed on 24 September 2022) website as one of the factors affecting urban sprawl trends.

In Georgia, families and individuals are the predominant owners of forestlands that can range from less than a single acre to many thousands of acres in size. Although there are policies and programs encouraging forest owners to maintain their forestlands through offering technical assistance and property tax reduction incentives, there are substantial costs or other barriers such as minimum acreage threshold that make some of these programs not applicable or less feasible to smaller-size forest owners [88]. Because of economies of scale and the exclusion of smaller forest holdings from incentive programs [89], along with desires to live in or around the woods as a growing lifestyle trend that encourages the sale of forests to be used for residential purposes [90], smaller forest parcels and those closer to metropolitan areas are more vulnerable to urbanization. In this study we included a "Vulnerable Forests" layer in developing our CI layer, where "Vulnerable Forests" represent forestlands ranging from 0.5 to 20 ha in size and within the 30km proximity of the AMA.

Another policy that can help to restrict urbanization in some forestlands is the federal Endangered Species Act (ESA) (16 U.S.C. §1531 et seq. (1973)) which protects listed species from direct or indirect harm, including adverse modification of habitat [91]. The ESA operates through a mix of restrictions designed to protect existing members of species listed as "threatened" or "endangered" under the Act and programs designed to recover populations for eventual de-listing. The latter include incentive-based and cooperative programs with public, private, and tribal landowners [92]. To incorporate the ESA into our analysis, we searched for listed endangered and threatened species in our study area and found eleven species, five of which were invertebrates living in the Flint River, five of which were plant species inhabiting mesic areas mostly close to the Flint River, and only one bird species: *Picoides borealis*, the red-cockaded woodpecker (Table S2). We downloaded a critical habitat layer for the red-cockaded woodpecker from the Georgia Biodiversity portal through the following link: (https://georgiabiodiversity.org/natels/rangemaps?es_id=18726, accessed on 11 September 2022). Critical habitat designation does not

itself strictly prevent changes in land use or land cover, but the presence of the red-cockaded woodpecker in this area is likely to present complications to the conversion of forestlands to other uses. Note that the ESA provides only very limited protections for listed plants growing outside of federal land, and few to no terrestrial land use restrictions are associated with protected instream species such as freshwater mussels.

Table S2: Species listed as federally threatened or endangered under the Endangered Species Act within the UFW as of 2022.

Scientific Name	*Species group*	*Critical habitat*
Picoides borealis	Bird	Open pine woods; pine savannas
Amblema neislerii	Invertebrate	Rivers with fine sediments with low-moderate gradient and slow-moderate current; pools and riffles; substrate gravel/cobble to sand and sandy mud
Elliptoideus sloatianus	Invertebrate	Large rivers to small creeks; found in a variety of substrates
Hamiota subangulata	Invertebrate	Medium sized creeks to large rivers in sand substrates in slow to swift flowing water
Medionidus penicillatus	Invertebrate	Large rivers to small creeks; found in a variety of substrates
Pleurobema pyriforme	Invertebrate	Large rivers to small creeks with slow to moderate current in pool, run, and riffle habitats; combinations of clay, sand, and gravel substrate
Lindera melissifolia	Vascular Plant	Pond margins and wet savannas
Sarracenia oreophila	Vascular Plant	Wet meadows; upland bogs
Schwalbea americana	Vascular Plant	Open pinelands, as in well-managed, somewhat moist longleaf pine-wiregrass forests, seeps
Silene polypetala	Vascular Plant	Mesic deciduous forests
Trillium reliquum	Vascular Plant	Mesic hardwood forests; lime sink forests; usually with *Fagus*

Aside from Georgia rules and regulations on development and natural resource management, there are numerous state-level strategies developed to promote responsible forest management and to encourage private forest owners to contribute to conservation activities in return for receiving tax incentives or technical assistance. However, a majority of these strategies cannot assure the perpetuity of forestlands. In the United States, conservation easements (CEs) are a popular strategy for protecting undeveloped lands from subdivision and development [93] A CE is a type of legal contract entered into voluntarily between a landowner and a land conservation agency (a land trust or government agency) that restricts the use of the land to promote its conservation values. The legal mechanism is a transfer of development rights to the conservation agency [94] without transfer of full title ownership; in essence, the landowner "sells" their rights to undertake actions such as subdivision or residential development and those rights are then extinguished by the purchasing conservation agency. Easements are designed to conserve land that significantly protects open space, promotes recreation opportunities, preserves ecological benefits, and/or preserves historical resources in exchange for potential tax benefits and proceeds from the sale itself [10]. Like other kinds of easements, CEs follow the title to the property upon transfer to new owners. We acquired data on CE from (https://nrcsgeoservices.sc.egov.usda.gov/arcgis/rest/services/easements, accessed on 22 October 2022). In our CI layer we assumed that there is no possibility for LULC change within the boundary of established CEs.

The Georgia Planning Act (O.C.G.A. 50-8-32) established 12 regional commissions as public agencies to assist local governments to develop and promote comprehensive planning in the state [95]. These regional commissions have prepared and released their future comprehensive plans through 2040. UFW is shared between four of these regional commissions: the Atlanta Regional, Three Rivers, Middle Georgia, and River Valley Commissions. We acquired GIS layers of planned developments and planned set-aside areas for conservation purposes in developing our CI layer.

Forestlands offer a variety of ecosystem services important for local and regional communities' wellbeing. However, protecting all of them from conversion to other land uses sometimes can appear contradictory to forest landowners' expectations. The growing concern over the loss of ecosystem services has prompted scientists, land managers, and policymakers to develop methods for identifying forestlands with higher conservation values for conservation [96]. The concept of High Conservation Value Forest (HCVF), accompanied by the HCVF toolkit as a set of practical guidelines to distinguish forests of critical importance, was introduced by the Forest Stewardship Council in 2003 [97]. We applied the HCVF toolkit in our study area and identified forestlands with higher conservation values to prioritize their conservation under our conservation scenario.

The MC matrix used for model validation is given in Table S3 and the MC matrix for the LULC 2040 projection is given in Table S4. Table S5 is the error matrix for the LULC 2040 projection absent the CI layer, and Table S6 is the error matrix for the LULC 2040 projection with the CI layer.

Table S3. An example of Markov chain matrix used for model validation using NLCD2011 and NLCD 2016.

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9
Class 1	0.9708	0.0016	0.0018	0.0023	0.0023	0.102	0.0001	0.0000	0.0109
Class 2	0.0000	0.9998	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000
Class 3	0.0170	0.0382	0.8703	0.0169	0.0336	0.0031	0.0189	0.0010	0.0000
Class 4	0.0001	0.0067	0.0000	0.9285	0.0205	0.0328	0.0072	0.0011	0.0030
Class 5	0.0001	0.0061	0.0001	0.0047	0.9073	0.0763	0.0039	0.0007	0.0009
Class 6	0.0023	0.0120	0.0002	0.0620	0.1721	0.7403	0.0043	0.0053	0.0016
Class 7	0.0001	0.0231	0.0002	0.0183	0.0129	0.0029	0.9409	0.0007	0.0010
Class 8	0.0000	0.0055	0.0001	0.0030	0.0095	0.0043	0.0055	0.9701	0.0021
Class 9	0.0035	0.0004	0.0000	0.0006	0.0003	0.0001	0.0000	0.0001	0.9950

Note: Class numbers are the same as modified ID from Table S1.

Table S4. An example Markov chain matrix used for projecting LULC 2040 generated based on NLCD 2011 and NLCD 2019.

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9
Class 1	0.8999	0.0075	0.0062	0.0121	0.0125	0.0172	0.0005	0.0001	0.0439
Class 2	0.0000	0.9994	0.0000	0.0000	0.0000	0.0000	0.0005	0.0000	0.0000
Class 3	0.0558	0.1180	0.5307	0.0551	0.1068	0.0771	0.0489	0.0034	0.0041
Class 4	0.0007	0.0281	0.0016	0.7582	0.0830	0.0937	0.0212	0.0040	0.0095
Class 5	0.0010	0.0281	0.0050	0.0471	0.6897	0.2095	0.0125	0.0037	0.0033
Class 6	0.0049	0.0416	0.0094	0.2276	0.4351	0.2465	0.0166	0.0127	0.0055
Class 7	0.0004	0.0787	0.0018	0.0536	0.0392	0.0120	0.8088	0.0021	0.0034

Class 8	0.0001	0.0349	0.0008	0.0107	0.0311	0.0124	0.0170	0.8861	0.0068
Class 9	0.0112	0.0024	0.0001	0.0019	0.0010	0.0005	0.0001	0.0002	0.9826

Note: Class numbers are the same as modified ID from Table S1.

Table S5. Error matrix of the projected LULC without the CI layer (rows) against the NLCD 2019 map (columns) as the reference image.

LULC ID	1	2	3	4	5	6	7	8	9	Total
1	90015	62	123	3	37	47	0	0	608	90895
2	0	943623	126	3389	3337	2745	2353	1039	0	956612
3	220	145	19957	599	796	2012	93	0	0	23822
4	104	6151	1325	1918156	2761	83626	542	18	1	2012684
5	44	4498	3049	10154	1722719	171280	515	306	0	1912565
6	247	2164	6415	82479	166974	525974	1564	731	36	786584
7	11	3162	685	418	506	1410	918230	118	43	924583
8	0	1543	121	14	395	482	121	228035	8	230719
9	149	292	0	0	0	64	0	0	628427	628932
Total	90790	961640	31801	2015212	1897525	787640	923418	230247	629123	7567396

Note: Class numbers are the same as modified ID from Table S1.

Table S6. Error matrix of the projected LULC using the CI layer (rows) against the NLCD 2019 map (columns) as the reference image.

LULC ID	1	2	3	4	5	6	7	8	9	Total
1	90015	62	123	3	37	47	0	0	608	90895
2	0	942874	10	839	236	416	108	187	0	944670
3	220	138	20031	212	277	1444	0	0	0	22322
4	78	4977	1038	1950586	1732	58777	116	18	2	2017324
5	22	4319	3049	1245	1810898	134437	101	121	0	1954192
6	295	3941	6754	61508	83541	591892	1909	731	35	750606
7	11	3110	683	810	460	479	921047	25	43	926668
8	0	1927	113	9	344	84	137	229165	8	231787
9	149	292	0	0	0	64	0	0	628427	628932
Total	90790	961640	31801	2015212	1897525	787640	923418	230247	629123	7567396

Note: Class numbers are the same as modified ID from Table S1.

S2. Images of the Upper Flint Watershed

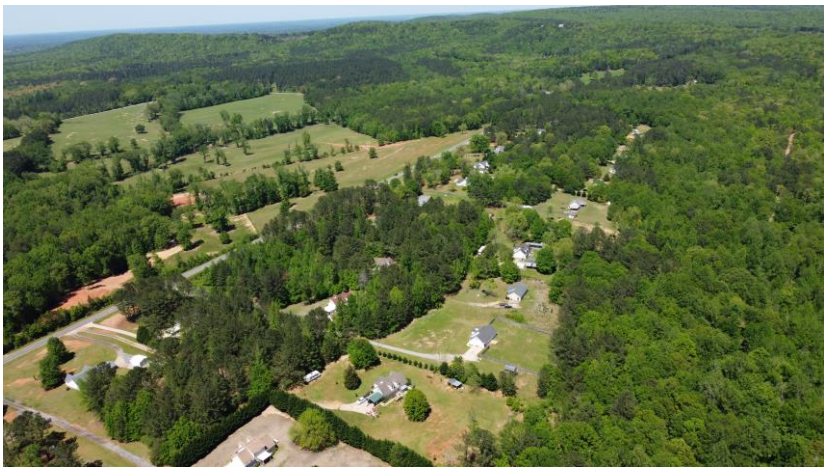

Figure S1. Urban sprawl in Deciduous/Mixed forests in the UFW, GA.

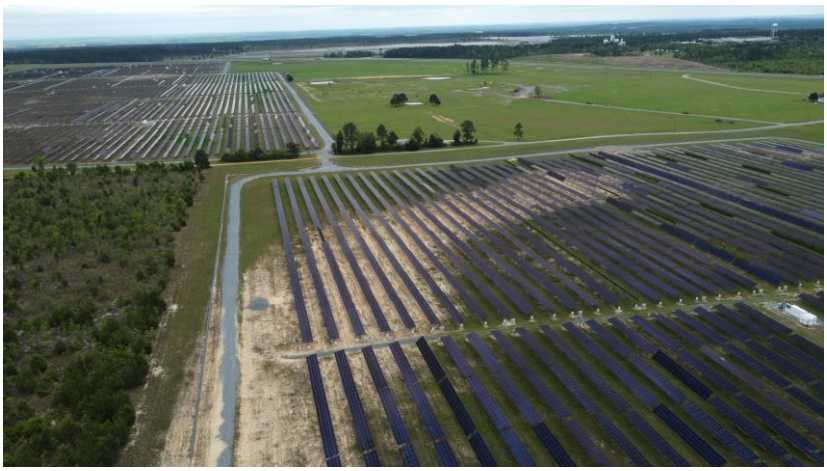

Figure S2. Solar panel farms in the UFW, GA.

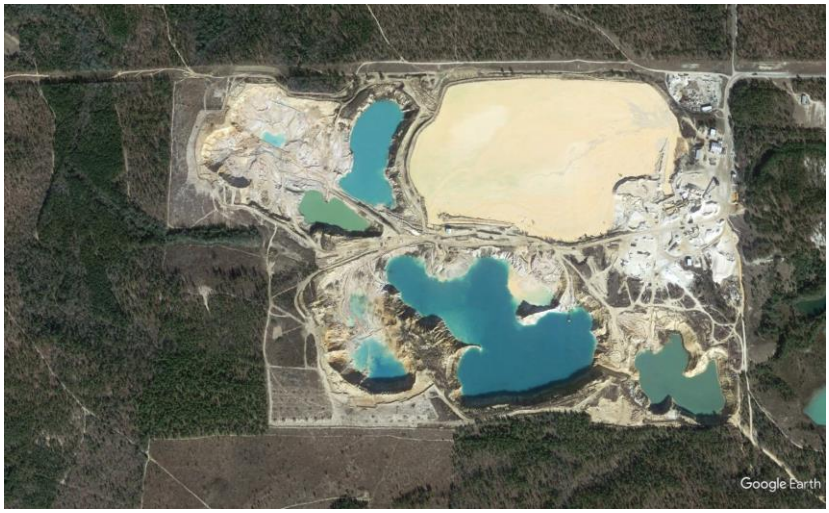

Figure S3. Kaolin Mines within the UFW, GA.

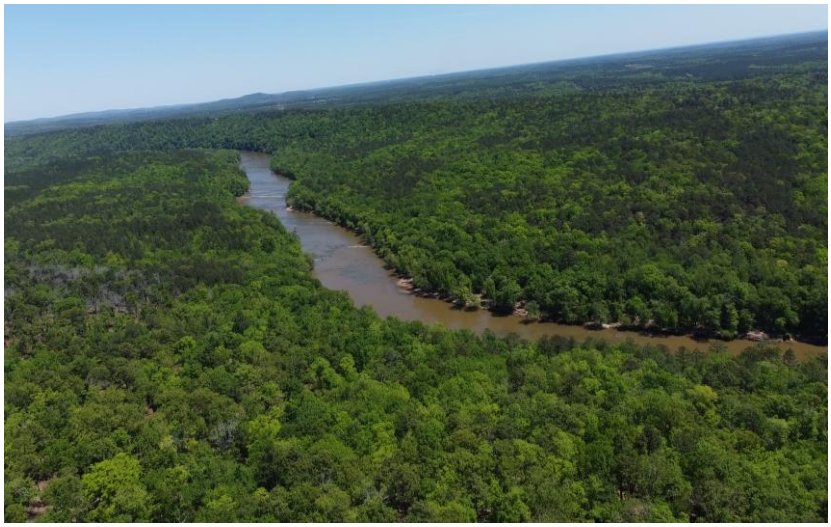

Figure S4. The Flint River, GA.

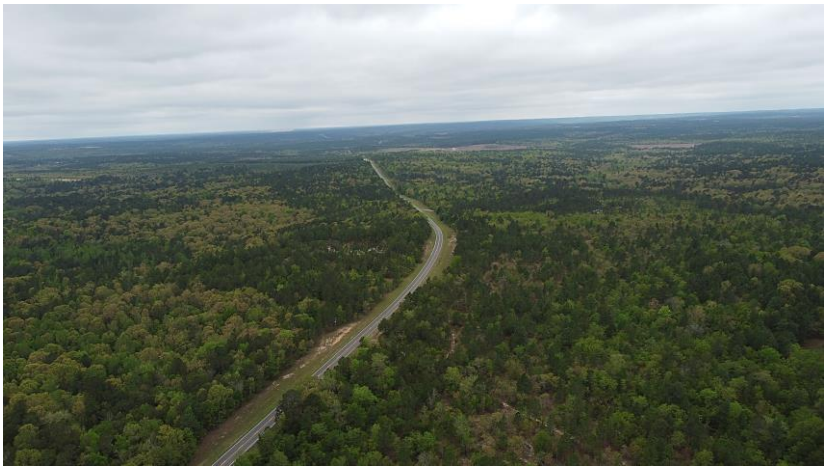

Figure S5. Deforestation due to road development in the UFW, GA.

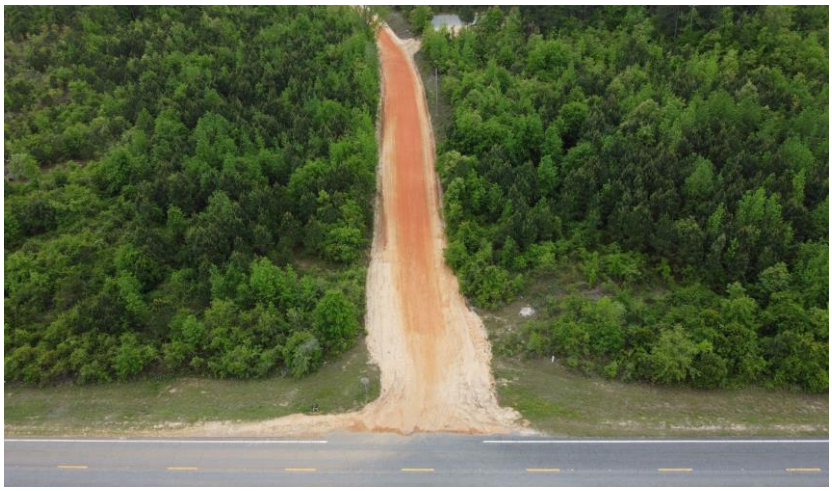

Figure S6. Deforestation due to road development in the UFW, GA.