Development of a ‘Water-Relevant’ Typology of Urban Neighborhoods:

Neighborhood Socio-Ecohydrology along a Gradient of Urbanization

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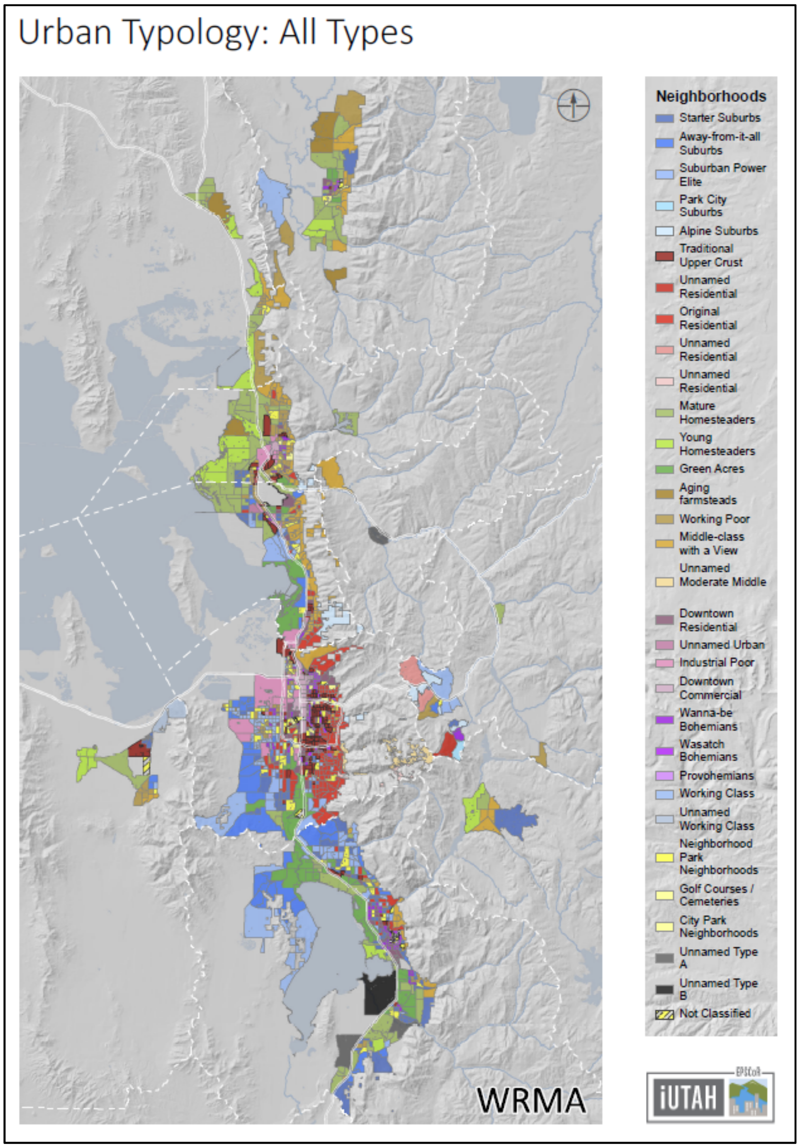

iUTAH TECHNICAL REPORT
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Introduction and Overview

The work reported here represents a fundamental building block of a larger NSF-funded project[1] that attempts to build the human and research infrastructure needed to understand and tackle the challenges of water sustainability in Utah now and in the future. A major emphasis of this larger project is the integration of both ecohydrologic and social science research to understand the complexities of water dynamics in urbanizing watersheds located within arid climatic regions. Our study area includes three neighboring watersheds representing a gradient of urbanization intensity, from relatively pristine montane slopes, to agriculture-dominated rural areas, to the heart of urban Salt Lake City.

In order to design an effective social and biophysical instrumentation network along this gradient, it was necessary to identify distinctive socio-ecohydrologic contexts that are meaningful and measurable expressions of the diverse ways humans occupy this landscape.

The project described here seeks to develop a typology of neighborhoods that would reflect combinations of measurable attributes that we expect will link a range of urban characteristics (biophysical context, built environment and sociodemographics) to core water system outcomes of interest to the iUTAH project (water use, water balance, water quality). The typology will be used to identify a subset of neighborhoods that can serve as locations for detailed instrumentation and further coordinated data collection on coupled social, engineering, biophysical, and ecological processes and outcomes.

The draft urban socio-ecohydrology typology presented in this document was constructed using a wide range of data aggregated at the level of Census Block Groups (CBGs) across the Wasatch Range Metropolitan Area (WRMA[2]). CBGs are geographic areas created by the US Census and approximate 'neighborhoods' in most urban settings. Only CBGs with population densities over 100 persons per square mile[3] were included in our typology.

A total of 48 independent variables were measured in each CBG, and a two-stage process involving factor and cluster analysis was used to identify distinctive combinations of land cover, land use, built environment, household structure, socioeconomic status, water infrastructure, policy, and climate characteristics. Variables used in the typology classification were selected because they represented characteristics of socio-ecohydrologic contexts that have been linked to particular patterns of water use, evapotranspiration, groundwater recharge, and surface water flows and fluxes. Over time, we will use the typology to explore the impacts of urban form on this suite of hydrologic outcomes and the ecosystem services that are driven by flows and fluxes of water in the urban landscape.

Research Questions

The urban typology was developed to help address several of the core research goals and questions that are presented in the iUTAH Strategic Plan. Specifically, we were interested in developing a systematic and empirically grounded typology of urban forms that could be used to help answer some of iUTAH's broad research questions, including:

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[1] An EPSCoR Track 1 award that began in 2012 and is titled the Innovative Urban Transitions and Aridregion Hydrosustainability or "iUTAH" project (see iutahepscor.org).
[2] The WRMA was defined as a 10 county area in northern Utah that included: Cache, Box Elder, Weber, Davis, Morgan, Salt Lake, Tooele, Utah, Summit, and Wasatch counties.
[3] Population density was calculated using 2010 census reports and are adjusted to reflect only the non-federal lands, non-water areas within each CBG.

- How do different urban forms impact water system processes and outcomes (including urban water balances and water quality)?
- Which aspects of urban forms most affect water outcomes?
- How do urban forms, policy contexts, built water infrastructure, climate conditions, and management decisions by local actors interact to explain variation in water use?

The urban typology is an empirical approach to classifying the urban landscape based on traits that have been linked to water outcomes. As we refined our methods, we were guided by three focused research questions:

- What social, built, and natural aspects of urban environments have been linked to a range of water system outcomes in previous research?
- What measures exist for these key attributes across all urban neighborhoods in the entire WRMA region?
- Can a statistical typology be developed for the WRMA that would reflect distinct combinations of measurable attributes that link urban characteristics and water system outcomes?
- How well does this statistical urban form typology fit with local understandings of neighborhood boundaries?

Literature Review

Urban Studies:

The neighborhood typology can be traced back to early urban geography and sociology studies on the population composition in urban settings. Many decades ago, "social area analysis" was a hot topic. After the first few studies, Hawley and Duncan (1957) asked three basic questions about social area analysis that are still relevant to our task: What is a social area? (or, what is the neighborhood?) What is the nature of the social area that have been identified empirically in the writings? What theoretical justification is there for social area analysis as a method of studying the differentiation of areas in a city?

Duany and Talen (2002) developed a neighborhood typology that they called urban transect planning. The transect is a cross-section of a city that shows a set of neighborhoods that vary by their level and intensity of urban character. The result is a continuum that ranges from rural to urban. In transect planning, the range of neighborhoods is the basis for organizing the components of the built world: building, lot, land use, street, and all of the other physical elements of the urban environment.

The continuum crosses six different "ecozones" where they use the term ecozone to promote the link to natural ecologies. Rural Preserve; Rural Reserve; Sub-Urban; General Urban; Urban Center; Urban Core

Although a persuasive and intuitive tool for modeling, analysis, and policy development, transects present technical challenges, including boundary issues and selection of appropriately scaled units of analysis (Shay and Khattak 2007). For example, where does *general urban* end and *urban center* begin?

Shay and Khattak (2007) applied a neighborhood typology to understand how the built environment affects auto ownership and travel. Their methodology to create neighborhood typologies is widely accepted and is similar to the path we follow below. The key steps these researchers employed were identification of relevant attributes of physical form, such as street design, density, land use mix, access, transport alternatives, natural environmental features, and socioeconomic characteristics; Factor analysis of the raw measures to derive major dimensions; and cluster analysis to group those neighborhoods that are most similar in terms of the factors.

For step one, these researchers used 34 direct measures of the built environment, chosen based on the literature as well as availability of data. Data were collected at the block group level. Factor analysis reduced their variables to five factors, and then the cluster analysis yielded eight neighborhood types, or clusters, so that variation is minimized within clusters and maximized between clusters.

Water Research

Water use and water demand

In the best literature review of water demand modeling to date, House-Peters and Chang (2012) review published articles on water use with a focus on variables that affect water use. In this review are key insights for the determinants of water use at the neighborhood scale and developing typologies.

The most frequently utilized *scale* to operationalize neighborhoods are the census block group and the census tract. Water consumption has been studied at the census block group scale (Chang et al., 2010; House-Peters et al., 2010) and at the census tract scale (Guhathakurta and Gober, 2007; Wentz and Gober, 2007; Balling et al., 2008). The goal is to identify neighborhoods that exhibit more or less sensitivity to variations in climate than average (Guhathakurta and Gober, 2007; Balling et al., 2008; House-Peters et al., 2010).

Larson, et al. (2013) also examined water use at the neighborhood level using census block groups. At the neighborhood the determinants of water demand (such as household and property attributes) often operate to influence locally differentiated rates of consumption (Aitken et al. 1991). Few water demand studies have been carried out at the neighborhood scale, which we define by census block groups (Larson et al. 2013). Water demand was aggregated by the City of Phoenix at the Census Block Group level and only examined single-family residences.

Urban hydrology

Urban environments significantly affect the hydrological processes in water and sediment flows because of changes in impervious land area (Paul and Meyer 2001; Arnold and Gibbons 1996; Alberti 2005). The reason is because urban development, through land conversion to impervious surfaces, reduces infiltration rates, and creates impervious surfaces that accelerate runoff rates (Sanders 1986). Knowing the amount of impervious surface is therefore useful to predict infiltration and runoff rates in urban neighborhoods.

Changes in land cover from natural wetlands to impervious surfaces also has significant effects. Following the conversion of wetlands to impervious surface, researchers have found changes in hydrologic flows, loss of natural water retention capacity, and increases in flooding (Brody et al. 2007).

Variation in the type and density of landscape vegetation not only affects water demand by urban users, but also alters the amount and timing of evapotranspiration in urban landscapes (Jenerette et al. 2013, Pataki et al. 2013).

Nitrate, phosphate and sediment pollution from runoff are challenging non-point sources of pollution greatly influenced by impervious surface and stormwater runoff from cities. The amount of each of these pollutants in stormwater runoff is dependent on the amount of impervious surface and the plant composition in urban landscapes and nitrate conversion of that landscape (Pickett and Cadenasso 2008)

Methodology

This study is a cross-sectional, exploratory research design. Our methodology included three steps. The first step was data collection. The census block group (CBG) was our unit of analysis for the typology. Data was collected for every census block group along the Wasatch Front Metropolitan Area, and where necessary was aggregated to the CBG level. These variables collected are described in the Measures section. Our second step was to conduct a factor analysis to identify commonalities between the variables. The third step was to conduct a cluster analysis to identify CBGs that were closely correlated according to the factor analysis results, as well as those that were not correlated at all. Both of these statistical analyses are described in the Analysis section.

Study Site and Units of Analysis

The demography in Utah is unique compared to other states in the U.S. Utah has the third largest population growth rate in 2011, 1.9 percent vs. 0.9 percent countrywide (US Census Bureau, 2011). Utah has the largest average household size in 2010, the only state in the U.S that has more than 3 people per household in average. Sixty-one percent of households in Utah are married husband-wife couple households, which is also the highest in the country. Utah also has the lowest percentages of households with a person 65 years or older (Lofquist, Lugaila, O'Connell and Feliz, 2012). In sum, Utah has the population with fast growth rate, large family size, and fewer elderly people, which results in a unique demography.

The majority of the population lives along the Wasatch Range Metropolitan Area (WRMA), a 10 county strip of land running north and south for approximately 160 miles along the Wasatch Mountain Range. Salt Lake City is the capital city, and centrally located in the WRMA. The population of the WRMA is expected to reach a population of 2 million by 2040 with the majority located in Salt Lake County (Woods and Poole Economics 2009).

Water resource management is a central challenge throughout Utah. Utah ranks 49th in the US according annual precipitation but 2nd in the US according to per-capita water use (UDWR 2010). Utah's major metropolitan hub, Salt Lake City, has effective rainfall during the growing season equivalent to other major urban areas in the desert southwest, including Phoenix and Albuquerque (UDWR 2009; UDWR 2010). Salt Lake City's water supply system is fed by surface water from the nearby mountains and from deep wells tapping groundwater (US EPA, 2010). The Utah Division of Water Resources predicts that urban demand will soon outstrip this supply system.

Similar to previous work in this area (Shay and Khattak 2007), we utilized the census block group as the unit of analysis for our project. Census block groups (CBGs) represent officially recognized geographic areas that approximate actual neighborhood boundaries in most urban areas. We selected CBGs for this analysis based on population density. Because this region contains significant federal land (where human occupation is generally not allowed) and several large water bodies (most notably, the Great Salt Lake), we used geospatial information about federal land ownership and water bodies to exclude these from the official TIGER CBG boundary areas. We then estimated an adjusted population density variable based on the ratio of total CBG population to the non-federal, non-water area. We then excluded all census block groups whose adjusted population density was less than 100 persons per square mile. The 10-county WRMA study area is comprised of 1,457 CBGs. A total of 1,384 CBGs had adjusted population densities above 100 persons per square mile. A map of these urban CBGs is shown in Figure 1.

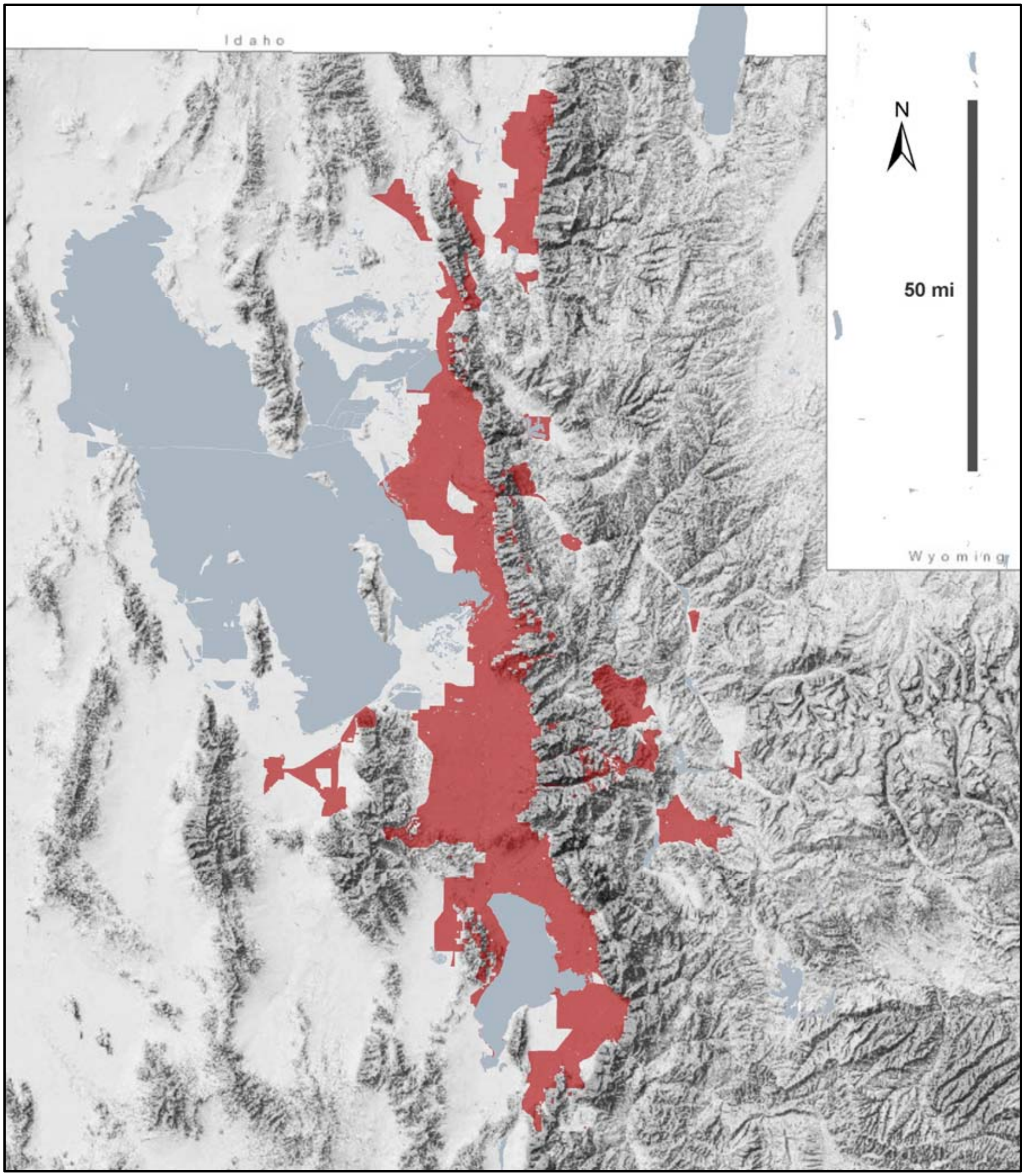


Figure 1: Study area in red: census block groups in Northern Utah with adjusted population densities over 100 persons per square mile.

Measures

In this section, we present the complete list of variables used in our typology analysis. For each variable, we justify the variable's inclusion in the analysis by reporting previous work that has identified relationships to relevant water outcomes. All variables describe characteristics of a Census Block Group (CBG) as described above. Variables were collected to cover 8 major topics:

- Land cover
- Land use
- Biophysical context/microclimate
- Built environment
- Housing characteristics
- Household characteristics
- Individual characteristics
- Public water system attributes

Complete data were obtained for 1,350 census block groups. Table 1. summarizes the complete list of variables used, and the sections following the table provide justifications and further detail on how each variable was calcuated.

Table 1. Variables included in typology analysis.

Category	Label	Description	Variable name	Source
LAND COVER	% Impervious Surface	Average CBG Impervious Surface Cover. Derived from National Land Cover Dataset (NLCD) which reports cover per 30m pixel in 10% bins. Averaged across all pixels in the CBG using ArcGIS "Zonal Statistics" geoprocessing tool.	LC_ImSu	National Land Cover Dataset (30m pixels)
	% Tree Cover	Average CBG percent tree cover. Derived from rasterized MODIS VCF data (~250m pixels). Average value calculated using ArcGIS Zonal Statistics too.	LC_TrCv	Modis VCF (250m pixels)
	Greeness (NDVI)	Average NDVI score based on LandSat5 raster imagery (30 m pixels) obtained from flyover of region in July 2006 and 2007	LC_Green	Landsat 5
LAND USE	% Parks	Percent of CBG in local, city or state parks. Based on merger of data from AGRC and ESRI.	LU_Park	ESRI and AGRC park layers (combined)
	% Residential	Percent area of residential land use (based on AGRC Water Related Land Use - WRLU – layer divided by total CBG land area (excluding fed lands and water)	LU_pcRES	Water Related Land Use dataset (UT Div of Water Resources)
	% Commercial / Industrial	Percent area in commercial or industrial land use (WRLU)	LU_pcCOM	same
	% Urban Open Spaces	Percent area in urban open space or parks (based on reported WRLU data); more expansive definition than AGRC/ESRI (above) and captures golf courses and public open spaces associated with schools, universities, etc.	LU_pcOSp	same
	% Irrigated Agriculture	Percent area in irrigated agricultural land uses (WRLU).	LU_pcIRR	same
	% Non-Irrigated Agriculture	Percent area in non-irrigated agricultural land uses (WRLU; includes subirrigated land)	LU_pcNI	same
	% Farmsteads	Percent area in 'farmstead' land use uses - residential parcel on farm properties	LU_pcFST	same
	Land Use Entropy Index (WRLU)	Index of land use diversity in CBG - Inverse Simpson Index for all WRLU categories	LU_LuEn	same
BIOPHYSICAL CONTEXT	Avg summer temp	mean monthly max for June, July, Aug of 2010-2012	CL_MSumT	PRIZM data
	Avg summer precip	mean monthly max for June, July, Aug of 2010-2012	CL_MSumP	same
	Avg annual temp	mean monthly max for all months, 2010-2012	CL_MAnnT	same
	Avg annual precip	mean monthly max for all months, 2010-2012	CL_MAnnP	same
	Mean Elevation	mean elevation of rasters	CL_AvgEL	DEMs from AGRC

Table 1. Variables included in typology analysis (continued)

Category	Label	Description	Variable name	Source
BUILT ENVIRONMENT	Housing Density	Overall housing density: housing units / total area (excluding federal lands and water)	BE_HDen	2010 Census of Population
	Residential Housing Density (logged)	Natural log of Residential Housing Density (# housing units/area of residential land use)	BE_HDnRL	Census and WRLU
	Average Parcel Size	Mean parcel size in CBG (in sq m) - based on AGRC parcel maps	BE_AvPcl	AGRC county parcel maps
	Median Parcel Size	Median parcel size in CBG (in sq m) - based on AGRC parcel maps	BE_MdPcl	same
	Average Block Size	Mean street block length by CBG (in meters), based on AGRC Statewide Roads data. Excludes freeways, U.S. and State highways, and trails	BE_AvBlk	AGRC Utah road layer
	Median Block Size	Median street block length by CBG (in meters), based on AGRC Statewide Roads data. Excludes freeways, U.S. and State highways, and trails	BE_MdBlk	Same
	Intersection Density	Number of intersections per land area	BE_InDen	Same
	% 4-Way Intersections	Percent of road intersections that are 4-way configurations.	BE_Pct4w	Same
HOUSING UNIT CHARACTERISTICS	Percent Vacant Housing Units	Percent of housing units that were not occupied in 2010	HU_PcVHU	2010 Census of Population
	Percent renter occupied	Percent of occupied housing units that were occupied by renters 2010	HU_PcRHU	Same
	Percent housing units that are detached single family homes	Percent housing units that are detached single family homes	HU_PDSFH	American Community Survey (2006-2010 5-year)
	Percent of Housing Built Since 1990	Percent of Housing Built Since 1990	HU_PHU90	Same
	Median year structure built	Median year structure built	HU_MdHYr	Same
	Median number of rooms	Median number of rooms	HU_MdRms	Same
	Median housing value (dollars)	Median housing value	HU_MdHVa	Same
	Percent housing units that are mobile homes	Percent housing units that are mobile homes	HU_PcMbH	Same
	Diversity of Building/Housing Types	Index of diversity of housing types; Value of Inverse Simpsons Index calculated using census housing categories in ACS table # B25024	BE_HuDiv	Same

Table 1. Variables included in typology analysis (continued)

Category	Label	Description	Variable name	Source
HOUSEHOLD CHARACTERISTICS	Mean HH Size	Average household size reported in US Census	HC_HHSz	2010 Census of Population
	Percent HHs that are Family HHs	Percent of households that are family households (group of 2 or more people related by birth, marriage, or adoption and residing together)	HC_PcFHH	Same
	Working adults per occupied housing unit	Resident workers in CBG / number of occupied housing units	EE_JHBal	US BLS and 2010 Census
DEMOGRAPHICS	Population Density	Persons per square mile (excluding federal lands and water)	DM_PDen	2010 Census of Population
	Residential Population Density (logged)	Natural log of residential population density (population/area of residential LU), with asymptotically high values recoded to 5 and very low values coded to 0	BE_RDnLg	US Census & WRLU
	Median age: Both sexes	Median age of population	DM_MdAge	2010 Census of Population
	Percent of population over 65	Percent of population over 65 years old	DM_PcO65	Same
	Percent of population Non-Hispanic White	Percent of population that are non-hispanic whites	DM_PcWht	Same
	Percent adults with BS or higher ed	Percent of adults over 25 with BS or higher education level	DM_PcBS	American Community Survey (2006-2010 5-year)
	Percent Households with income > 100K	Percent of households reporting total income over $100,000	DM_P100K	Same
	Median Household income (est)	Median household income	DM_MdHHI	Same
	Per Capita Income (est)	Per capital income	DM_PCI	Same
	Estimated Poverty Rate	Estimated individual poverty rate	DM_PovRt	Same
PUBLIC WATER SYSTEM	% parcels Served by Public Water Supplier	Percent of county parcels in CBG that are inside public community water system service areas	WI_PcPWS	AGRC parcel maps & Utah Div of Water Resources PCWS coverage

Land Cover:

We use three measures of land cover, the percent of impervious surface, the percent tree cover for all CBGs, and the NDVI greenness measure. The first two of these measures are derived from the National Land Cover Database (NLCD) for 2006. Tree cover and impervious surface area have been used in quantitative methods of classifying neighborhoods (Song and Knapp 2004) and have been found to be an important determinate for water demand in Pheonix (Larson et al. 2013) and urban hydrologic processes (Paul and Meyer 2001; Arnold and Gibbons 1996; Alberti 2005).

For the percent of impervious cover, we averaged the amount of impervious area across all pixels in the CBG using the ArcGIS zonal statistics geoprocessing tool.

For percent of tree cover, we used the mean value by rasterized CBG, from the MODIS VCF data at 250m pixels.

The Normalized Difference Vegetation Index (NDVI) is derived from remotely sensed multispectral imagery. NDVI can be calculated from publicly available Landsat remote sensing data at the 30 m resolution. Specifically, NDVI is computed as:

$$NDVI = \frac{NIR - R}{NIR + R}$$

where NIR is reflectance in the near-infrared band and R is reflectance in the red band. NDVI of vegetated surfaces ranges between 0 and 1, and is strongly correlated with the abundance of healthy vegetation canopy (Rouse, Haas, Schell, & Deering, 1974).

We estimated an average NDVI value for each census block group in the study area. We obtained data at 30m resolution for our study area from a global composite image service served by ESRI at arcgisonline.com (ESRI, 2014). Nominal 2005 NDVI in the ESRI data product is computed from the USGS/NASA Global Land Survey (GLS) 2005-epoch collection of Landsat ETM+ image tiles; we chose the 2005 epoch to most closely match the 2006 conditions reflected in land cover variables derived from the National Land Cover Database (NLCD) data. Imagery coverage in the 2005 GLS for the southern part of our study area was acquired by the Landsat 5 TM sensor on 22 June 2006 (USGS, 2014a) and for the northern part of our study area by the Landsat 7 ETM+ sensor on 03 July 2007 (USGS, 2014b). We transformed ESRI data from their [0,255] range as served, to the native [-1,1] range of the NDVI. We then reclassified the data to eliminate all pixels with negative values, which are typical of clouds, snow, and surface water, and computed the mean of the surviving pixel values for each CBG in the study area.

Land Use:

Land use patterns are important drivers of a wide range of ecohydrologic processes along the rural-to-urban gradient. Different land uses have significantly different water outcomes. For example, across the globe, as well as in the WRMA, agriculture is the number one user of water. Runoff, and infiltration also differ across land uses, where an agricultural field will differ substantially from an industrial park. These measures are crucial to differentiate neighborhoods.

In the urban and urbanizing areas along the WRMA, residential land use dominates, but there can be significant areas devoted to parks and opens spaces, commercial/industrial uses, and (at the rural/urban fringe) irrigated and non-irrigated agriculture (Table 2).

The typology utilizes eight measures of land use; percent of and area in designated urban parks; percent residential; percent commercial/industrial; percent in urban open and green spaces; percent irrigated agriculture; percent non-irrigated agriculture; percent farmsteads; and an overall measure of land use diversity (using an entropy index).

- Parks: The first land use indicator combined geospatial information about designated parks and recreation sites obtained from the national ESRI parks layer and spatial data on the locations of Utah parks that were obtained from the state AGRC spatial data archive (http://gis.utah.gov/data/).
- Other Land Uses: All the remaining land use measures were derived from the Water Related Land Use (WRLU) data set developed by the Utah Division of Water Resources and made available at the AGRC website. WRLU data from the 2005-2010 period were downloaded and processed to remove a few minor geometric errors, then clipped to the urban CBG boundaries used in the typology analysis. For each CBG, the area and percent of each reported land use class was calculated. To address problems with model specification and increase the efficiency of statistical estimates, our final analysis excluded areas in the WRLU categories of ‘riparian’ or ‘unclassified’ land uses (which each reflect relatively small proportions of the urban CBG area in the WRMA). The locations of urban parks and open space in the WRLU dataset were significantly more detailed and accurate than (and only lightly overlapped with) the ESRI/AGRC parks layer noted above – mainly because the WRLU urban open space layer captured institutional lawns, school yards and golf courses.
- For the land use entropy index, we calculated the inverse Simpson index on each of the WRLU land categories. The index represents the weighted arithmetic mean of the proportional abundances of the types of interest, and large values represent situations where diversity is greater. The index is calculated using the following formula, where R = the number of potential categories and p = the proportion of land area in each category:

$$\frac{1}{\sum_{i=1}^{R} p_i^2}$$

Across the 1,384 census block groups for which we have complete data in the WRMA study area, the most common land use involved residential housing (roughly 37% of the total study area, and 60% of a census block group area on average).

Table 2: Land Use Characteristics of Urban Census Block Groups in WRMA.

Water-Related Land Use Category	Mean CBG	Median CBG	Minimum CBG	Maximum CBG	Total Combined Area (km2)	% total urban WRMA
Residential	60.7%	66.6%	0.0%	100.0%	1,001.2	37.3%
Commercial/Industrial	14.8%	7.1%	0.0%	100.0%	401.7	15.0%
Urban Open Space	4.2%	1.6%	0.0%	62.7%	88.9	3.3%
Irrigated Agriculture	6.3%	0.0%	0.0%	84.1%	613.6	22.9%
Non-Irrigated Agriculture	4.9%	0.5%	0.0%	65.0%	403.9	15.0%
Farmsteads	0.6%	0.0%	0.0%	19.6%	45.4	1.7%
Riparian Areas	1.4%	0.0%	0.0%	55.7%	129.6	4.8%
Land Use Diversity Index	0.414	0.448	0.000	0.838		

Biophysical Context/Micro-climate

Weather is a significant factor in residential water demand. In the summer months as temperatures rise, gardens dry out and households increase outdoor water use (Abrams 2011; Worthington 2011). Studies of water use during the summer months have seen increases in water use of 30% to 40% (Kenney 2008; Cavanagh et al. 2002; Guhathakurta 2007). For example, a study in in Phoenix (Guhathakurta 2007) found that two-thirds of residential water use was for outdoor irrigation use during the summer. Balling (2007) found that 40% of annual water use occurs during June, July, August, and September. Despite the seasonal fluctuations in residential water demand there are few studies that determine elasticities for variables on a seasonal basis, despite the fact that significant differences may exist (Lyman 1992; Bowman et al. 1997; Polebitski and Palmer 2010).

Differences in regional climate affect water demand. Residents in arid regions with warmer temperatures, less rainfall, and greater rates of evapotranspiration in the growing season use significantly more water on a per capita basis than those in more humid regions. In most cities in the Western United States, the majority of residential water use is for outdoor irrigation use during the summer (Balling 2007, Guhathakurta 2007). Similar differences in microclimate related to elevation, topography, proximity to open space, or the impacts of urban heat islands can also lead to variation in water demand within urban areas (Nouri et al 2013; Whitlow, Bassuk and Riechert 1992).

We use five measures of climate for our analysis: average summer temperature, average summer precipitation, average annual temperature, average annual precipitation, average annual precipitation, and elevation. The summer climate measurements are mean monthly for June, July, and August for three years, 2010-2012. The annual measurements are based on mean monthly maximums for all months 2010-2012. These measures are derived from the PRISM Climate Group climate database. This database that uses point data and an underlying grid such as a digital elevation model (DEM) to generate gridded estimates of monthly and annual precipitation and temperature. The climate in the WRMA region varies from north to south, as well as with changes in elevation. We therefore expect that CBGs with higher average summer temperatures, and lower summer precipitation will use a greater amount of water. Finally, elevation was included because of the diversity of elevations throughout our study area, and elevation has a strong impact on climate and weather. Mean elevation was calculated as the mean elevation of rasters from digital elevation maps from AGRC.

Built Environment:

Our first two measures of the built environment are housing density, and the log of residential housing density. Both measures are estimated using data obtained from the 2010 U.S. population census and the WRLU dataset described above. Housing density is the simple ratio of a county of housing units in a CBG divided by the area of the CBG[4], and represent the degree to which a neighborhood is residential, and the density of housing in the CGB.

In addition, we used data from county parcel maps (downloaded from the Utah AGRC website in the fall 2012) to calculate two measures of parcel size at the CBG level: average parcel size and median parcel size. Households on large lots, on average, have higher levels of water use (Abrams 2011). Larger lots usually mean larger lawns, more vegetative cover, and larger houses, and therefore lot size has a positive correlation with water use (Renwick and Green 2000; Guhathakurta 2007; Balling 2007; Polebitski and Palmer 2010; Blokker 2010). Guhathakurta (2007) found that controlling for other variables, lot size had

[4] It is important to note that all density measures used in our analysis utilized an adjusted 'area' for the CBG that removes any federal lands and open water area.

the greatest impact on water use, where with each 1,000 square foot increase in average lot size, monthly water use increases by about 1.8%. Renwick and Green (2000) found that with a 10% increase in lot size water demand increases by 2.7%.

A third indicator of the built environment reflects the configuration of road networks. We estimated two measures of block size based on detailed spatial information about road networks: average block length and median block length CBGs that have higher average and median block size can be expected to represent large lot suburban or exurban neighborhoods, or less residential neighborhoods with large industrial, commercial, or agricultural parcels. Conversely, block groups with small average and median block size are likely to be more urban, or have a mix of land uses. Small blocks have been associated with higher density urban design while long blocks typify contemporary suburban neighborhoods and can be an indicator of sprawl (Ewing 1996). The water use outcomes associated with neighborhoods typified by large blocks, such as sprawling residential neighborhoods, is expected to be different than compact neighborhoods likely due to differences in parcel size, associated lawn sizes, and street stormwater infrastructure.

Another characteristic of the urban environment that is shaped by road networks is captured in the density and pattern of road intersections (Ewing and Cervero 2010). In our analysis we used two measures of intersections: intersection density and percentage of 4-way intersections. CBGs that have high intersection density are more densely built than CBGs with low intersection density. Water use outcomes would differ between CBGs that are densely built and those that are not, because the amount of impervious surface, or the relative concentration of residential and commercial uses will differ. The percentage of 4-way intersection CBG's captures the *design* of the built environment, where higher percentage of 4-way intersections represent a built environment form representative of highly interconnected urban grids. This form contrasts with typical suburban neighborhoods characterized by cul-de-sacs and curving streets networks. Water use outcomes likely vary from suburban neighborhoods to urban neighborhoods, and the percentage of 4-way intersections is a measure to differentiate between these urban forms. These variables were calculated from the road network database provided by the NAVTEQ company for the state of Utah. Intersection Density was calculated by the number of intersections/area of census block group. The percentage of 4-way intersections were calculated as the number of 4 way intersections/ total intersections.

Housing Unit Characteristics:

Troy et al. (2005) explored the water consumption profiles of households living in different forms of residential development in a range of locations across Sydney, Australia. In particular, they sought to understand how different types of dwellings – separate houses, semi- detached houses and flats – were related to household water use. An overall finding of the research was that the per capita consumption of water is, for all practical purposes, the same for people living in traditional houses as it is for those in high density dwellings. However, Stoker & Rothfeder (*in review*) found that total annual water use for buildings in Salt Lake City varies according to building type.

We obtained nine measures of housing unit characteristics from the US Census Bureau: percent vacant housing units, percent renter occupied, percent housing units that are detached single family homes, percent of housing built since 1990, median year structure built, median number of rooms, median housing value, percent housing units that are mobile homes, and diversity of building housing types. All but the last measure of housing unit characteristics are based on data reported at the CBG-level by the U.S. Census Bureau and are based on the American Community Survey – an annual sample survey conducted to estimate detailed demographic, economic, and housing characteristics at different levels of geography between decennial census years. The ACS at the CBG level reports a rolling 5-year estimate of each characteristic; in our analysis, we used the 2006-2010 estimate for CBGs in the WRMA. The final measure, the diversity of building housing types, was calculated using the inverse simsons index using the census housing categories (single family detached, single family non-detached, 2-unit, 3-unit, mobile homes, etc.) in the American Community Survey (ACS) table # B25024.

Household Characteristics:

Household size significantly influences water consumption (Gaudin 2006; Wentz and Gober 2007; Arbues 2010). Households with more people use more appliances with greater frequency than smaller households. Arbues et al. 2004 found that as household size increases, water use increases, although it is not a proportional increase. For example, a household with two people uses less water than a household with four people, but not 50 percent less. From a review of similar studies, the average elasticity of consumption with respect to household size is between 0.734 and 0.868 (Arbues 2004).

We use three measures of household characteristics, mean household size, percent of households that are family households, and average number of working adults per household. The first two measures were obtained from the 2010 U.S. Census, and are reported at the CBG level. The third measure combines 2012 estimates of working adults from the US Bureau of Labor Statistics with 2010 Census data on household numbers.

Demographics:

Income has been found to be a significant determinant of urban water use: as with nearly all goods and services, as income rises there is a corresponding increase in water usage (Guhathakurta 2007; Ferrara 2008). Wealthier households are more likely to have water consuming appliances, swimming pools, and larger lots (Ferrara 2008). Significant differences in personal water habits in households with different incomes have not been found; therefore indoor usage is more of a function of square footage of the dwelling and the number of household members (Polebitski and Palmer 2010; Domene and Sauri 2005; Ferrara 2008). Where income has its biggest impact is on outdoor water use. Consequently, income is a more significant factor during the summer months as more water is used for irrigation purposes (Polebitski and Palmer 2010).

In order to capture the social and demographic characteristics of CBGs, we use ten measures to describe the aggregate demographic attributes of households and individuals in our study area: population density; log of residential population density, median age, percent of population of 65, percent of population non-hispanic white, percent adults with BS or higher education, percent households with income over 100,000, median household income, per capita income, and estimated poverty rate. Population density was calculated as persons per square mile, not including federal lands and water. All of these measures were obtained from either the 2010 US Census (population density, age, race/ethnicity) or American Community Survey estimate for 2006-2010 (education, income, and poverty). The difference between population density and residential population density reflects the use of different denominators: total density is the number of residents divided by the total area of the CBG; residential density is the total resident population divided by the area in residential housing.

Public Water System:

Previous analysis of water use in Utah suggests that access to a public culinary water supply can shape water use rates and behaviors. Persons living outside of public water service areas rely on wells for their drinking water (and either wells or secondary canal systems for irrigation water). To capture the role of public water systems, our final analysis developed a measure of the percent of parcels served by a public water supplier. This measure was calculated based on overlaying a parcel map (obtained by the AGRC) on a map of public water supplier service areas provided by the Utah Division of Water Resources. The variable used in the analysis is the percent of AGRC parcels in a CBG that are inside public community water system services areas. This measure will capture the difference between neighborhoods that are served by a public water supplier, and those that are not.

Analysis:

Our analytic approach to building a typology of urban neighborhoods (represented by CBGs) utilized a two-stage process that first identifies sets of underlying dimensions or ‘factors’ that are reflected in the patterns of statistical correlation among the many variables used in our study. Each CBG then grouped into similar clusters based on their relative level of each ‘factor’ identified in the first stage. This two-stage approach has been commonly used to develop formal statistically-based typologies in other research contexts (Shat and Khattak 2007). These researchers developed a neighborhood typology to understand how the built environment affects auto ownership and travel. Their methodology to create neighborhood typologies included:

1. Identification of relevant attributes of physical form, such as street design, density, land use mix, access, transport alternatives, natural environmental features, and socioeconomic characteristics;
2. Factor analysis of the raw measures to derive major dimensions; and
3. Cluster analysis to group those neighborhoods that are most similar in terms of the factors.

For step one, these researchers used 34 direct measures of the built environment, chosen based on the literature as well as availability of data. Data were collected at the block group level. Factor analysis reduced their variables to five factors, and then the cluster analysis yielded eight neighborhood types, or clusters, so that variation is minimized within clusters and maximized between clusters.

Factor Analysis

The first step in our statistical analysis utilized factor analysis to identify key underlying factors that can help reduce the number of variables used to differentiate neighborhoods. A factor analysis uses patterns of correlation among diverse variables to identify underlying (unobserved) factors that can account for observed variation in these data. In this study we used a principle components method to identify the number and initial characteristics of factors, then rotated the factor matrix to obtain orthogonal (uncorrelated) factors which best fit the dataset. The process produces a set of factors that each explain a significant proportion of the variation (the first principle component selected in the analysis will explain the highest variance and each successive factor will be the orthogonal dimension that explains the next most variation in the data (Thompson 2004).

Our factor analysis identified a set of 9 distinct factors which together explained 76.4% of the variation among the 48 observed variables (Table 3).

Table 3: Factor Loadings for all 48 Variables used in Analysis.

	Housing Mix: Suburban	Elevation	Land Use Mix: Non-Residential	SES	Lower Density	Pop Age	Land Cover: Irrigated Ag / Greenness	Urban Parks & Open Space	Mobile Homes
% housing units detached SF homes	0.933								
% renter occupied	(-0.896)								
Diversity of Building/Housing Types	(-0.888)								
% HHs that are Family HHs	0.858					0.279			
Median number of rooms	0.842			0.375					
Log form of BE_HDnRs	(-0.736)				(-0.292)		(-0.437)		
Mean HH Size	0.694					0.613			
Estimated Poverty Rate	(-0.611)			(-0.285)		0.201			
Log of residential pop density	(-0.569)	(-0.282)	(-0.205)		(-0.291)	0.201	(-0.502)		
Employed adults per household	0.557					0.296			
Avg summer temp		(-0.930)							
Avg annual temp		(-0.888)							
MEAN elevation		0.797		0.331					
Avg annual precip		0.784		0.250		(-0.249)			
Avg summer precip	0.283	0.748							
%Vacant Housing Units	(-0.447)	0.549							
% land in residential land use			(-0.834)		(-0.359)				
Land Use Entropy Index (WRLU)			0.776					0.274	
Population Density (nonfed/nonwater)	(-0.379)		(-0.768)		(-0.210)				
Intersection Density		(-0.230)	(-0.718)		(-0.319)		(-0.234)		
Overall Housing Density	(-0.579)		(-0.659)						
% land in Non-irr Ag			0.483			0.326			
% Tree cover		0.389	(-0.460)	0.384		(-0.324)			
% adults with BS or higher ed		0.208		0.818					
Median housing value (dollars)		0.296		0.805					
Per Capita Income (est)		0.319		0.744		(-0.342)			
% Households with income > 100K	0.509			0.738					
Median Household income (est)	0.627			0.649					
% of population Non-Hispanic White	0.348			0.528		(-0.210)	0.394		
Median Parcel Size	0.254				0.812				
Average Block Size		0.242	0.277		0.801				
Average Parcel Size		0.214	0.276		0.785				
Median block size					0.778				(-0.344)
% parcels Served by Public Water Supplier					(-0.774)				
% of population over 65						(-0.861)			
Median age: Both sexes				0.297		(-0.826)			
% of Housing Built Since 1990			0.445	0.236		0.588	0.212		0.308
Median year structure built	0.255		0.390			0.537			0.489
Greeness (NDVI)				0.225			0.620		
% land in Comm/Industrial uses	(-0.504)		0.458				(-0.582)		
% land in Irrigated Ag			0.365		0.424		0.568		
% Impervious Surface	(-0.422)	(-0.339)	(-0.355)		(-0.325)		(-0.513)		
% land in farmsteads		(-0.230)	0.297		0.319		0.500		
% land in open space								0.944	
% land in urban parks								0.936	
%% 4-Way Intersections	(-0.270)			(-0.219)					(-0.668)
% housing units that are mobile homes				(-0.302)					0.624
Percent of Variance Explained by Factor	17.9	10.4	10.0	9.0	8.9	7.1	5.6	4.3	3.4

Housing Mix: Suburban Factor:

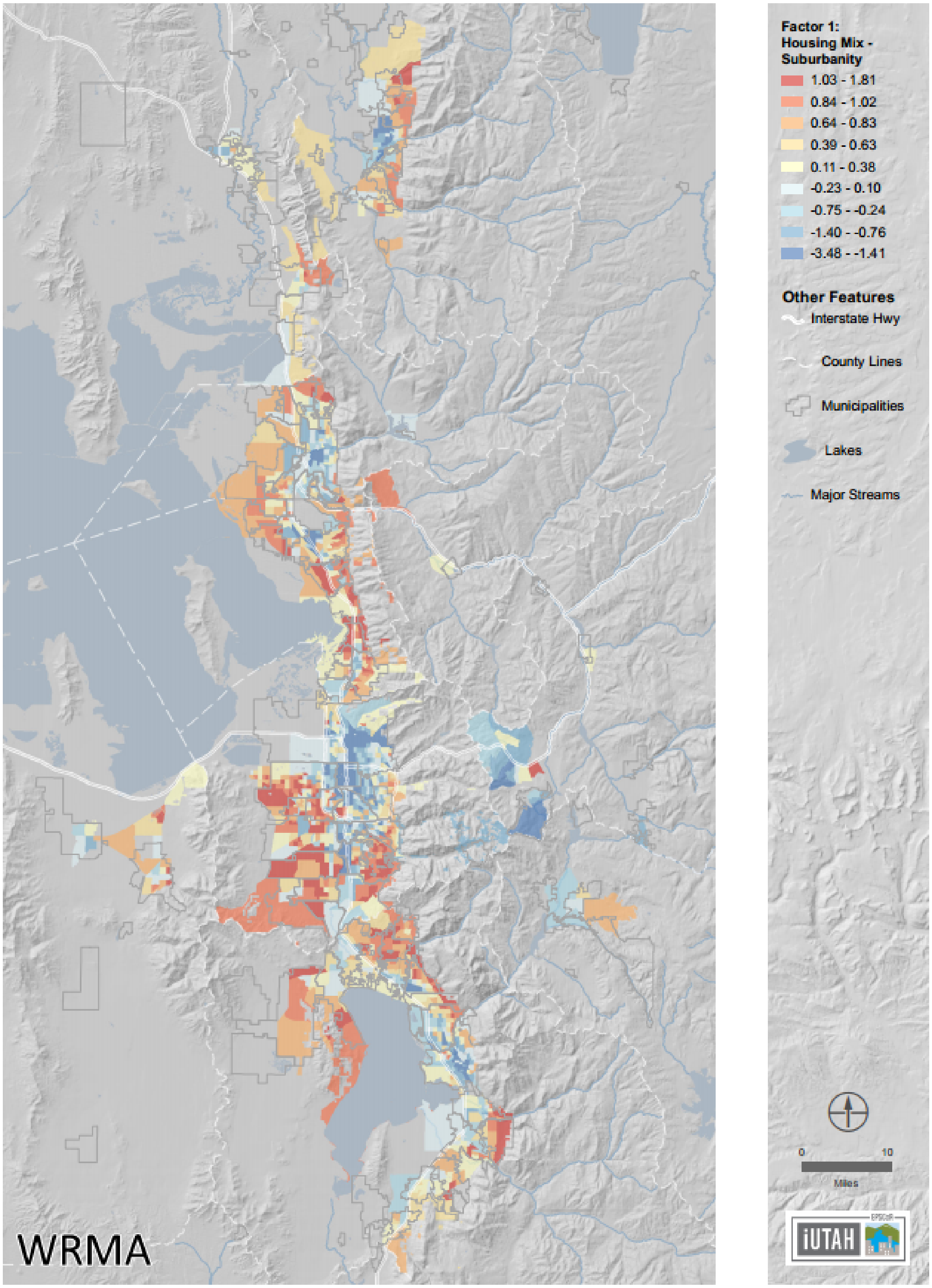
High scores on the suburban factor describe CBGs that have a high percentage of single family homes, and high percentages of households that are families. Other variables that load strongly on this factor include a high percentage of housing units that are detached single family homes, a high percentage of households that are family households, high number of rooms, large mean household size, and higher median household income. Also included are low measures of renter occupied households, low diversity of building and housing types, low population density and low poverty rates (Table 4).

Table 4. Factor loadings on the Suburban Factor.

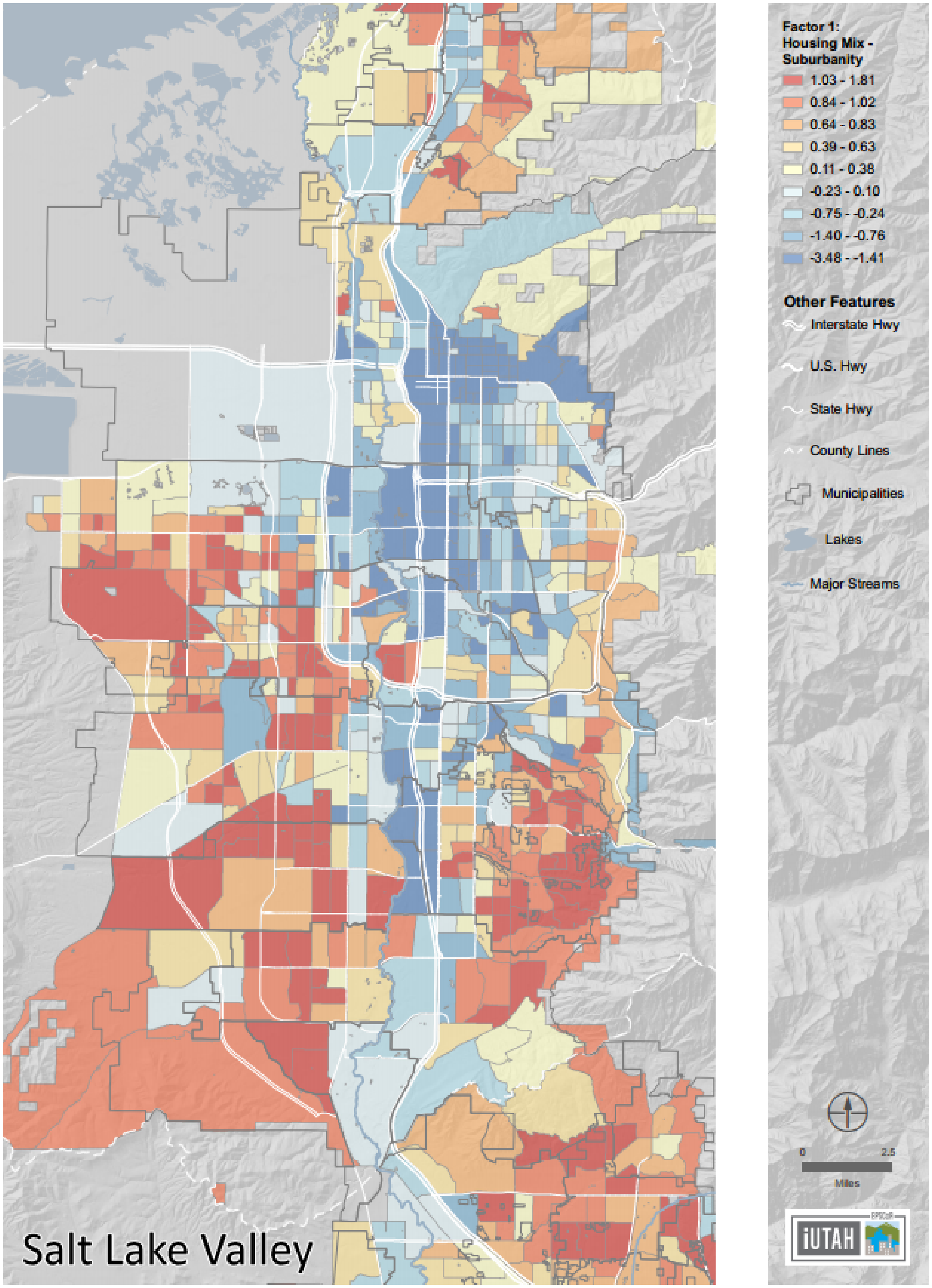
Suburban	
Percent housing units that are detached single family homes	0.933
Percent HHs that are Family HHs	0.858
Median number of rooms	0.842
Mean HH Size	0.694
Median Household income (est)	0.627
Jobs-Housing Balance	0.557
Percent Households with income > 100K	0.509
Percent of population Non-Hispanic White	0.348
Avg summer precip	0.283
Median year structure built	0.255
Median Parcel Size	0.254
% 4-Way Intersections	(-0.270)
Population Density (nonfed/nonwater)	(-0.379)
% Impervious Surface	(-0.422)
Percent Vacant Housing Units	(-0.447)
Pct land in Comm/Industrial uses	(-0.504)
Log of residential pop density	(-0.569)
Overall Housing Density	(-0.579)
Estimated Poverty Rate	(-0.611)
Log form of BE_HDnRs	(-0.736)
Diversity of Building/Housing Types	(-0.888)
Percent renter occupied	(-0.896)

Maps illustrating the location of census block groups that have higher and lower scores on the Suburban factor are illustrated for the entire WRMA, Salt Lake Valley, and urban GAMUT river study areas below.

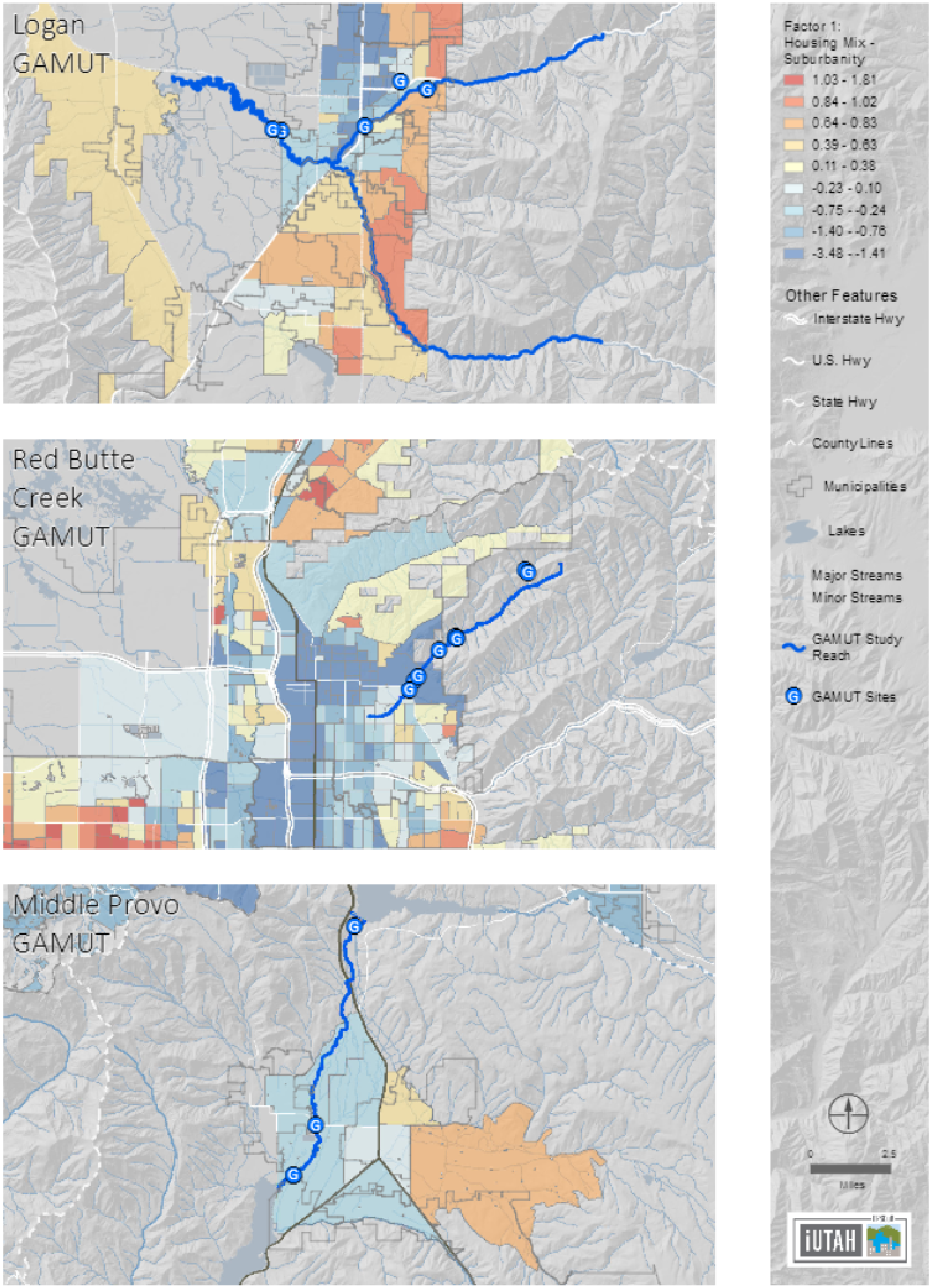
Factor 1: Housing Mix - Suburbanity



Factor 1: Housing Mix - Suburbanity



Factor 1: Housing Mix - Suburbanity



Elevation/Climate Factor:

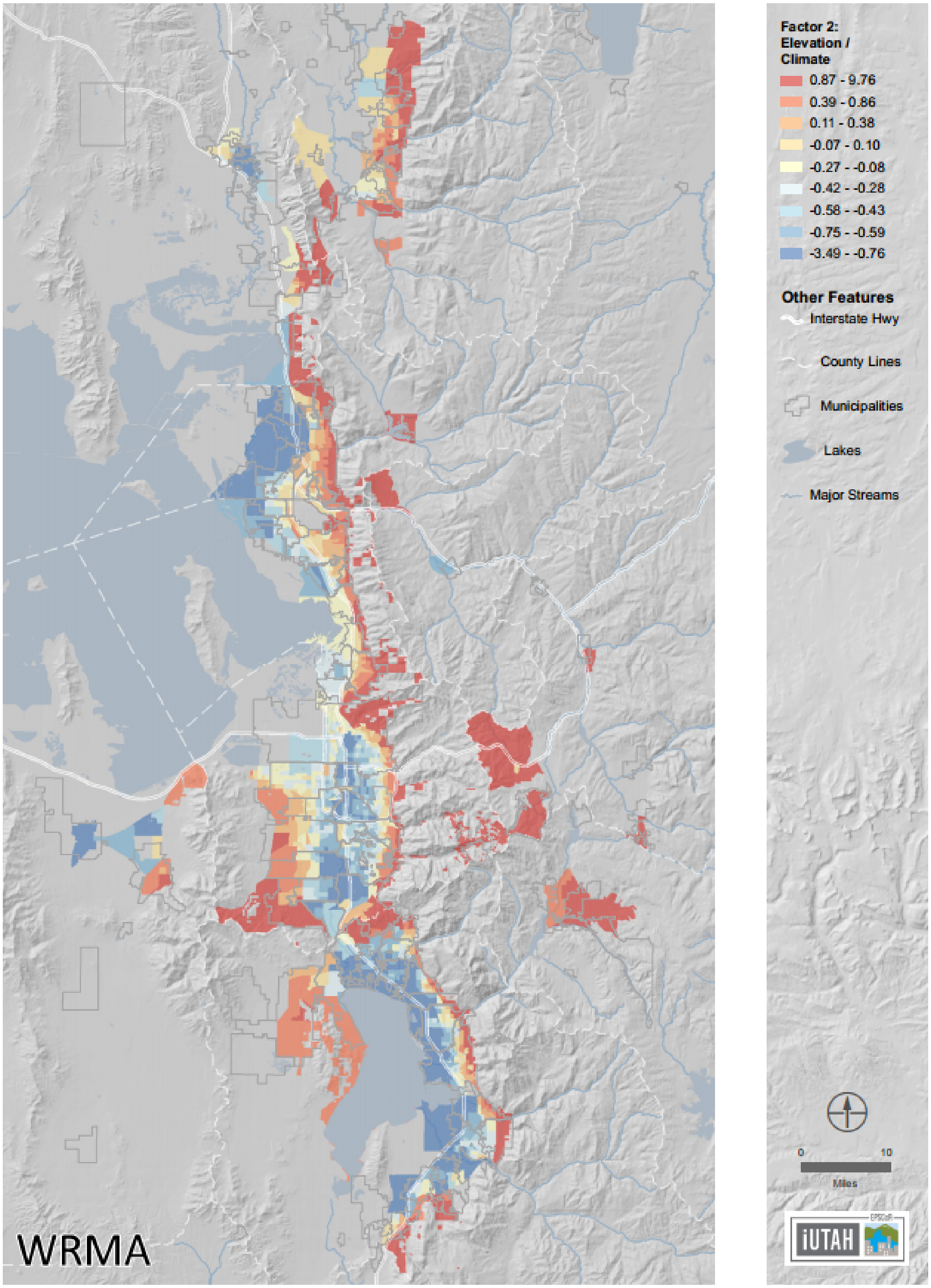
High scores on the elevation/climate factor describe CBG's that are high elevation and high precipitation The factor describes CBGs that have high annual and summer precipitation, and low annual and summer temperatures. The factor also captures places that have higher than average percentages of vacant housing and tree cover typically found in areas of second home development in the mountains.

Table 5: Factor loadings on the Elevation/Climate factor

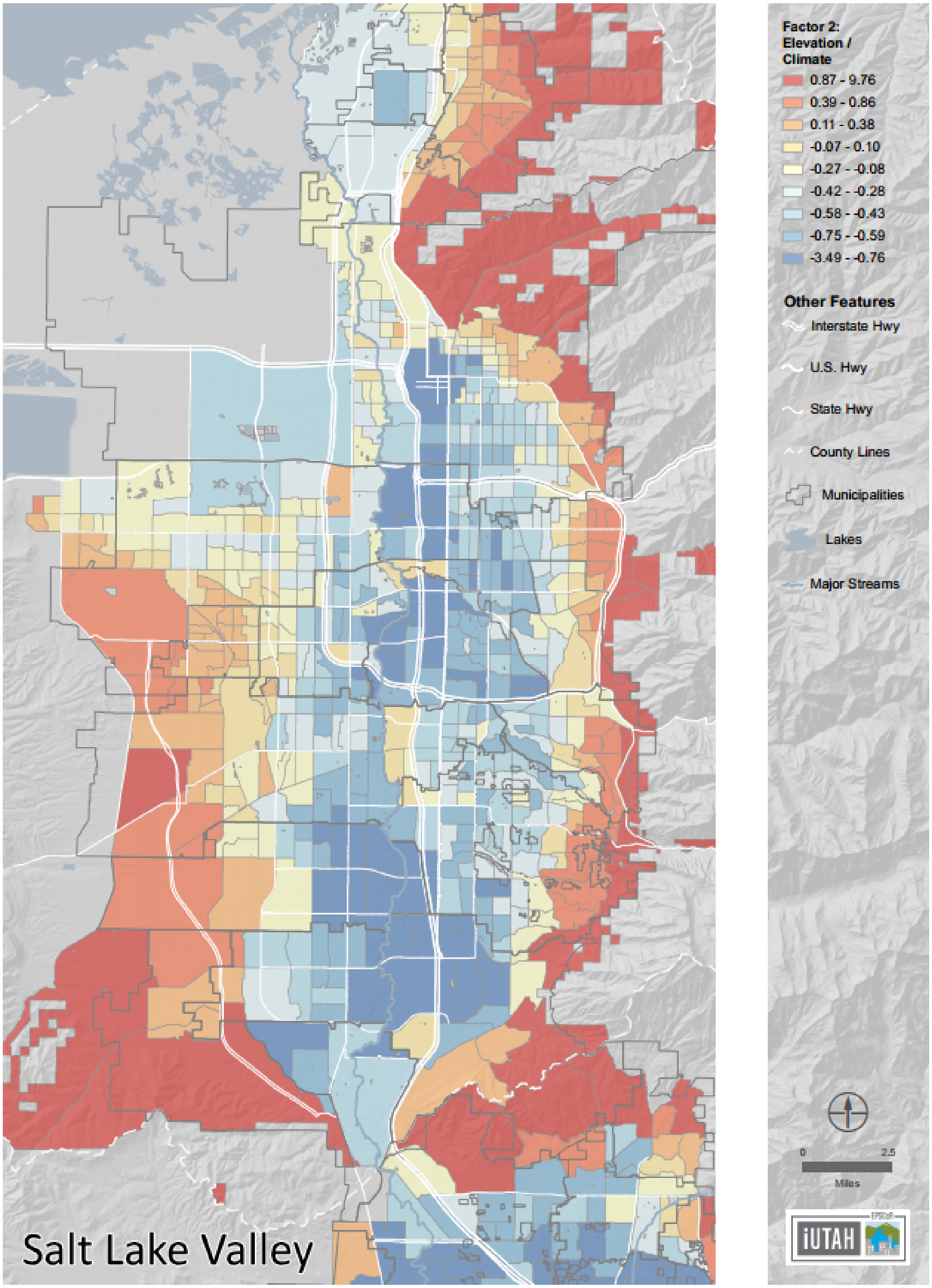
Elevation	
CL_AvgEL MEAN elevation	0.797
CL_MAnnP Avg annual precip	0.784
CL_MSumP Avg summer precip	0.748
HU_PcVHU Percent Vacant Housing Units	0.549
LC_TrCv % Tree cover	0.389
DM_PCI Per Capita Income (est)	0.319
HU_MdHVa Median housing value (dollars)	0.296
BE_AvBlk Average Block Size	0.242
BE_AvPcl Average Parcel Size	0.214
DM_PcBS Percent adults with BS or higher ed	0.208
BE_InDen Intersection Density	(-0.230)
LU_pcFST Pct land in farmsteads	(-0.230)
BE_RDenL Log of residential pop density	(-0.282)
LC_ImSu % Impervious Surface	(-0.339)
CL_MAnnT Avg annual temp	(-0.888)
CL_MSumT Avg summer temp	(-0.930)

Maps illustrating the location of census block groups that have higher and lower scores on the Elevation/Climate factor are illustrated for the entire WRMA, Salt Lake Valley, and urban GAMUT river study areas below.

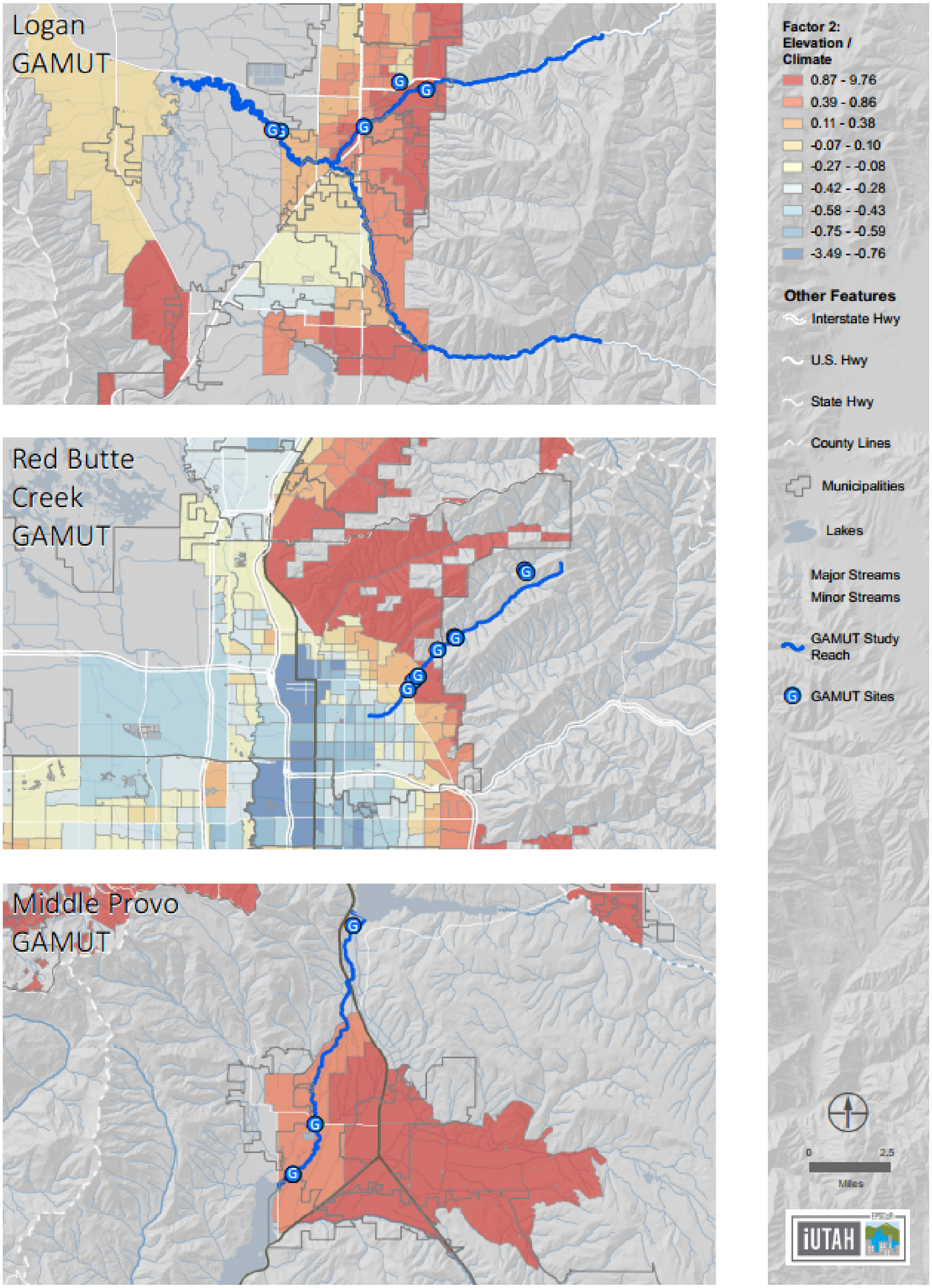
Factor 2: Elevation / Climate



Factor 2: Elevation / Climate



Factor 2: Elevation / Climate



Land Use Mix: Non-Residential Factor

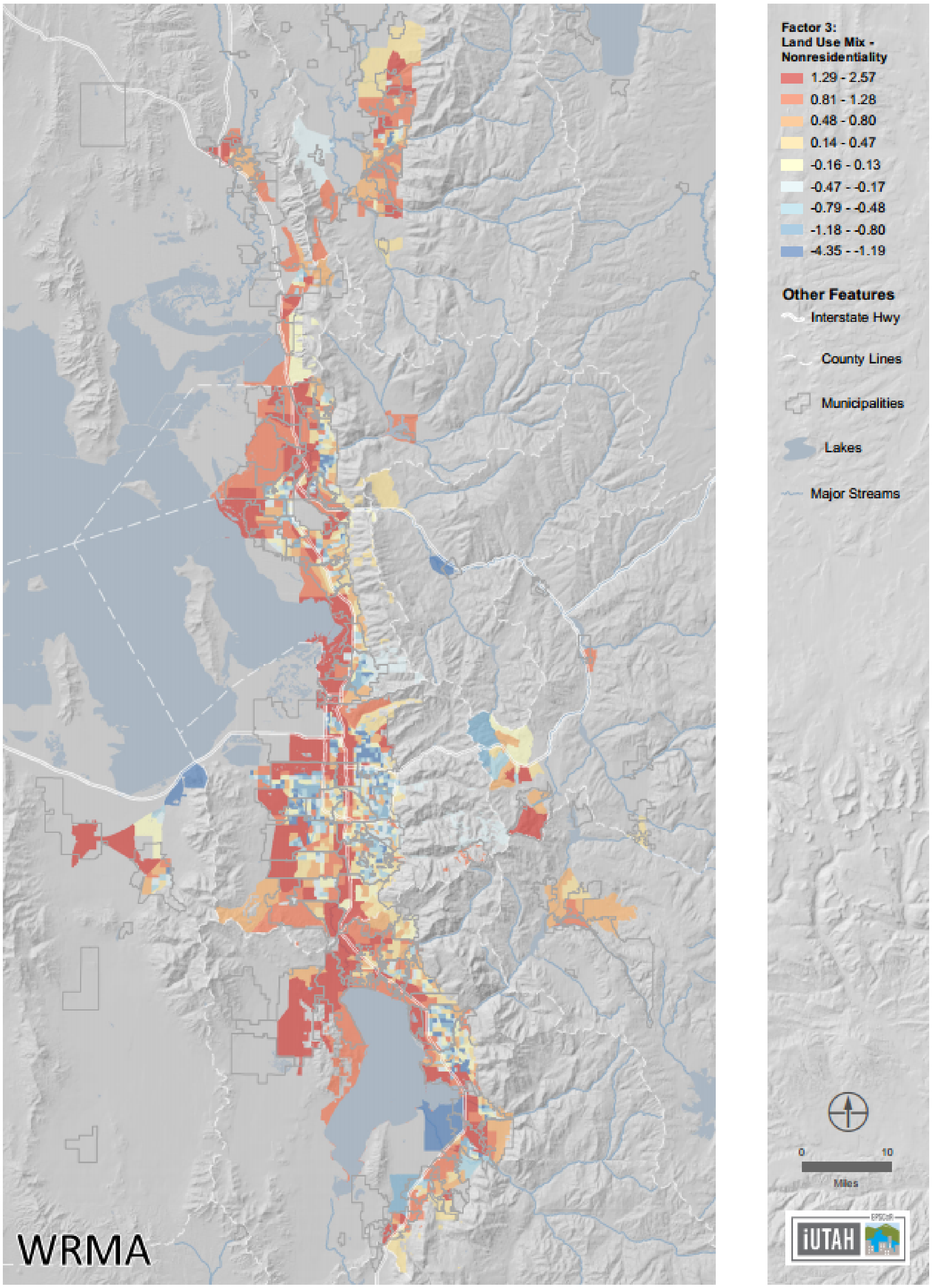
High scores on the land use mix/non-residential factor describes CBGs that have a high diversity of land uses. These also tend to be places that have a high percentage of land in non-irrigated agriculture/farmsteads or commercial or industrial uses (and relatively low amounts of residential land use). Areas with land use diversity in this region also tend to have a low density of population and housing, relatively low percentage of impervious surface and tree cover, and low intersection density.

Table 6: Factor loadings for Land Use Mix factor.

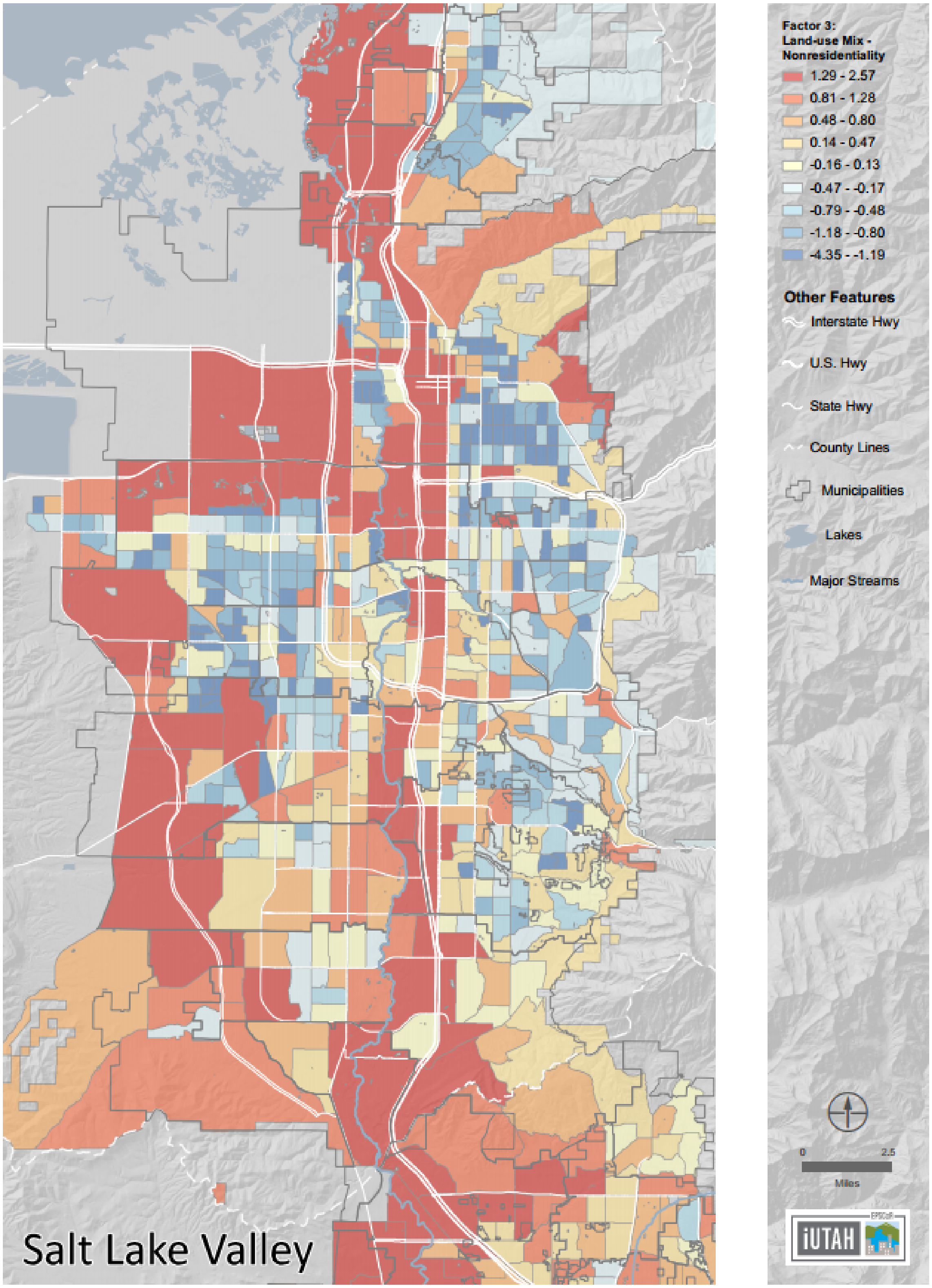
Non-Residential	
LU_LuEn Land Use Entropy Index (WRLU)	0.776
LU_pcNI Pct land in Non-irr Ag	0.483
LU_pcCOM Pct land in Comm/Industrial uses	0.458
HU_PHU90 Percent of Housing Built Since 1990	0.445
HU_MdHYr Median year structure built	0.390
LU_pcIRR Pct land in Irrigated Ag	0.365
LU_pcFST Pct land in farmsteads	0.297
BE_AvBlk Average Block Size	0.277
BE_AvPcl Average Parcel Size	0.276
BE_RDenL Log of residential pop density	(-0.205)
LC_ImSu % Impervious Surface	(-0.355)
LC_TrCv % Tree cover	(-0.460)
BE_HDen Overall Housing Density	(-0.659)
BE_InDen Intersection Density	(-0.718)
DM_PDen Population Density (nonfed/nonwater)	(-0.768)
LU_pcRES Pct land in residential land	(-0.834)

Maps illustrating the location of census block groups that have higher and lower scores on the Land Use Mix factor are illustrated for the entire WRMA, Salt Lake Valley, and urban GAMUT river study areas below.

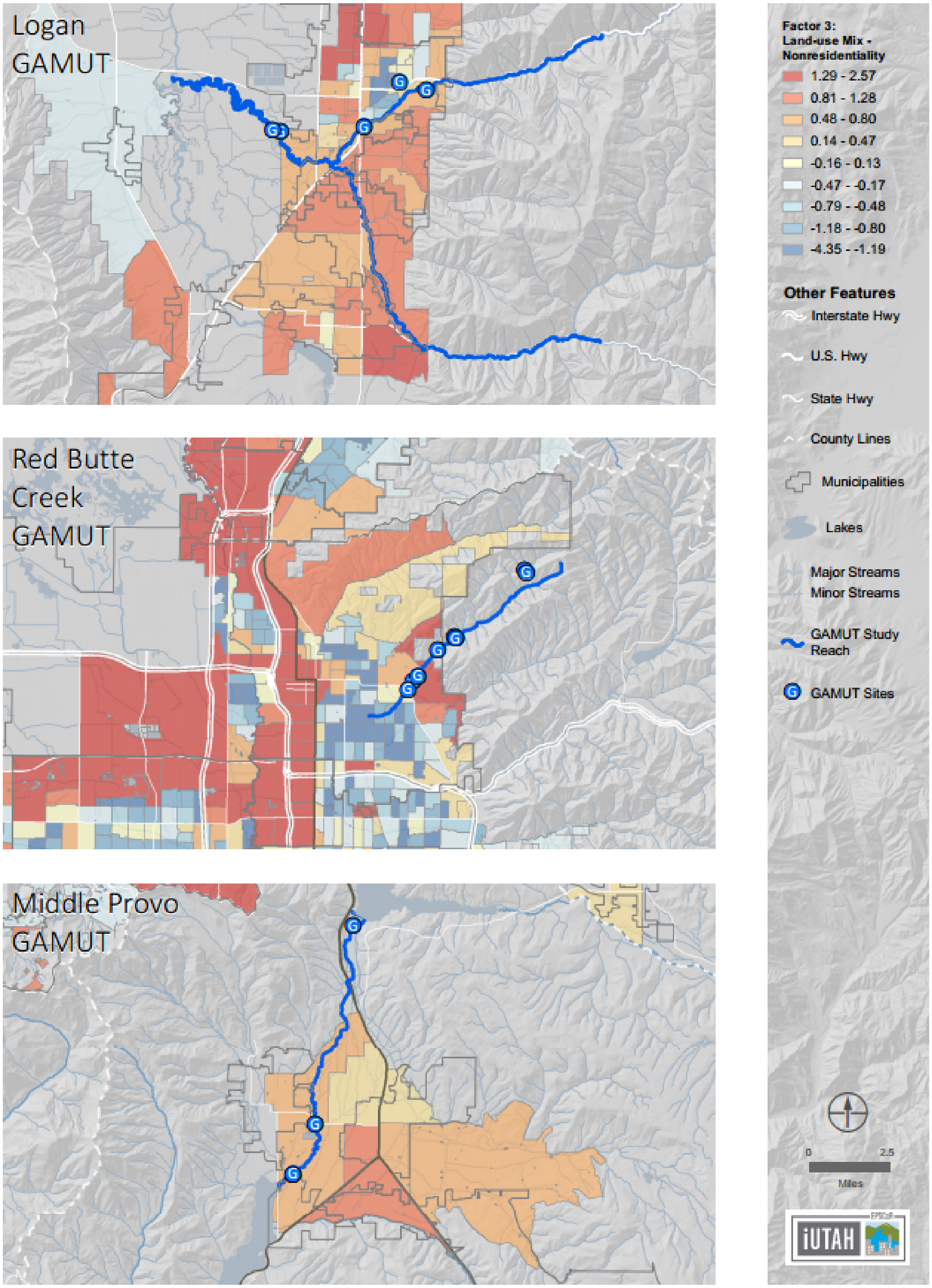
Factor 3: Land Use Mix - Nonresidentiality



Factor 3: Land-use Mix - Nonresidentiality



Factor 3: Land-use Mix - Nonresidentiality



Socioeconomic Status (SES) Factor:

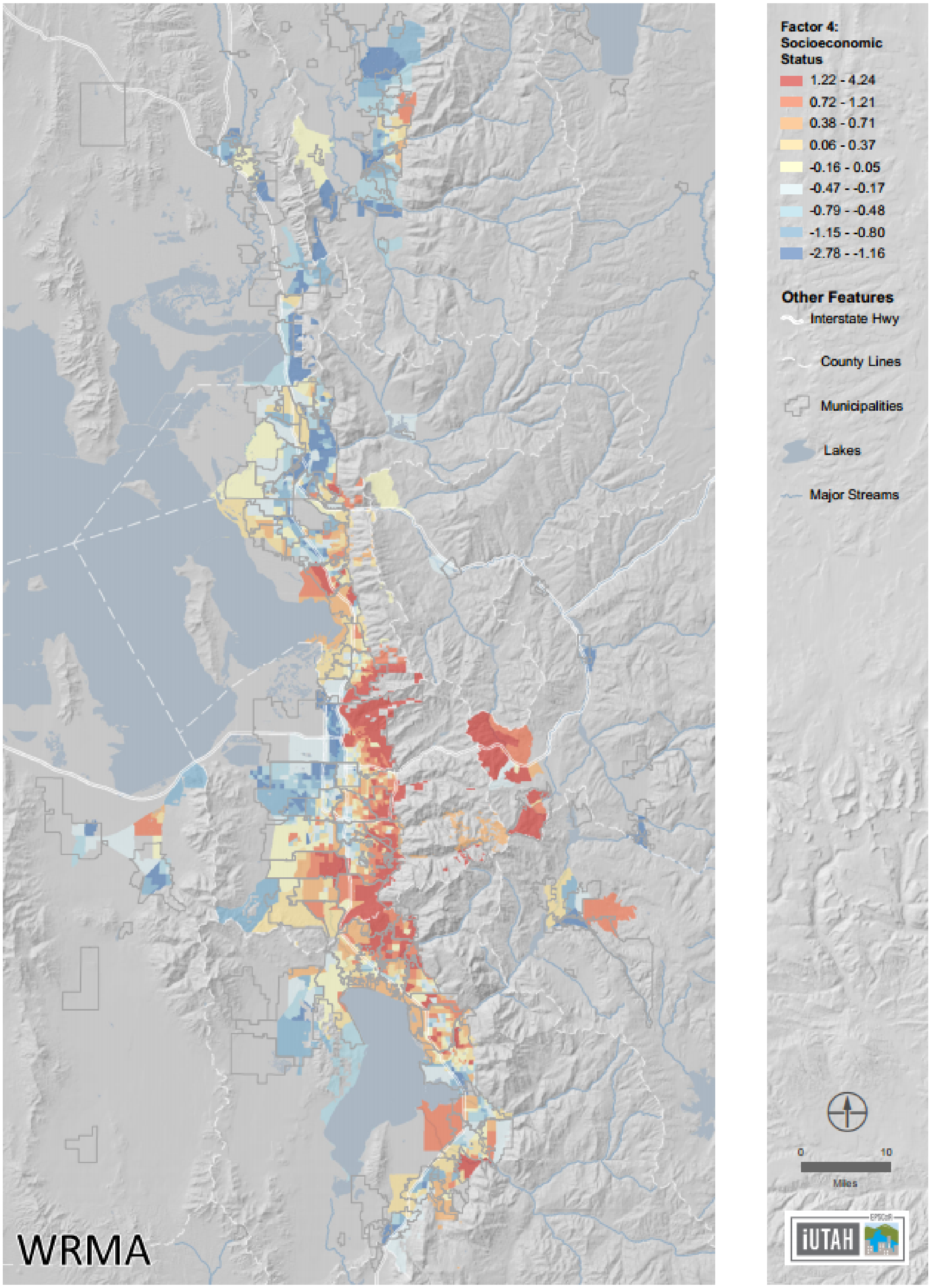
High scores on the SES factor describe CBG's that have a high percentage of adults with a BS degree or higher, high median housing value, high per capita income, a high percentage of households with an income greater than $100,000.

Table 7: Factor Loadings on Socioeconomic Status factor.

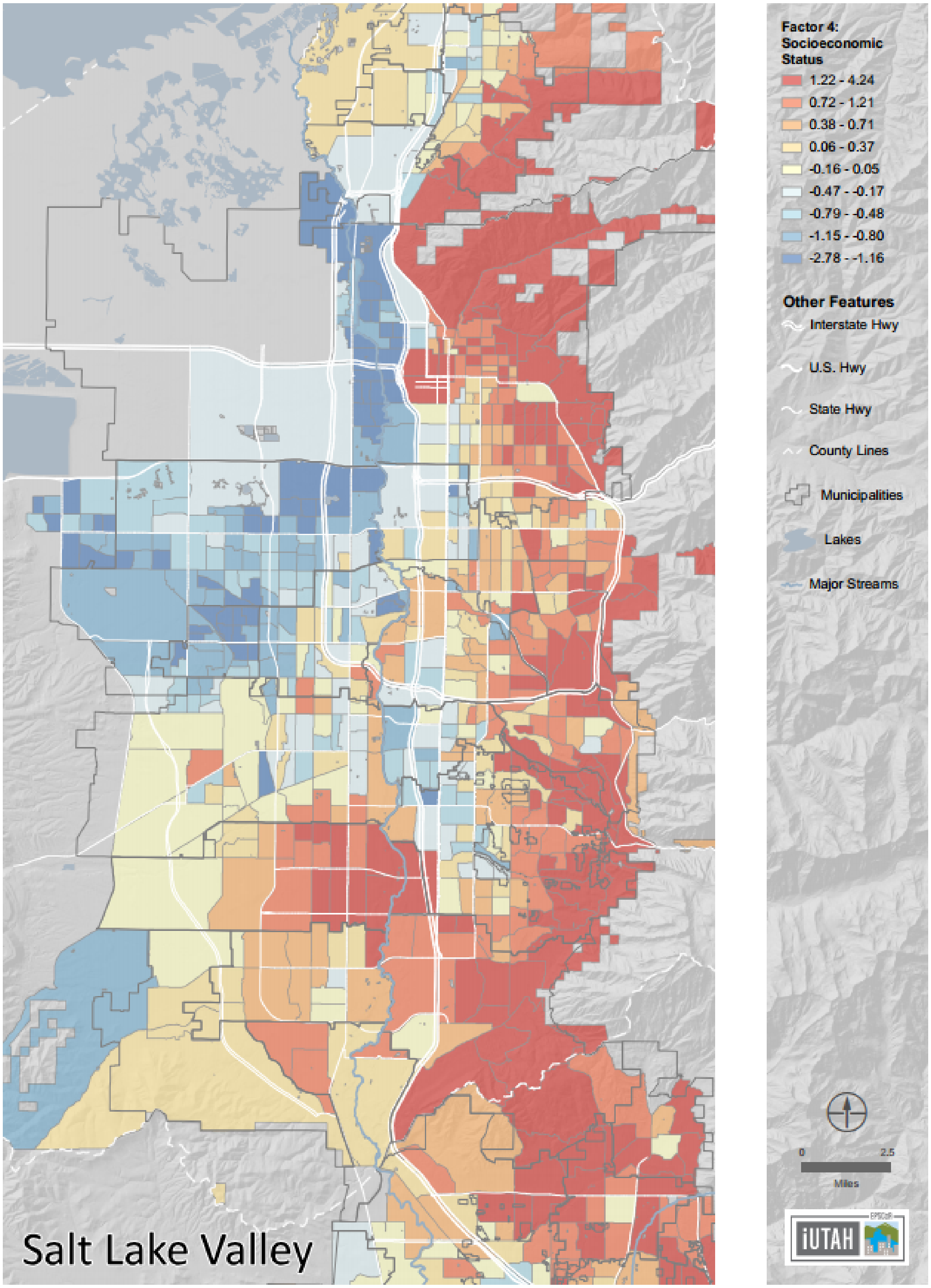
SES	
DM_PcBS Percent adults with BS or higher ed	0.818
HU_MdHVa Median housing value (dollars)	0.805
DM_PCI Per Capita Income (est)	0.744
DM_P100K Percent Households with income > 100K	0.738
DM_MdHHI Median Household income (est)	0.649
DM_PcWht Percent of population Non-Hispanic White	0.528
LC_TrCv % Tree cover	0.384
HU_MdRms Median number of rooms	0.375
CL_AvgEL MEAN elevation	0.331
DM_MdAge Median age: Both sexes	0.297
CL_MAnnP Avg annual precip	0.250
HU_PHU90 Percent of Housing Built Since 1990	0.236
LC_Green Greeness (NDVI)	0.225
BE_Pct4w % 4-Way Intersections	(-0.219)
DM_PovRt Estimated Poverty Rate	(-0.285)
HU_PcMbH Percent housing units that are mobile homes	(-0.302)

Maps illustrating the location of census block groups that have higher and lower scores on the Socioeconomic Status factor are illustrated for the entire WRMA, Salt Lake Valley, and urban GAMUT river study areas below.

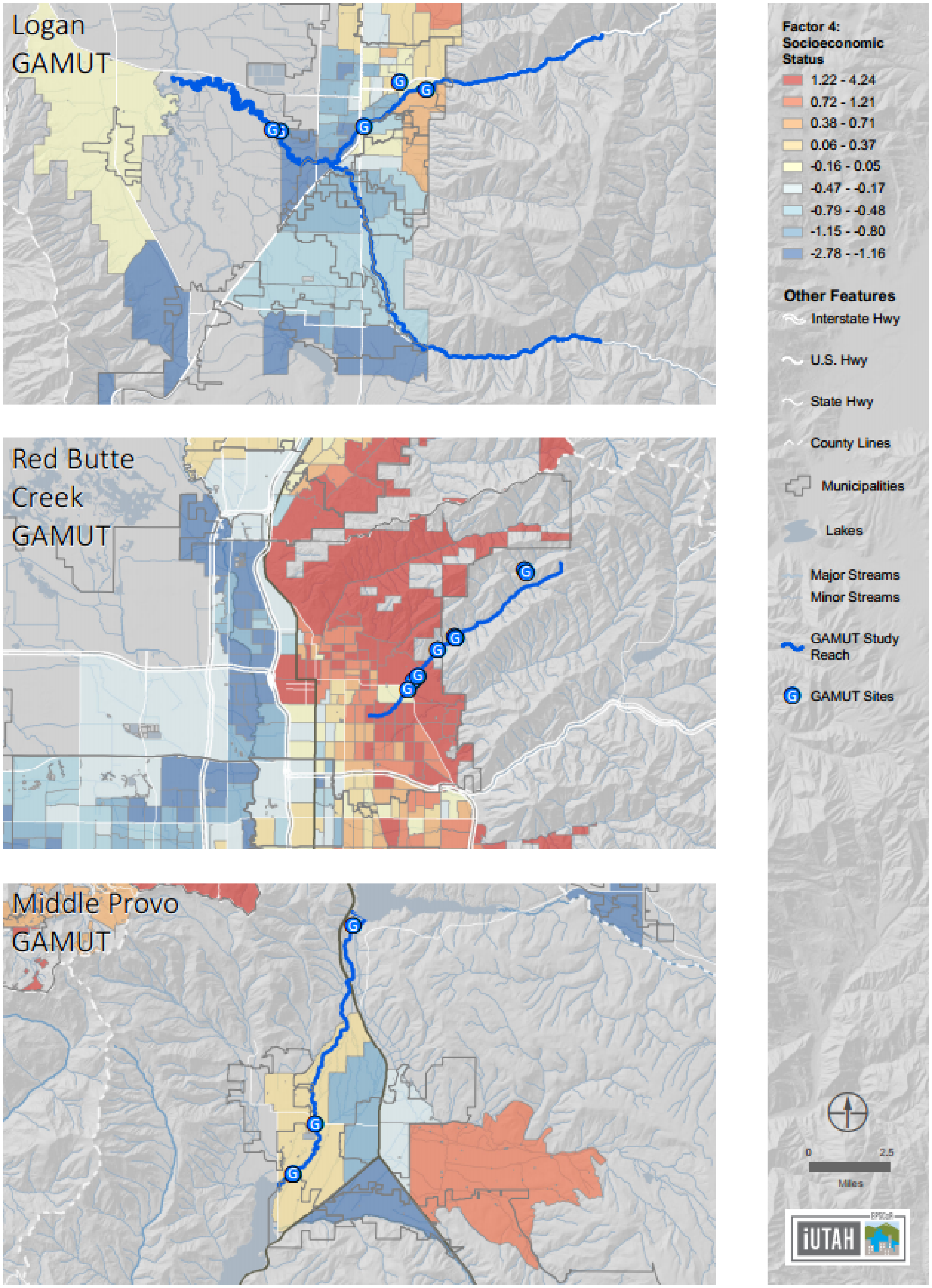
Factor 4: Socioeconomic Status



Factor 4: Socioeconomic Status



Factor 4: Socioeconomic Status



LOW DENSITY DEVELOPMENT Factor:

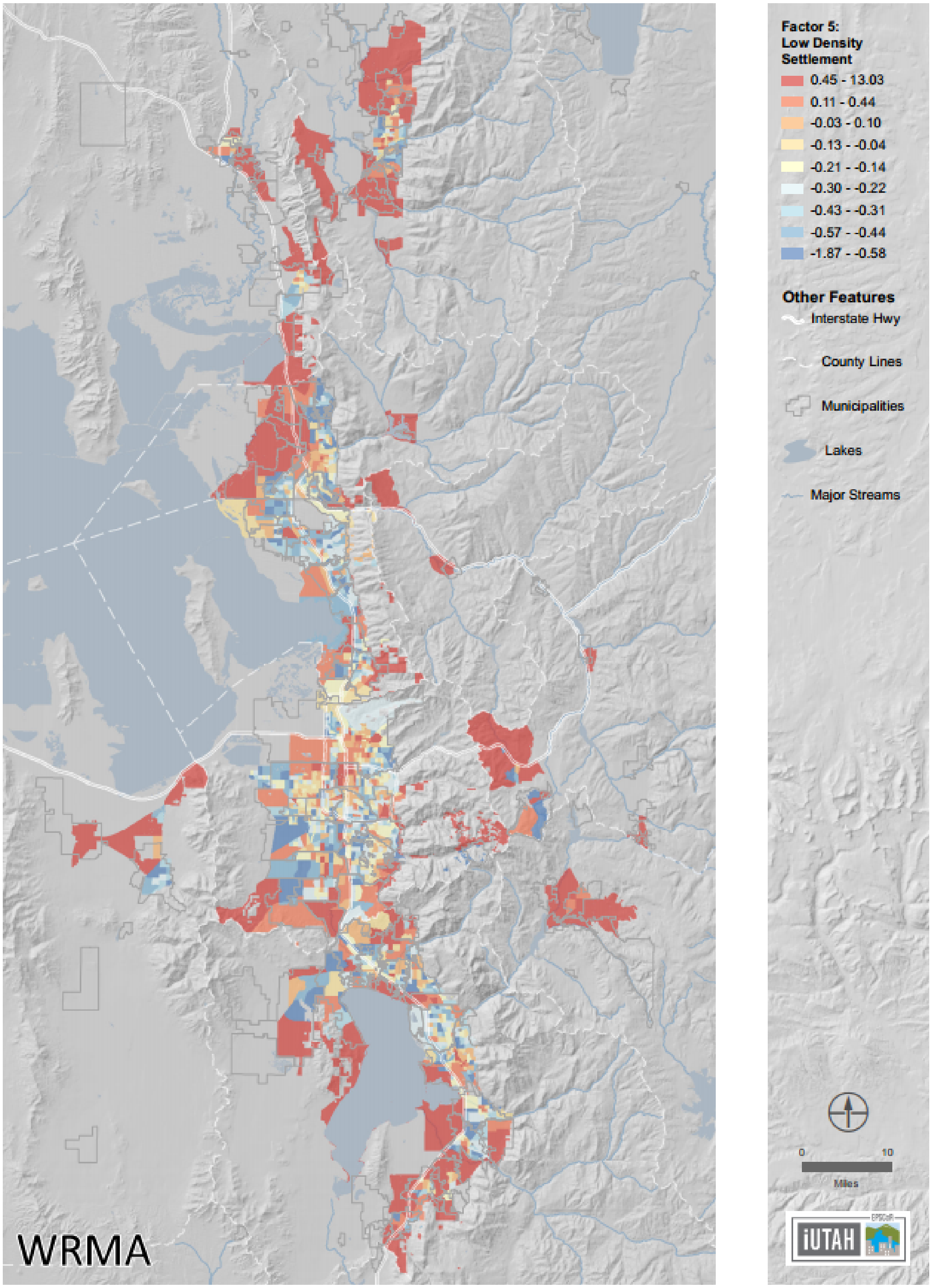
High scores on the low density development factor describe CBG's that have large parcel and block sizes. This factor primarily includes variables related to the size of the lot. These CBGs also tend to be places that are less likely to be served by a public water supplier.

Table 8: Factor loadings on Low Density Development Factor

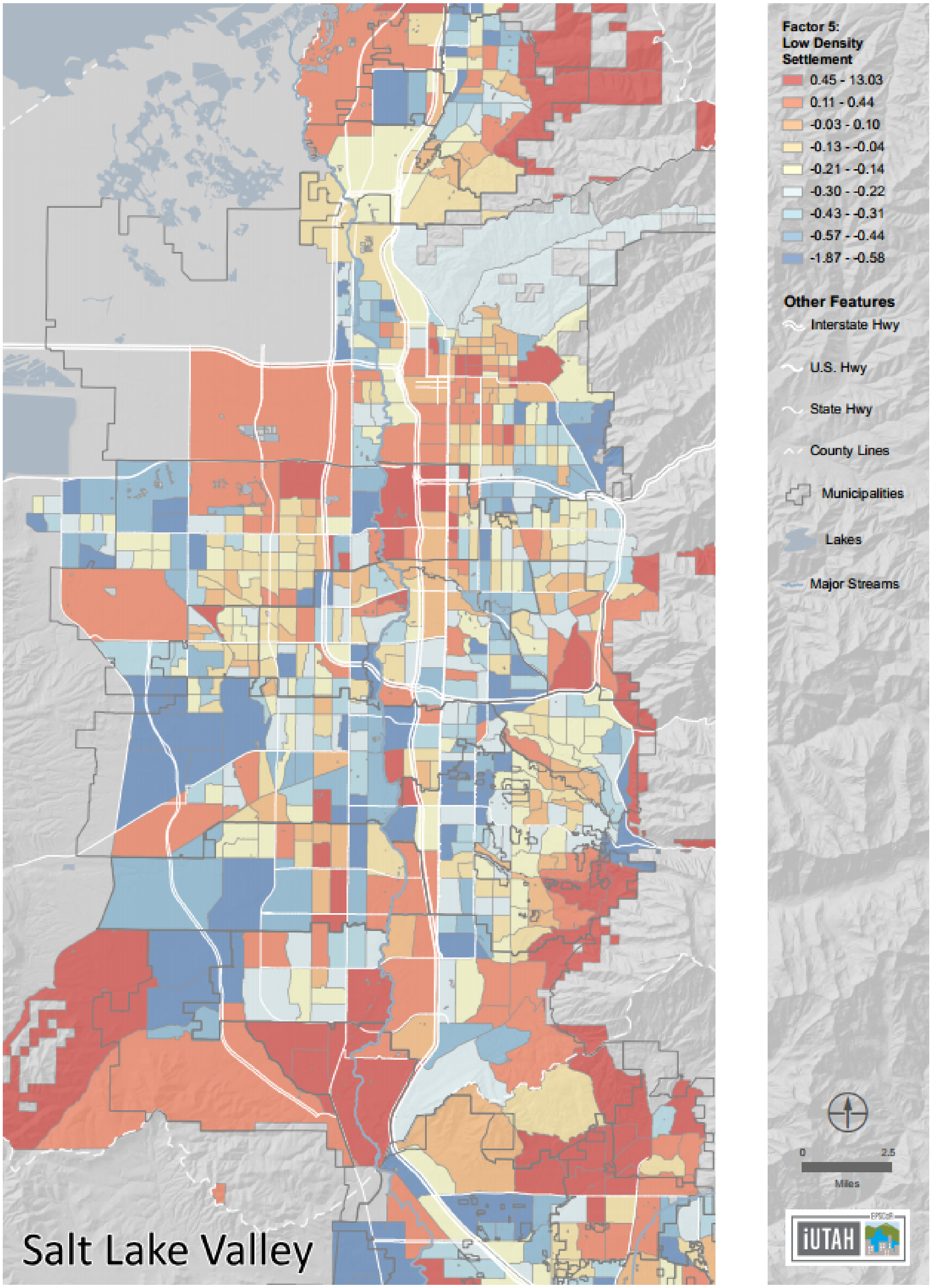
LargeLots	
BE_MdPcl Median Parcel Size	0.812
BE_AvBlk Average Block Size	0.801
BE_AvPcl Average Parcel Size	0.785
BE_MdBlk Median block size	0.778
LU_pcIRR Pct land in Irrigated Ag	0.424
LU_pcFST Pct land in farmsteads	0.319
DM_PDen Population Density (nonfed/nonwater)	(-0.210)
BE_RDenL Log of residential pop density	(-0.291)
BE_HDnRL Log form of BE_HDnRs	(-0.292)
BE_InDen Intersection Density	(-0.319)
LC_ImSu % Impervious Surface	(-0.325)
LU_pcRES Pct land in residential land	(-0.359)
WI_PcPWS % parcels Served by Public Water Supplier	(-0.774)

Maps illustrating the location of census block groups that have higher and lower scores on the Lower Density factor are illustrated for the entire WRMA, Salt Lake Valley, and urban GAMUT river study areas below.

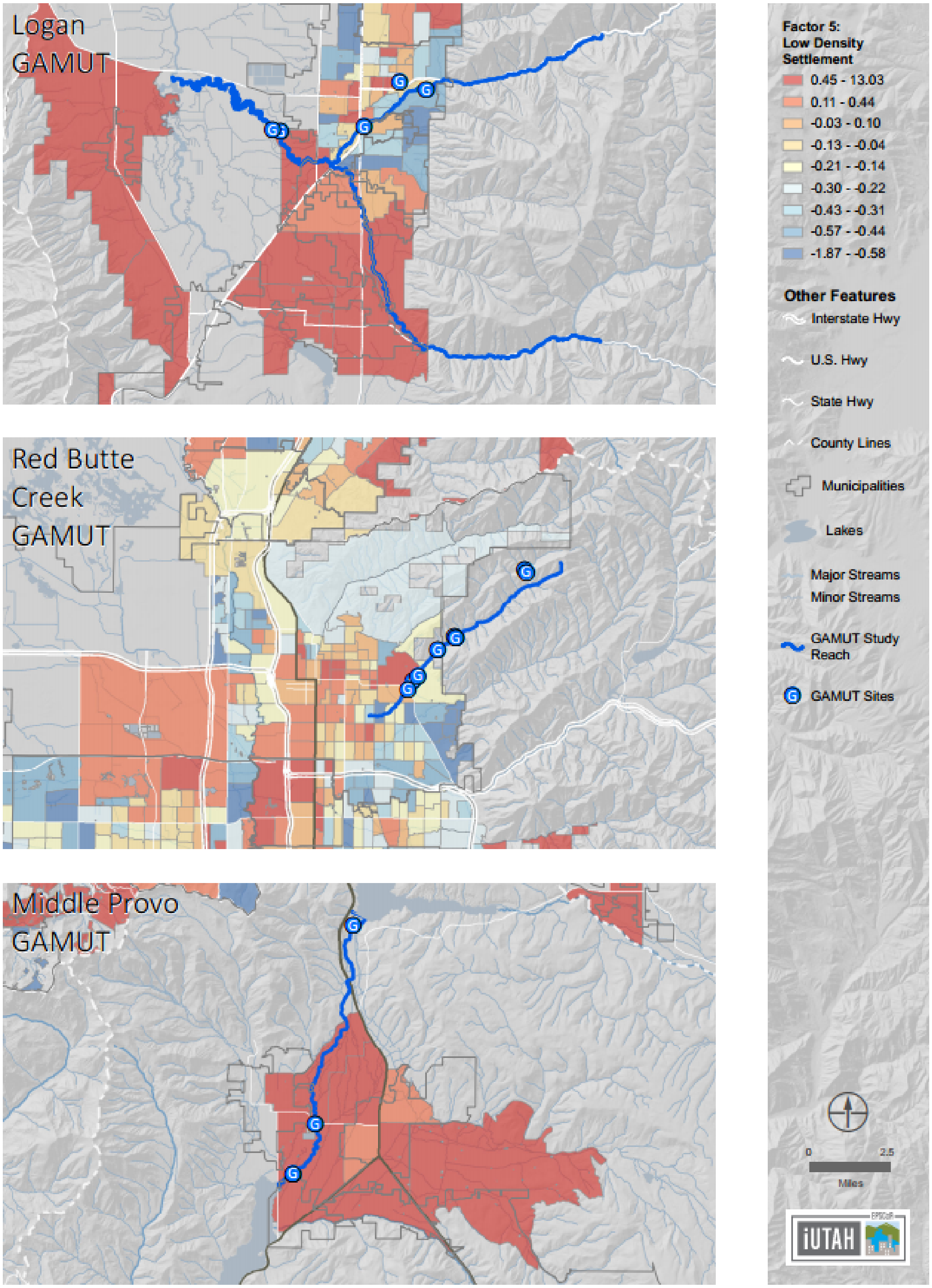
Factor 5: Low Density Settlement



Factor 5: Low Density Settlement



Factor 5: Low Density Settlement



Population/Housing Age Factor:

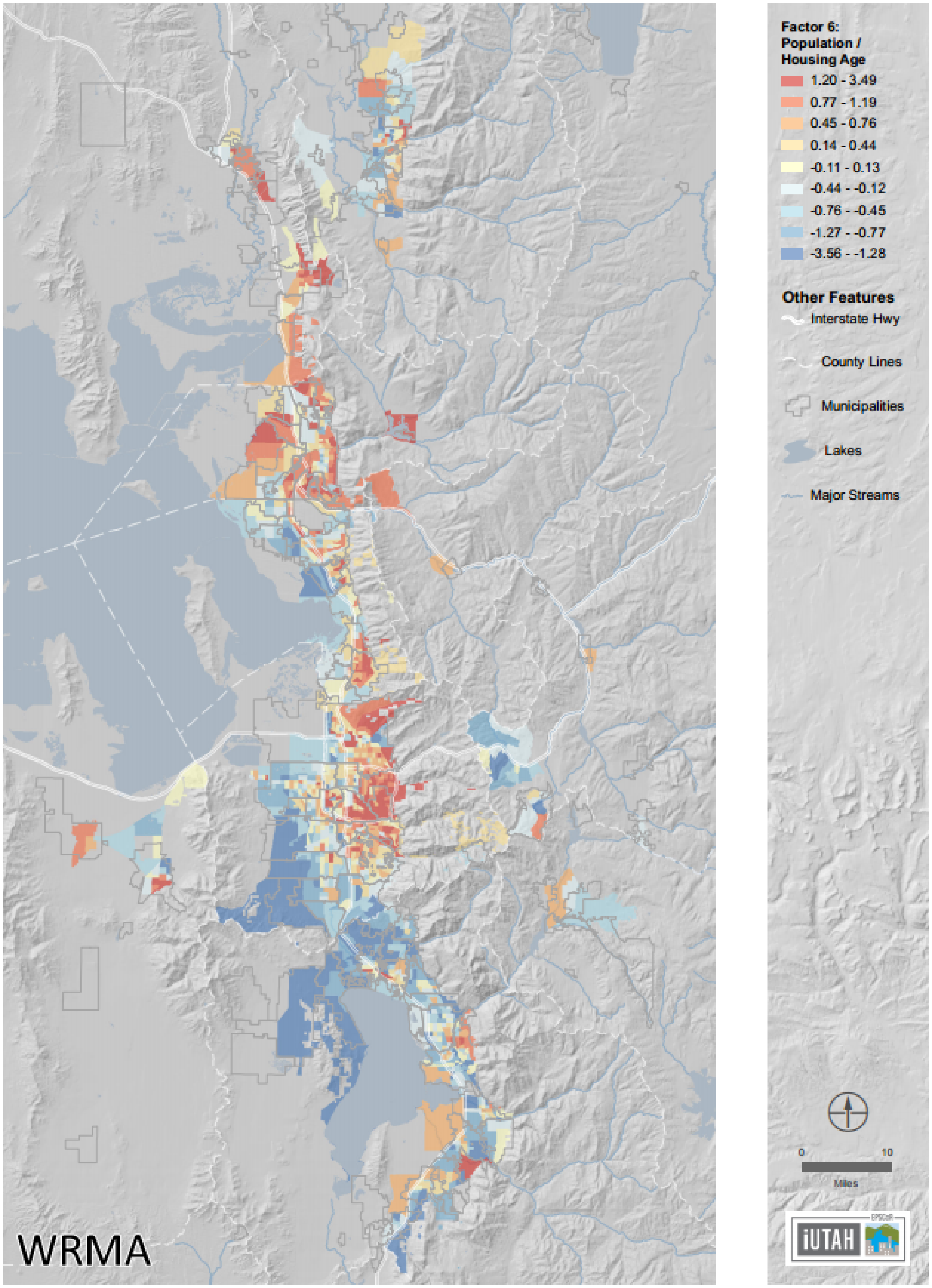
This factor describes CBGs that have a relatively young population, large household sizes, and a high percentage of housing built since 1990, as well as a high (recent) median year built. One interesting finding is that age of population and age of housing stock are positively related in Utah – younger populations tend to live in more recently built housing (and vice versa).

Table 9: Factor loadings on population/housing age factor.

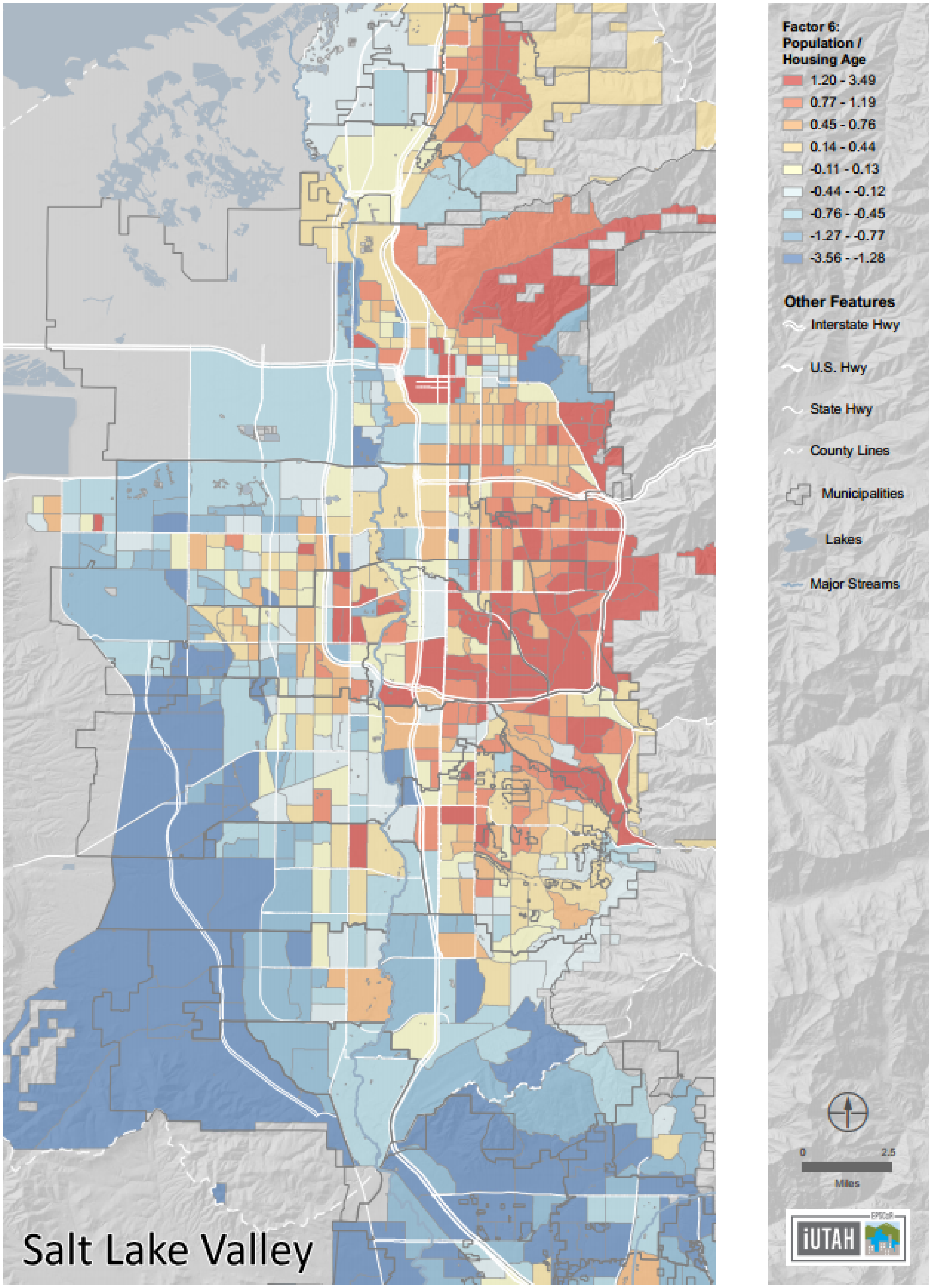
PopAge	
HC_HHSz Mean HH Size	0.613
HU_PHU90 Percent of Housing Built Since 1990	0.588
HU_MdHYr Median year structure built	0.537
LU_pcNI Pct land in Non-irr Ag	0.326
EE_JHBAL Jobs-Housing Balance	0.296
HC_PcFHH Percent HHs that are Family HHs	0.279
DM_PovRt Estimated Poverty Rate	0.201
BE_RDenL Log of residential pop density	0.201
DM_PcWht Percent of population Non-Hispanic White	(-0.210)
CL_MAnnP Avg annual precip	(-0.249)
LC_TrCv % Tree cover	(-0.324)
DM_PCI Per Capita Income (est)	(-0.342)
DM_MdAge Median age: Both sexes	(-0.826)
DM_PcO65 Percent of population over 65	(-0.861)

Maps illustrating the location of census block groups that have higher and lower scores on the Population/Housing Age factor are illustrated for the entire WRMA, Salt Lake Valley, and urban GAMUT river study areas below.

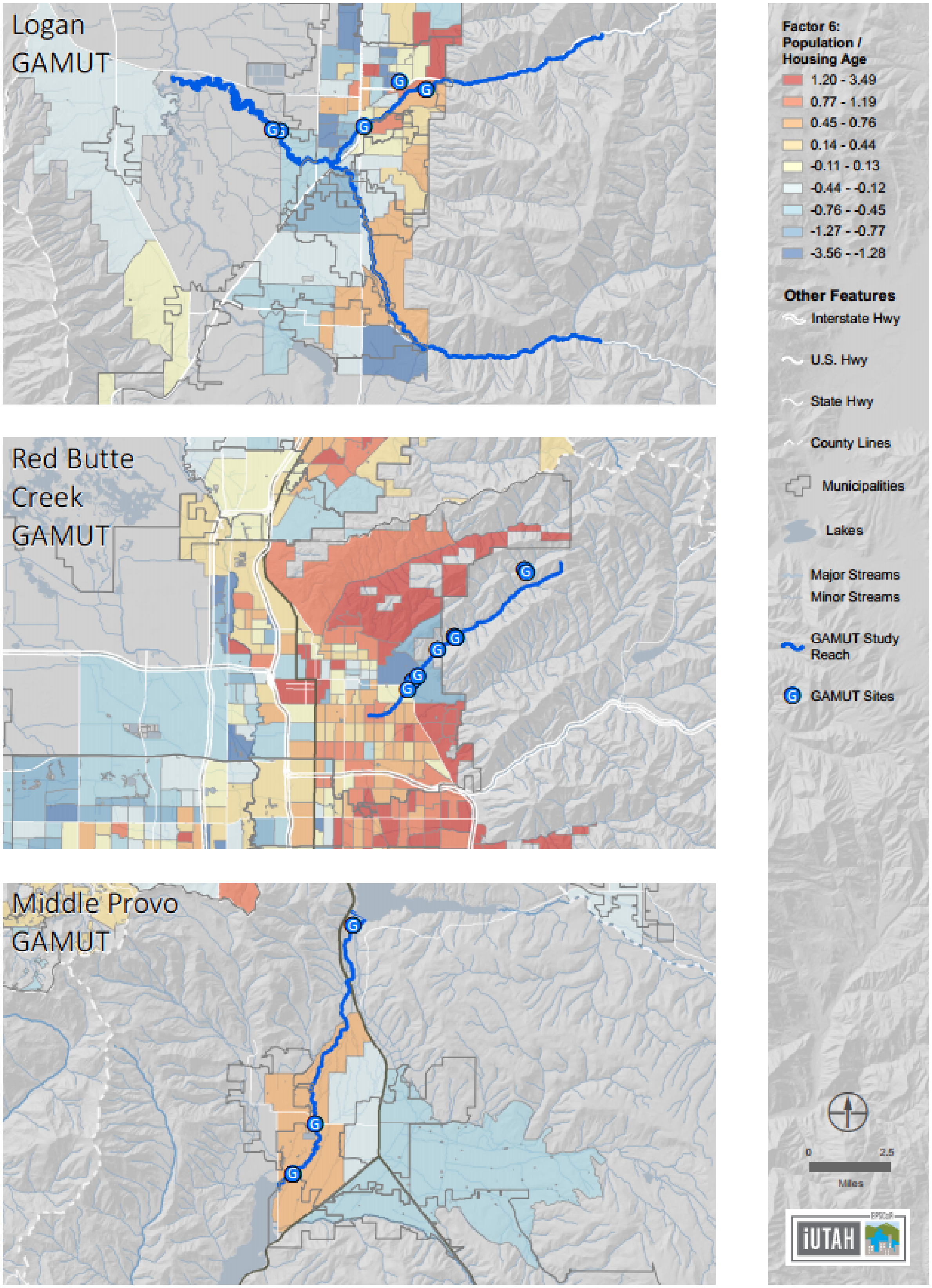
Factor 6: Population / Housing Age



Factor 6: Population / Housing Age



Factor 6: Population / Housing Age



Land Cover: Irrigated Agriculture and Greenness Factor

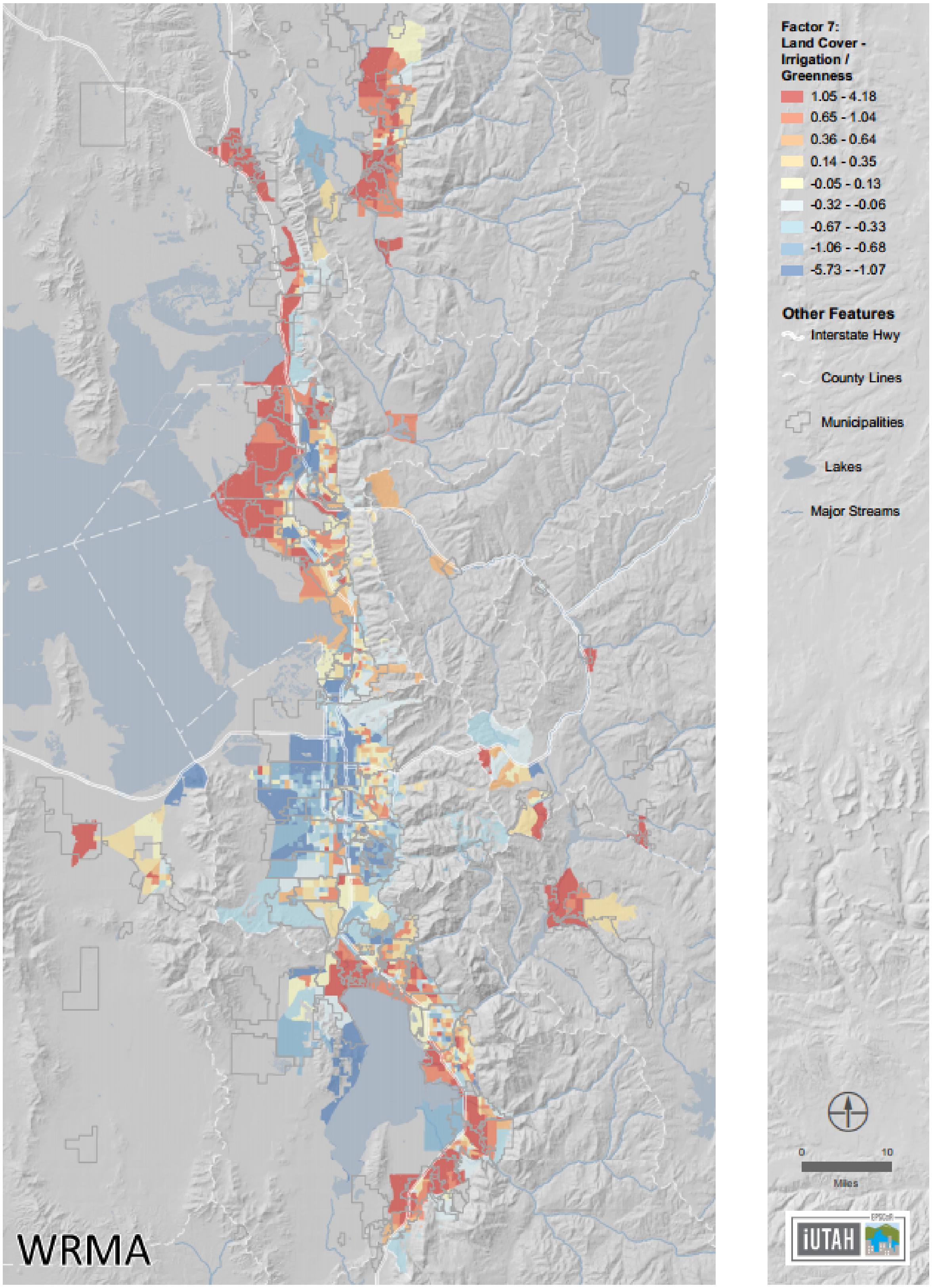
This factor describes CBGs that tend to be 'green' (e.g., have a high relative NDVI index). This is associated with a high percentage of land in irrigated agriculture and farmsteads, and low percentages of impervious surface or commercial and industrial land uses.

Table 10: Factor loadings for Land Cover / Greenness factor.

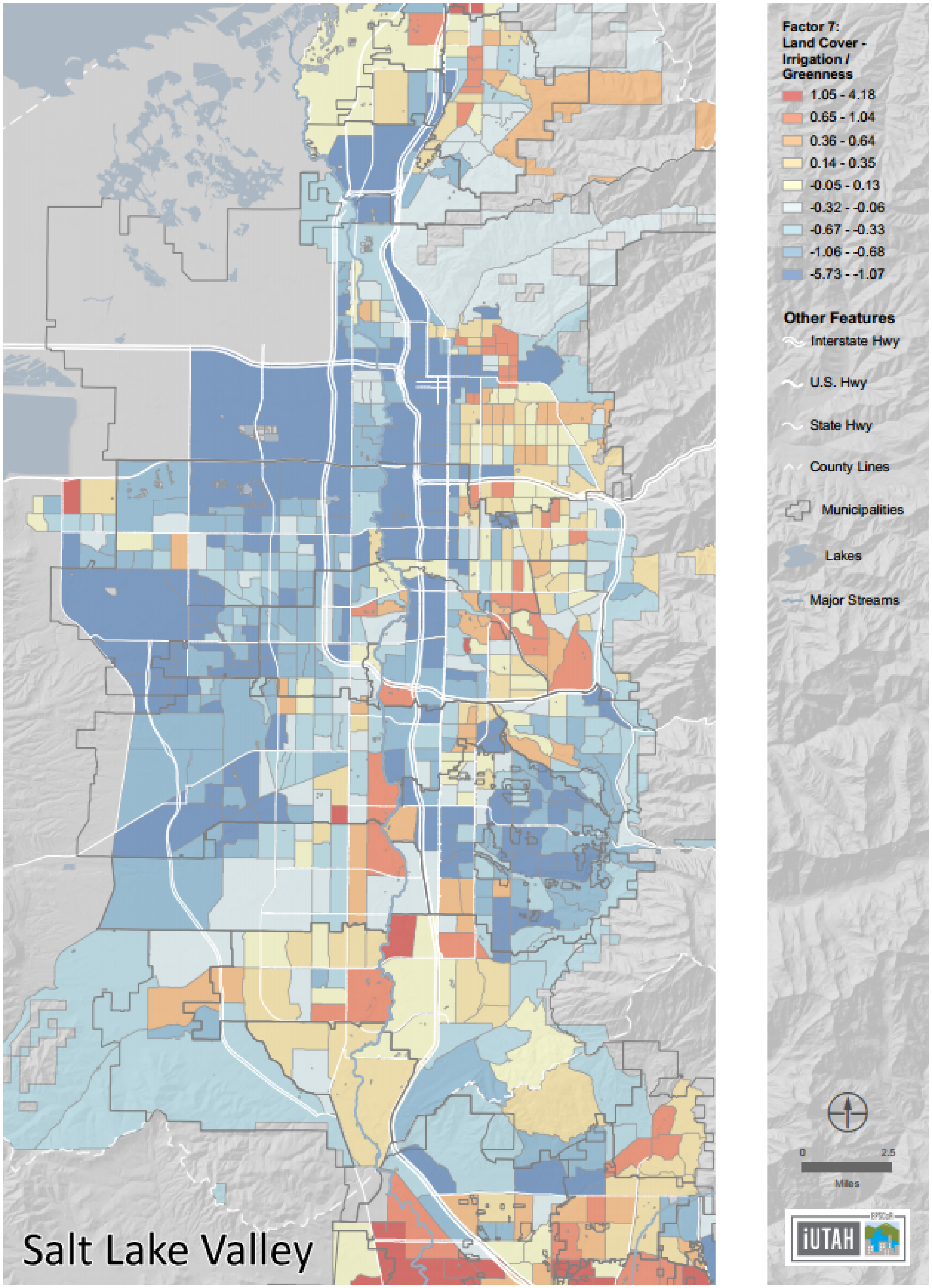
***Irrigated Ag/*Greenness**	
LC_Green Greeness (NDVI)	0.620
LU_pcIRR Pct land in Irrigated Ag	0.568
LU_pcFST Pct land in farmsteads	0.500
DM_PcWht Percent of population Non-Hispanic White	0.394
HU_PHU90 Percent of Housing Built Since 1990	0.212
BE_InDen Intersection Density	(-0.234)
BE_HDnRL Log form of BE_HDnRs	(-0.437)
BE_RDenL Log of residential pop density	(-0.502)
LC_ImSu % Impervious Surface	(-0.513)
LU_pcCOM Pct land in Comm/Industrial uses	(-0.582)

Maps illustrating the location of census block groups that have higher and lower scores on the Land Cover factor are illustrated for the entire WRMA, Salt Lake Valley, and urban GAMUT river study areas below.

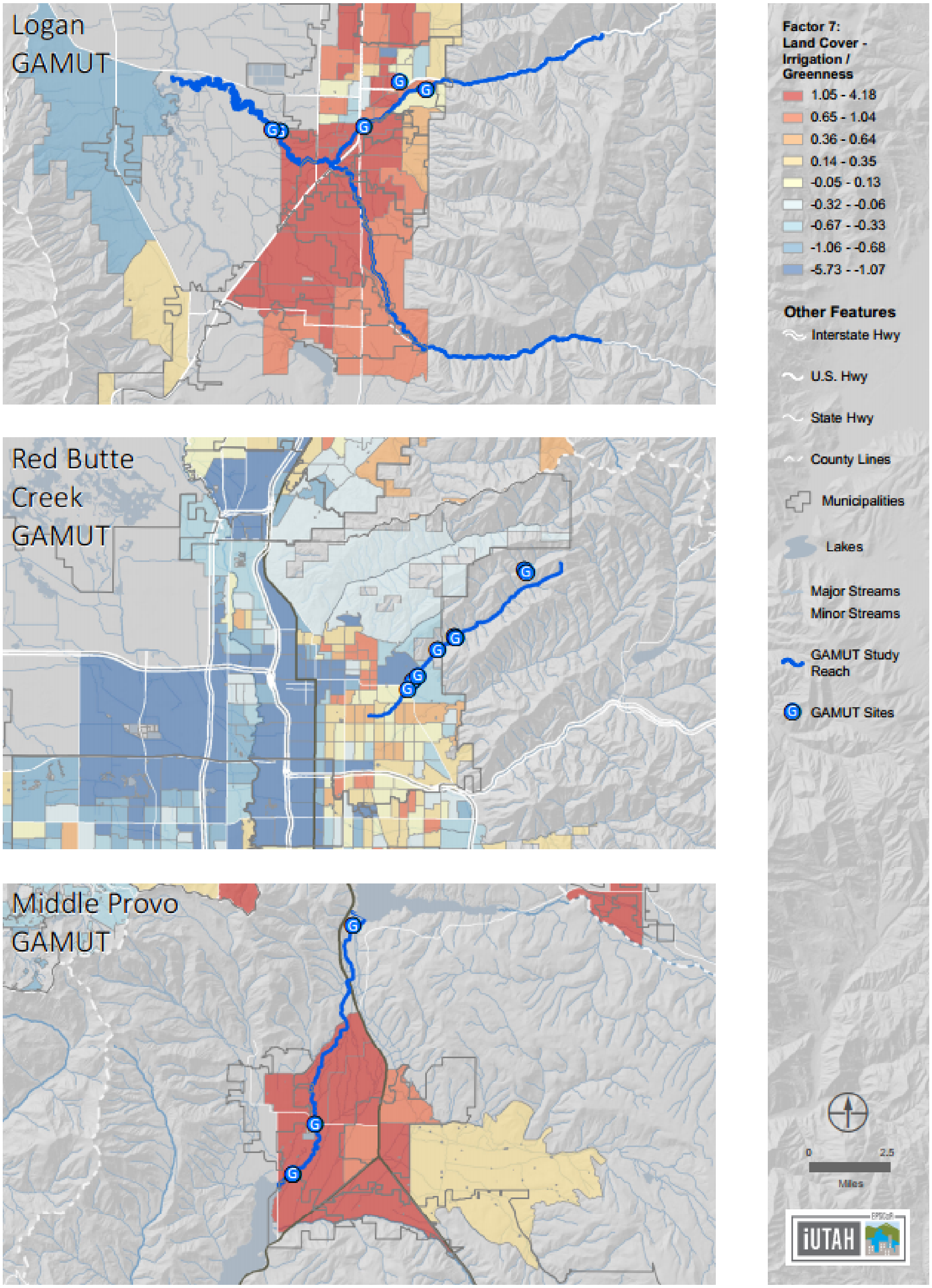
Factor 7: Land Cover - Irrigation / Greenness



Factor 7: Land Cover - Irrigation / Greenness



Factor 7: Land Cover - Irrigation / Greenness



Urban Open Space Factor:

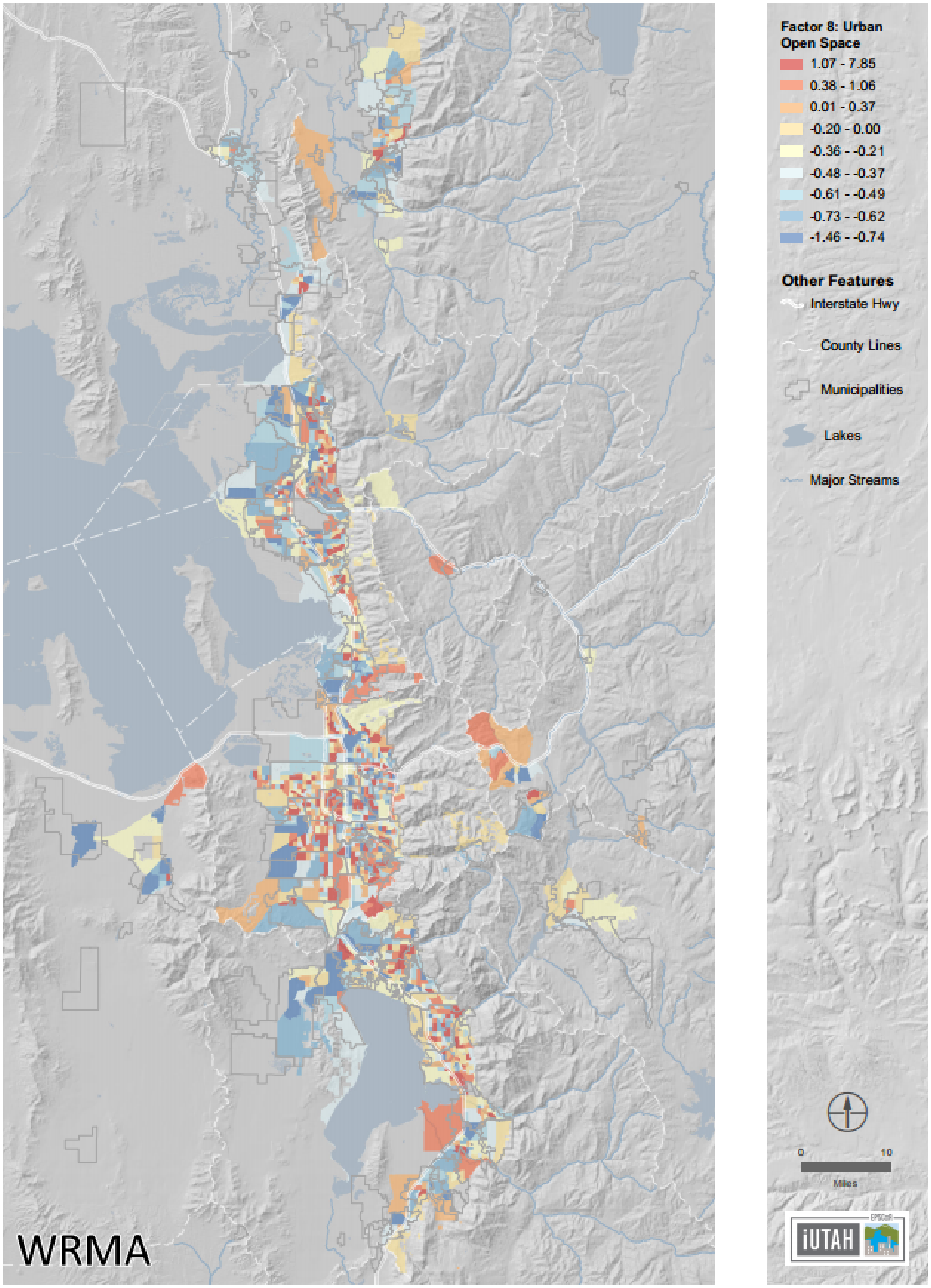
High scores on the urban open space factor describe CBG's that have a high percentage of land in urban open space, and a high percentage of parks.

Table 11: Factor loadings for Urban Open Space factor.

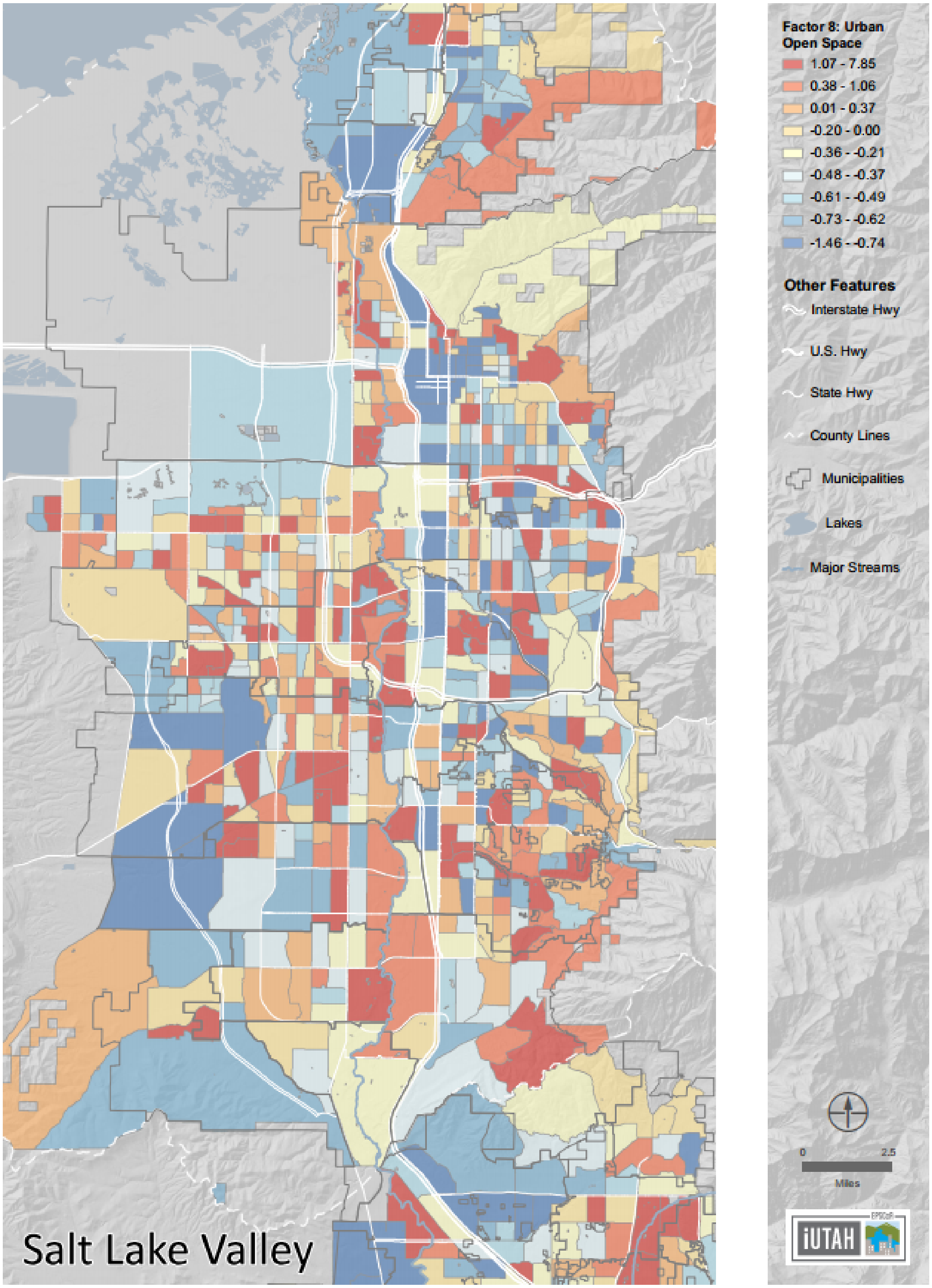
Urban Parks/Open Space	
LU_pcOSp Pct land in open space	0.944
LU_Park % Parks	0.936
LU_LuEn Land Use Entropy Index (WRLU)	0.274

Maps illustrating the location of census block groups that have higher and lower scores on the Land Cover factor are illustrated for the entire WRMA, Salt Lake Valley, and urban GAMUT river study areas below.

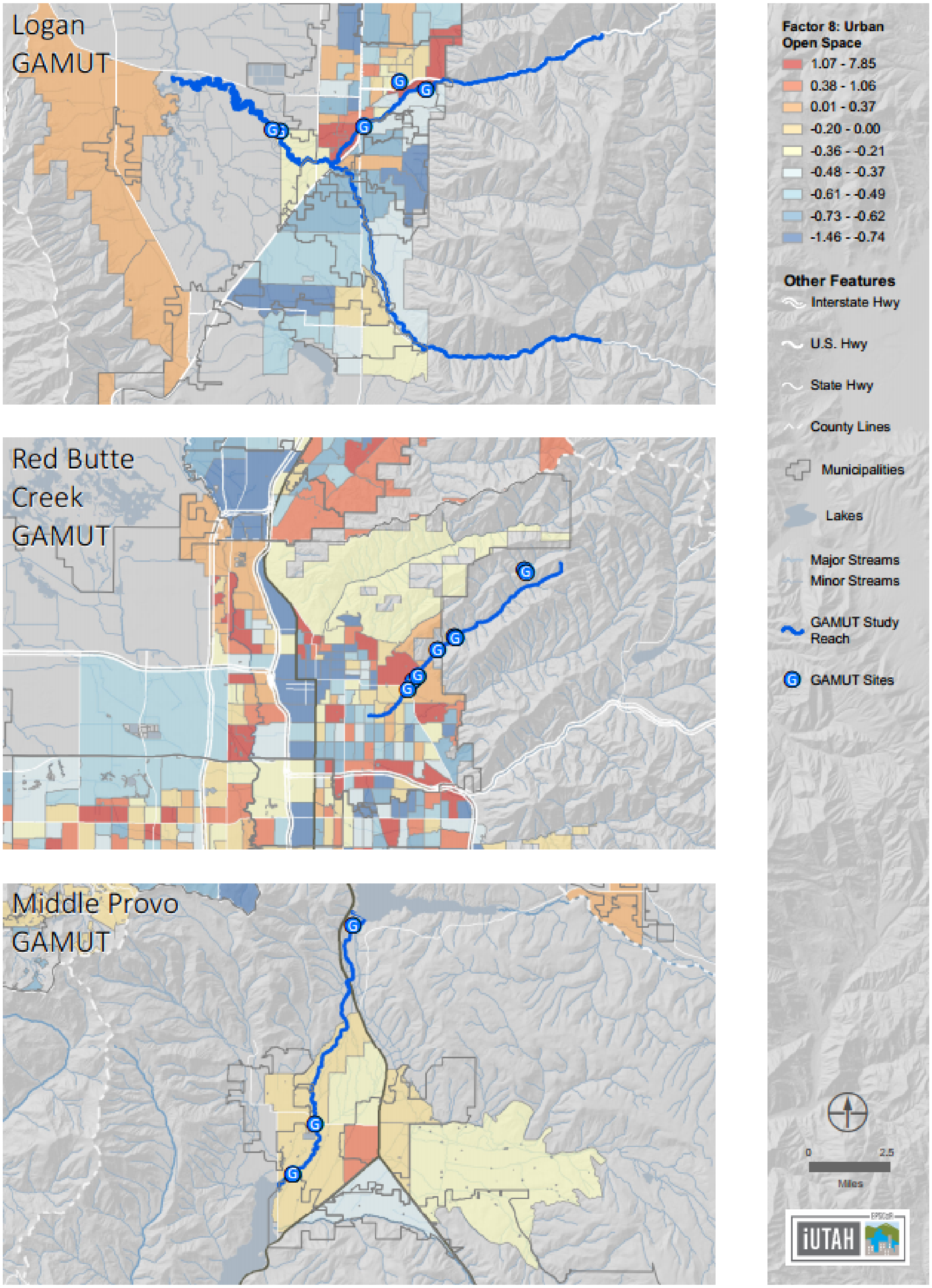
Factor 8: Urban Open Space



Factor 8: Urban Open Space



Factor 8: Urban Open Space



Mobile Homes Factor:

The mobile homes factor describes CBGs that have a high percentage of housing units that are mobile homes (and relatively recently built housing stock). Areas with many mobile homes also tend to have fewer 4-way intersections and shorter median block lengths.

Table 12: Factor loadings on Mobile Homes factor.

Mobile Homes	
HU_PcMbH Percent housing units that are mobile homes	0.624
HU_MdHYr Median year structure built	0.489
HU_PHU90 Percent of Housing Built Since 1990	0.308
BE_MdBlk Median block size	(-0.344)
BE_Pct4w % 4-Way Intersections	(-0.668)

Because it explained the least amount of overall variance and did not contribute well to an intuitive cluster analysis, this factor was excluded from the cluster modeling that is described below.

Cluster Analysis

We used hierarchical cluster analysis to group CBGs into clusters based on their factor scores on the first 8 factors described above[5]. Cluster analysis is frequently used to combine diverse units of analysis into groups that are as homogenous as possible within each cluster, and as different as possible between the clusters. Similarity (or difference) is measured in terms of 'communalities' that reflect various statistical measures of 'distance' between individual members and the aggregated clusters. In our analysis, we used a hierarchical clustering technique that sequentially combines CBGs into clusters via a series of steps that repeatedly merge unclustered CBGs (or previously identified clusters) into new cluster groups that are similar across all 8 factors. There are a variety of techniques used to determine the number of clusters that represent the optimal combination of within-cluster 'homogeneity' and parsimony (e.g., fewer total cluster groups). Our study examined the final 50 cluster merger steps that were performed on our dataset (sets of clusters ranging from 50 distinct clusters to a single merged cluster), and used statistical indicators of 'distance' and a visual examination of the merger 'dendogram' to identify critical thresholds where intra-cluster homogeneity and inter-cluster differentiation were maximized.

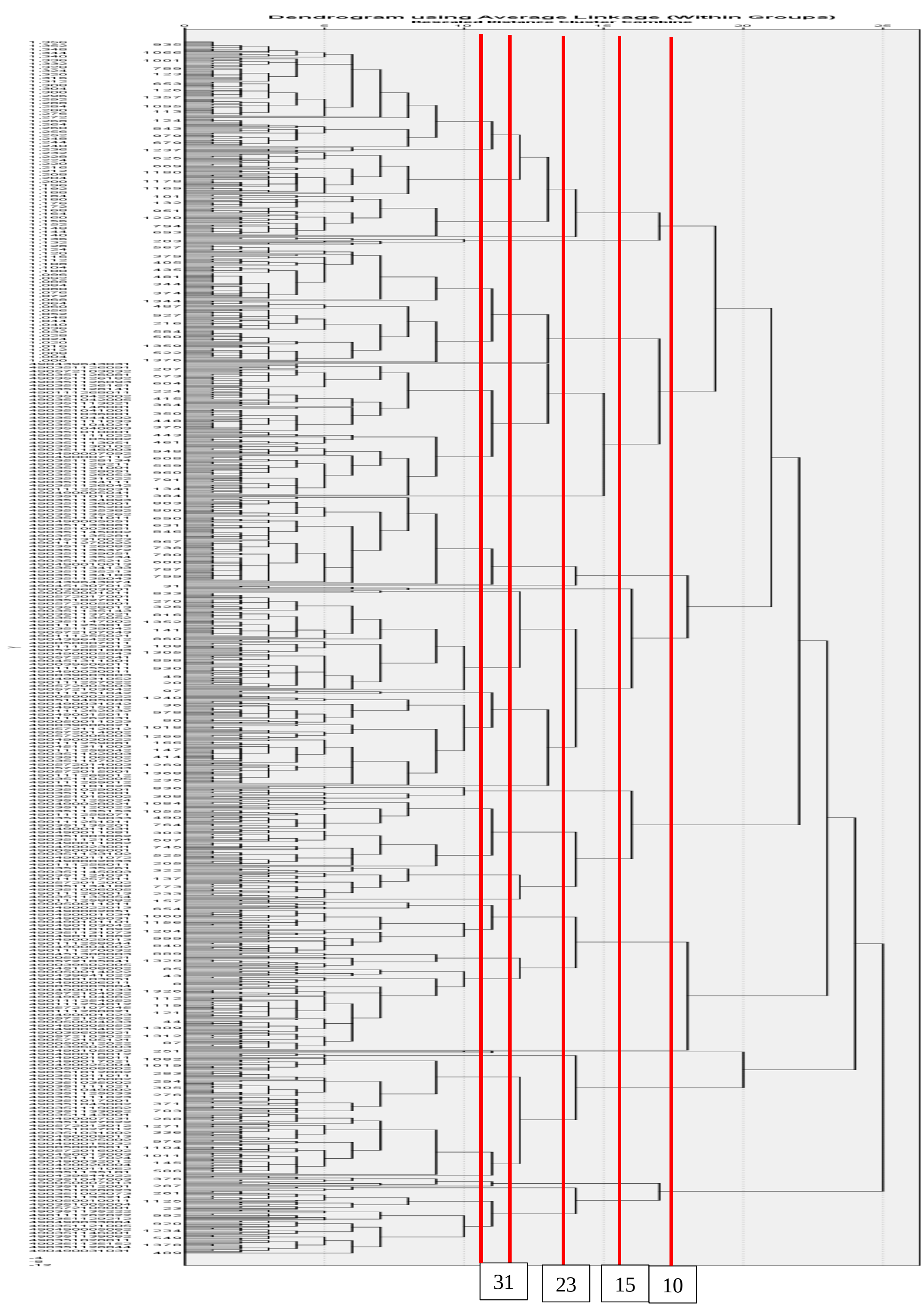
The resulting cluster classification identified several clear 'cutoff' points where additional clustering required relatively unlike groups to be merged. Based on an evaluation of the cluster distance scores and a visual assessment of the dendogram associated with the final stepwise clustering mergers (Figure 2), we identified two points where stable and coherent sets of clusters were found. The more refined set included 31 individual neighborhood types. A more coarse/aggregated set of 10 major neighborhood cluster types was also defined, with each of the 31 detailed clusters being members of one of the 10 major clusters. Two of these 10 major clusters had three or fewer CBG members and were dropped since they represent outliers that did not fit with any other cases.

The remaining 8 major cluster groups and their associated subclusters (those with at least with 5 or more CBG members) are described below. Each cluster (and subcluster) is given a specific name that reflects the attributes that make each cluster distinctive. We begin by noting some of the factors that distinguish each major group of clusters. We then present detailed descriptions and profiles of the major individual clusters, and illustrate their spatial locations across the WRMA and within each GAMUT study area.

---

[5] We dropped the 9th factor (mobile homes) for four reasons: (a) it was the factor that explained the least variance; (b) the map of factor scores did not have face validity since high and low score locations were not intuitive given our knowledge of particular neighborhoods; (c) it was not obvious how it should theoretically be linked to water outcomes; and (d) it had disproportionate influence on the eventual classification of individual cases into clusters given its relative low importance to our theory and model.

FIGURE 2: Dendogram of Hierarchical Cluster Mergers



Major Cluster Groups

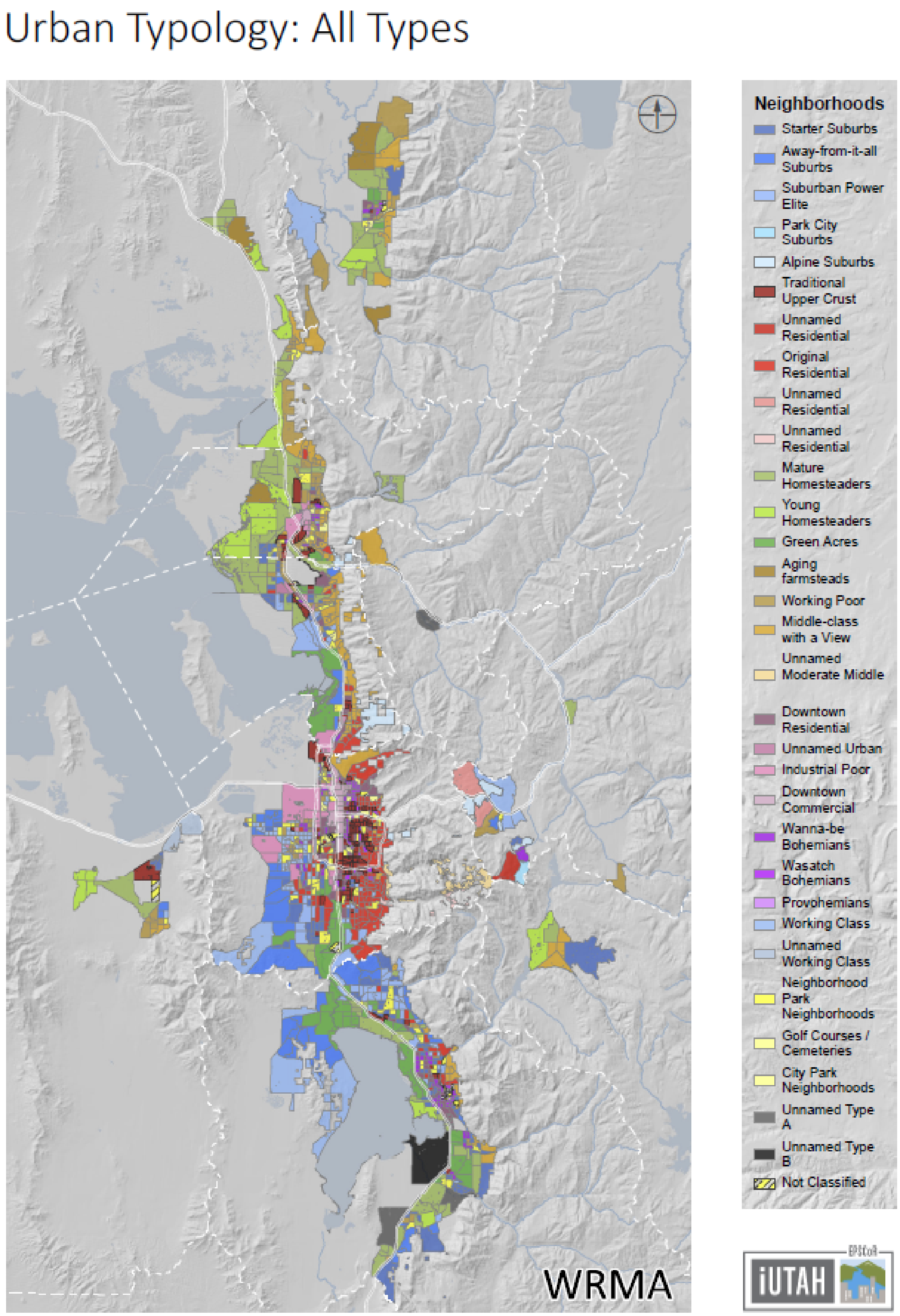
There are 8 major cluster groups and 22 individual subcluster types in the WRMA region (see Table 13)[6]. Each of the major clusters represents between 6-21% of the population and 2-27% of the land area in the urban WRMA.

Table 13: Wasatch Range Metropolitan Area Urban Typology

- *The Expanding City (T0) - 15% population; 27% area*
    - EC-A: Mature Homesteaders (n=91)
    - EC-B: Young Homesteaders (n=60)
    - EC-C: Green Acres (n=17)
- *New Suburban (T3) - 21% population; 20% area*
    - NS-A: Starter Suburbs (n=124)
    - NS-B: Away-From-It-All Suburbs (n=47)
    - NS-C: Suburban Elite (n=47)
    - NS-D: Alpine Suburbs (n-9)
- *Suburban Working Class (T7) - 8% population; 9% area*
    - SWC: Working Class Suburban (n=99)
- *The Moderate Middle (T1) - 15% population; 17% area*
    - MM-A: Aging Farmsteads (n=5)
    - MM-B: Working Class Traditional (n=112)
    - MM-C: Middle-Class with a View (n=106)
- *Traditional Residential Core (T5) - 18% population; 11% area*
    - TRC-A: Original Residential (n=131)
    - TRC-B: Traditional Upper Crust (n=146)
- *Parkside Residential(T2) - 6% population; 3% area*
    - PR-A: Neighborhood Park neighborhoods (n=70)
    - PR-B: Golf courses and Cemeteries (n=5)
    - PR-C: City Park neighborhoods (n=12)
- *Mixed Urban Residential (T4) - 9% population; 2% area*
    - BN-A: Working Class Mixed (n=70)
    - BN-B: Wasatch Bohemians (n=62)
    - BN-C: Provohemians (n=5)
- *The Urban Scene (T6) - 9% population; 7% area*
    - US-A: Downtown Residential (n=75)
    - US-B: Downtown Industrial (n=36)
    - US-C: Downtown Commercial (n=15)

[6] Four of these individual types have less than 10 CBG members. While they represent interesting and distinctive neighborhood types, because they represent relatively few places in the WRMA, they are not discussed in depth in the sections below.

Figure XX: Map of the Distribution of Neighborhood Types and Major Cluster Groups in WRMA



Major Cluster Groups: Housing Type and Land Use Patterns

Initially, the mean factor scores on two key indicators of housing and land use patterns – Suburban and Non-Residential – are shown in Figure 3 for each of the largest 18 individual clusters[7]. Orange boxes are drawn around each major cluster group to highlight the shared membership.

Three major cluster groups are notable for unusually high scores on the "Suburban" factor, which captures primarily differences in housing types and settlement patterns. The individual clusters in the New Suburban, Suburban Working Class, and Moderate Middle groups consistently score above average on the Suburban factor. This reflects a greater predominance of single-family homes, less diversity in housing types, larger household sizes, lower overall housing density, and fewer renters. At the same time, two other groups have unusually low scores on the same factor: Mixed Urban Residential Neighborhoods and Urban Scene. These places have more non-family housing, greater housing diversity and density, and smaller housing units.

Meanwhile, two major cluster groups are distinguished for having high scores on the "Non-Residential" factor, which captures mainly differences in land use mix (higher scores reflect greater land use diversity and lower levels of residential land use). The first group (Expanding City) consists of three sub clusters who all share unusually high scores on the 'non-residential' factor. In these cases, high scores reflect the presence of significant agricultural or undeveloped land use. The eighth group (Urban Scene), reflects three subgroups that all have high scores on non-residential that reflect a greater amount of commercial and industrial land uses.

Finally, three major cluster groups – Working Class Suburban, Moderate Middle, and Mixed Urban Residential neighborhoods – share notably low scores on the 'Non-Residential' factor. In these neighborhoods one finds less land use diversity, a greater use of land for housing, and higher population densities.

[7] In the descriptions below, we exclude neighborhood types that have less than 10 members.

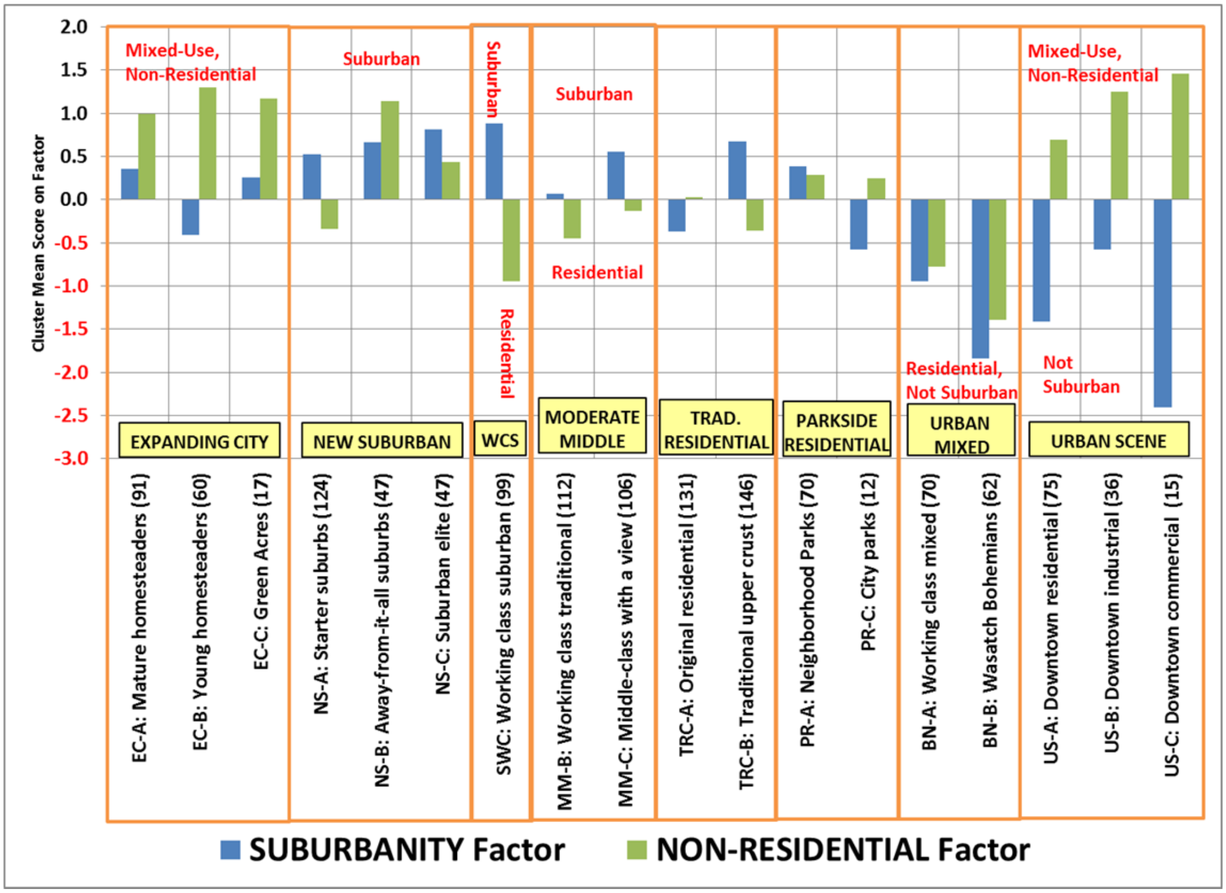


Figure 3: Mean Factor Scores for Housing Mix and Land Use Factors by Neighborhood Type.

Major Cluster Groups: Greenness and Urban Open Space

Combinations of two other factors reflect the types of land cover and amount of 'greenness' found within each census block group. The distribution of scores by major cluster groups and individual subclusters on these two factors is shown in Figure 4 below.

Initially, it is clear that two major cluster groups are uniquely defined by their relatively high (Expanding City) or low (Urban Scene) scores on the Irrigated Ag/Greenness factor (the blue bars). In the first instance, this reflects the fact that CBGs in the cluster are all located in transitioning areas at the urban fringe with significant amounts of agricultural land use and hobby farming. In the latter case, the opposite is true and (particularly for the Downtown Industrial and downtown commercial clusters) the remaining land cover has a much lower NDVI greenness score. Interestingly, among the 'suburban' groups – the working class suburban group is also distinctive for having relatively low greenness.

A separate factor – Urban Open Space – captures the percent of land area in a CBG that is in urban parks and open spaces.[8] One major cluster group – Parkside Residential – was formed primarily based on this factor. Both individual subclusters in this group have scores on the urban open space factor that are 2 to 5 standard deviations above the population average.

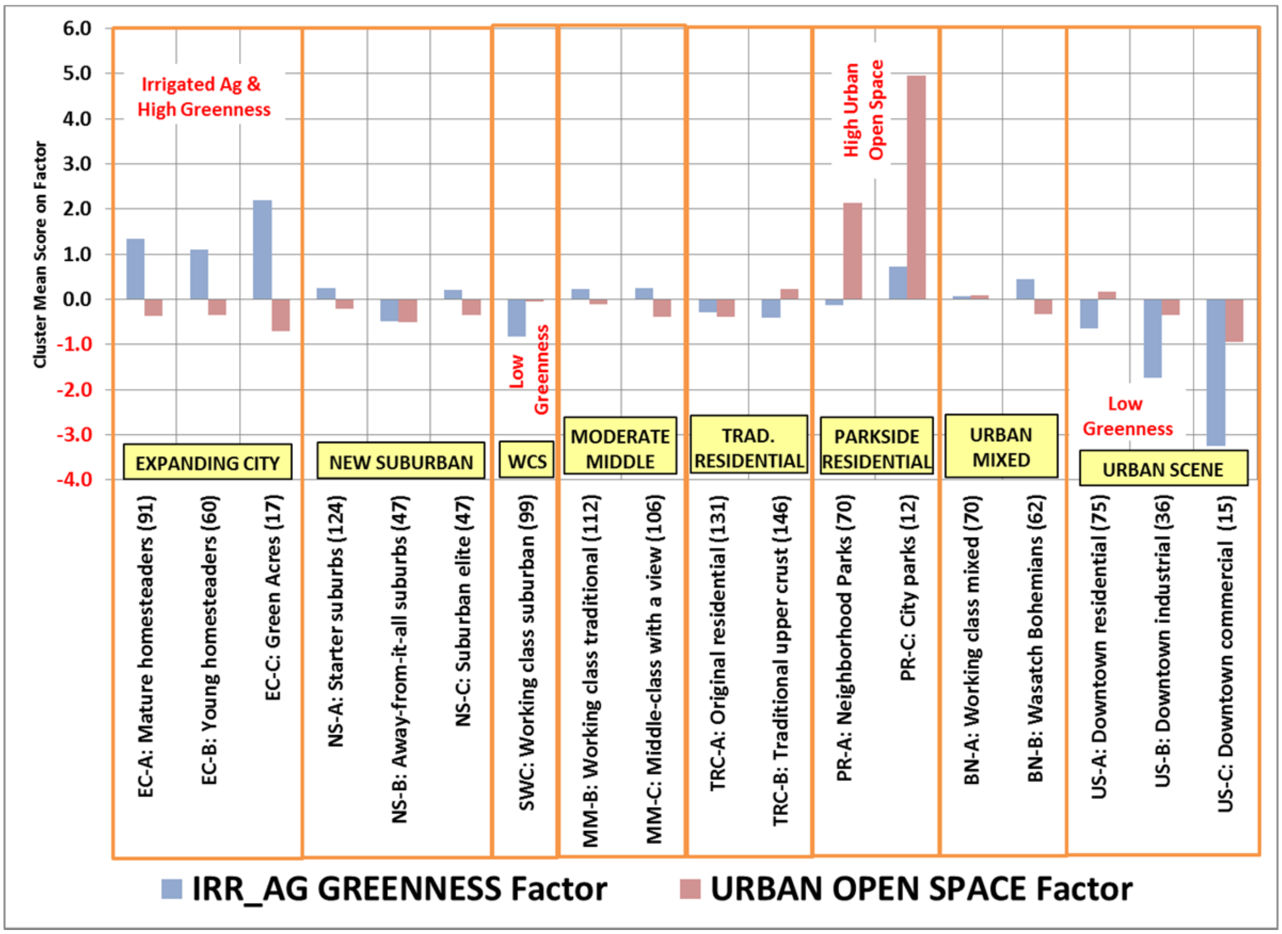


Figure 4: Mean Factor Scores for Land Cover and Urban Open Space factors by Type.

[8] By design this factor is not correlated with the irrigated ag/greenness factor.

Major Cluster Groups: Socioeconomic Status and Age

Figure 5 shows the mean factor scores for the 'SES' and 'Age' factors. In the first case, high scores reflect a population with greater income, wealth and education and fewer racial or ethnic minorities, while low scores reflect the inverse. The Age factor reflects both the age of the population and of the local housing stock. Higher scores reflect places that have a higher median age and more citizens over the age of 65. Lower scores reflect areas with recently built housing, younger families, and larger average household sizes.

Several major cluster groups are noted for having older than average populations and older housing stock: Moderate Middle, Traditional Residential, and Parkside Residential. By contrast, three groups have notably younger housing stock and residents: New Suburban, Working Class Suburban, and Mixed Urban Residential neighborhoods.

Aside from the Working Class Suburban and Moderate Middle groups, the SES factor scores did not define many major cluster groups, but rather serves as a key factor that distinguishes individual clusters within major cluster groups. For example, within the New Suburban and Traditional Residential groups, a single cluster type (Suburban Elite and Traditional Upper Crust, respectively) present the two highest SES clusters in the WRMA. However, the other clusters in their groups did not have notably high or low scores on the SES factor. Similarly, the four clusters with the lowest SES scores (Working Class Traditional, Downtown Industrial, Working Class Suburban, and Working Class Mixed) are each found in different groups.

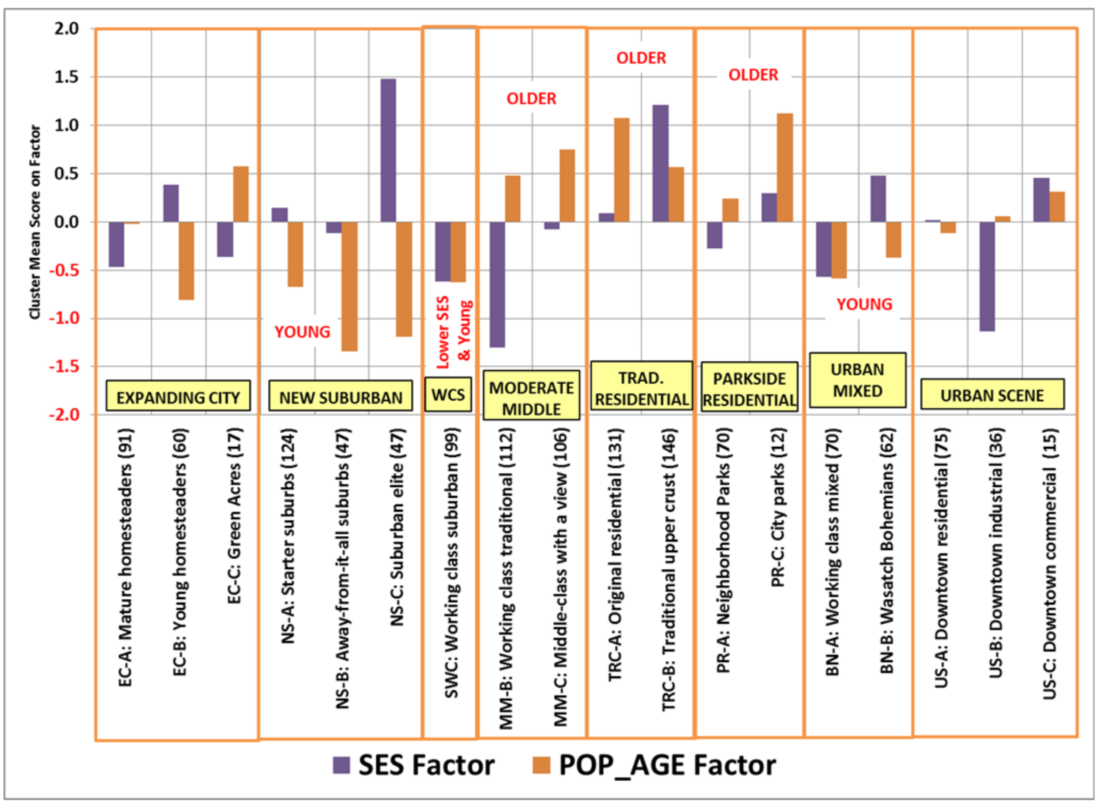


Figure 5: Mean Factor Scores for SES and Age factors by Type.

Major Cluster Groups: Elevation and Lot Size

Figure 6 shows the mean factor scores for the final two factors: Elevation and Lower Density. In the first case, high scores reflect CBGs that are located at higher elevations, have colder temperatures and higher amounts of annual and seasonal precipitation. Low scores reflect the opposite conditions. High scores on the Large Lot factor reflect larger average parcel sizes, longer street blocks, and areas that are less well served by a public water supplier.

Two major cluster groups share low scores on the elevation factor (Expanding City and Urban Scene), while one group has individual clusters that are located at notably higher elevations (Moderate Middle). In most of the other groups, individual clusters do not share common elevational traits and/or have scores on this factor that are close to the population average.

One individual cluster has a very large score on the Large Lot variable (Green Acres), though the Expanding City group also contains one cluster that has relatively small parcels (Young Homesteaders). Among the various suburban and residential groups, the New Suburban, Traditional Residential, and Parkside Residential groups appear to have consistently small average lot sizes.

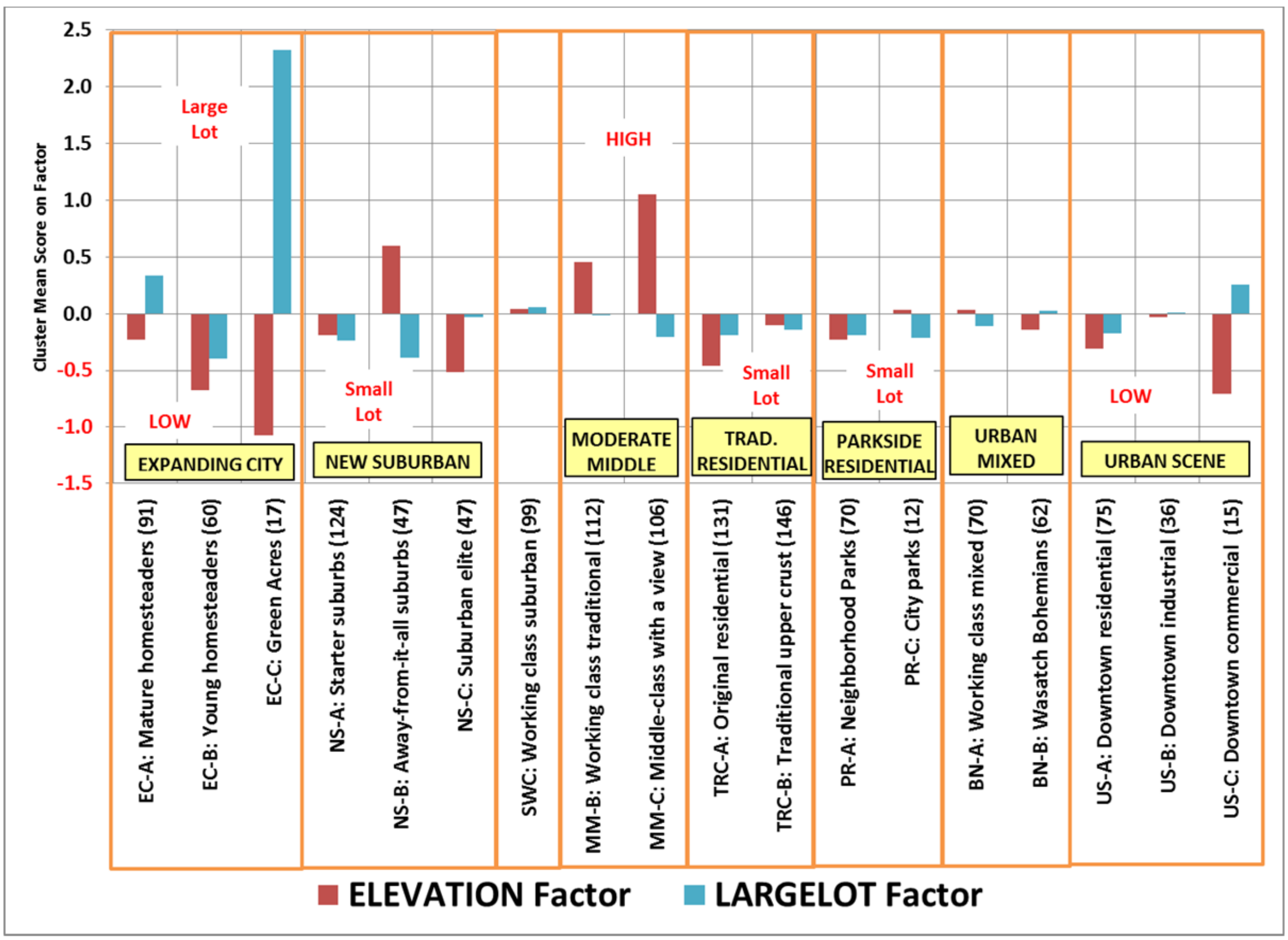


Figure 6: Mean Factor Scores for Elevation and Large Lot factors by Type .

Summary of Major Cluster Group Traits

The various combinations of distinctively high and low factor scores on the 8 factors used in our cluster analysis are summarized in Table 14. While the patterns are complex, it is clear that the eight major cluster groups reflect unique combinations of high and low scores on the some of the core analytical factors. Moreover, within each major cluster group, individual neighborhood types are disaggregated based on unusually high or low scores on additional factors.

For example, while all of the 'Urban Scene' neighborhoods are notable for low scores on the Surburban, Greenness, and Elevation factors (and high scores on the Non-residential factor), the Downtown Industrial neighborhoods are distinguished by a relatively low SES score among local residents, while the people living in Downtown Commercial neighborhoods have unusually high SES scores.

A more detailed description of each of the major cluster groups and its individual neighborhood types is presented in the next section, along with maps that illustrate the location of these neighborhoods within some of the major watersheds in the WRMA.

Table 14: Distinguishing Factors for 8 Major Cluster Groups and 18 Neighborhood Types

		MEAN FACTOR SCORE							
Code	**Cluster Group/Neighborhood Type**	**Suburban**	**Non-Residential**	**Irrig Ag/Green**	**Urban Open Space**	**SES**	**AGE**	**Elevation**	**Large Lot**
EC	**Expanding City**		**HIGH (1.1)**	**HIGH (1.3)**				**LOW (-0.5)**	**HIGH (0.3)**
EC-A	Mature Homesteaders (n=91)		*high*	*high*		**low**		*low*	**high**
EC-B	Young Homesteaders (n=60)	**low**	*high*	*high*		**high**	**low**	*low*	
EC-C	Green Acres (n=17)		*high*	*high*				*low*	
NS	**New Suburban**	**HIGH (0.6)**					**LOW (-0.9)**		**LOW (-0.2)**
NS-A	Starter Suburbs (n-124)	*high*					*low*		*low*
NS-B	Away-from-it-all Suburbs (n=47)	*high*		**low**			*low*		*low*
NS-C	Suburban Elite (n=47)	*high*				**high**	*low*		*low*
SWC	**Suburban Working Class**	**HIGH (0.9)**	**LOW (-0.9)**	**LOW (-0.8)**		**LOW (-0.6)**	**LOW (-0.6)**		
SWC	Working Class Suburban (n=99)	*high*	*low*	*low*		*low*	*low*		
MM	**Moderate Middle**	**HIGH (0.3)**	**LOW (-0.3)**			**LOW (-0.7)**	**HIGH (0.6)**	**HIGH (0.8)**	
MM-B	Working Class Traditional (n=112)	*high*	*low*			**low**	*high*	*high*	
MM-C	Middle-Class-With-A-View (n=106)	*high*	*low*				*high*	*high*	
TRC	**Traditional Residential Core**					**HIGH (0.7)**	**HIGH (0.8)**		**LOW (-0.1)**
TRC-A	Original Residential (n=131)	**low**					*high*		*low*
TRC-B	Traditional Upper Crust (n=146)	**high**		**low**		**high**	*high*		*low*
PR	**Parkside Residential**				**HIGH (2.7)**		**HIGH (0.3)**		**LOW (-0.2)**
PR-A	Neighborhood Parks (n=70)	**high**			*high*		*high*		*low*
PR-C	City Parks (n=12)	**low**			*high*		*high*		*low*
BN	**Mixed Urban Residential**	**LOW (-1.4)**	**LOW (-1.2)**				**LOW (-0.6)**		
BN-A	Working Class Mixed (n=70)	*low*	*low*				*low*		
BN-B	Wasatch Bohemians (n=62)	*low*	*low*			**high**	*low*		
US-A	**The Urban Scene**	**LOW (-1.3)**	**HIGH (1.0)**	**LOW (-1.3)**				**LOW (-0.3)**	
US-A	Downtown Residential (n=75)	*low*	*high*	*low*				*low*	
US-B	Downtown Industrial (n=36)	*low*	*high*	*low*		**low**		*low*	
US-C	Downtown Commercial (n=15)	*low*	*high*	*low*		**high**		*low*	

CLUSTER GROUP 1: THE EXPANDING CITY

The Expanding City cluster group of neighborhood types are all defined by having unusually large areas still in irrigated agriculture (and an associated 'green' NDVI signature), mixed land uses, relatively low percentages of area developed for residential land use, and are located at relatively low elevations within the WRMA (Figure 7). When viewed on a map (Figures Y1-43), these types clearly represent areas on the urban fringe that are actively transitioning from agricultural to residential land uses. While they have population densities above 100 pp/sq. mile, they are located on the 'rural' end of the rural-urban continuum. Within this group, the "Green Acre" neighborhood subtype (n=17) is notable for having very large lot sizes and a somewhat older population. Meanwhile, the "Young Homesteaders" neighborhood subtype (n=60) is distinctive for a younger population and housing stock and slightly *smaller* than average lot sizes.

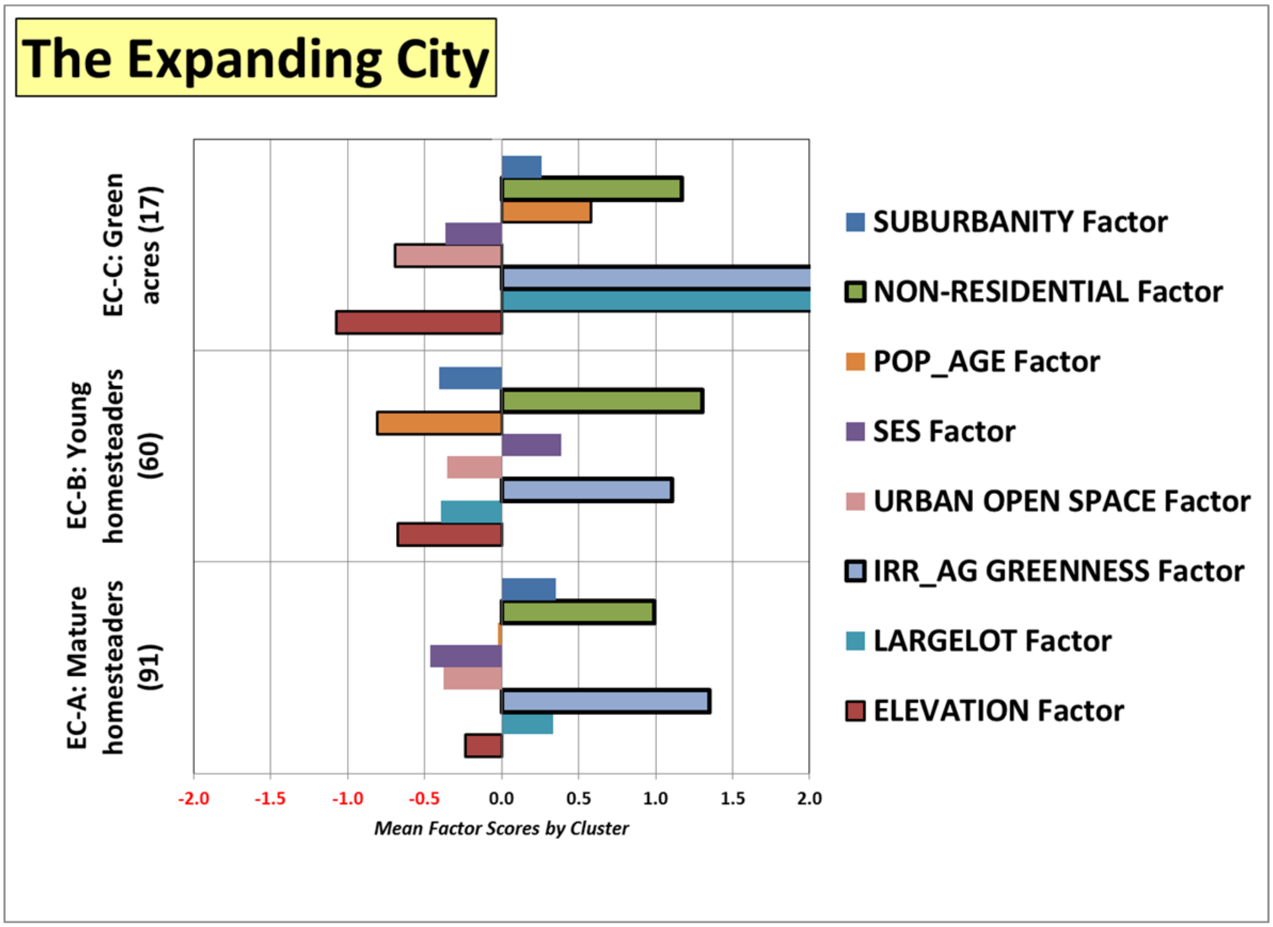
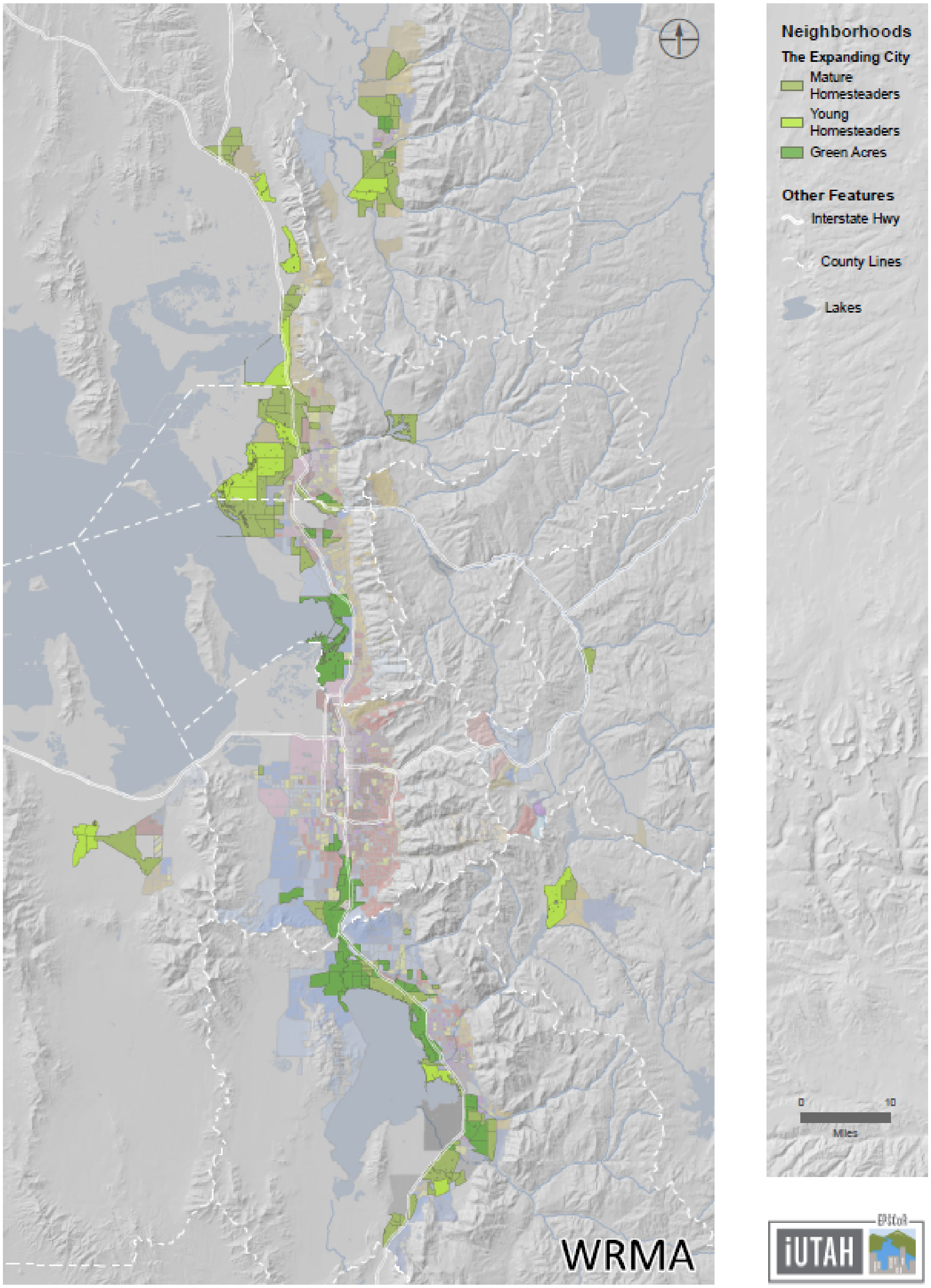


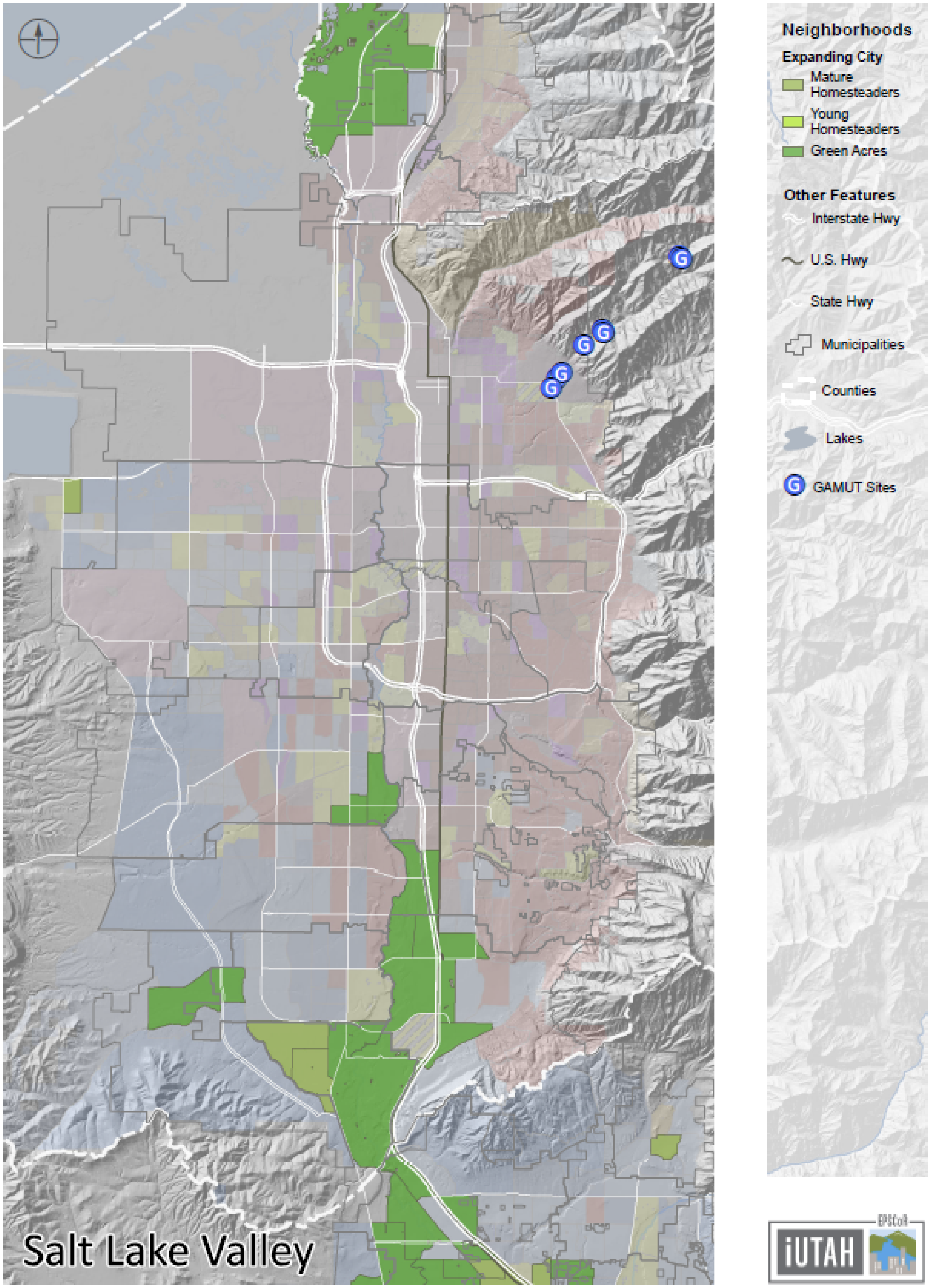
Figure 7: Mean Factor Scores for Neighborhood Types within Expanding City major cluster group.

Maps of the distribution of census block groups in this cluster group for the WRMA, Salt Lake Valley, and iUTAH GAMUT areas are illustrated in Figures X-Y.

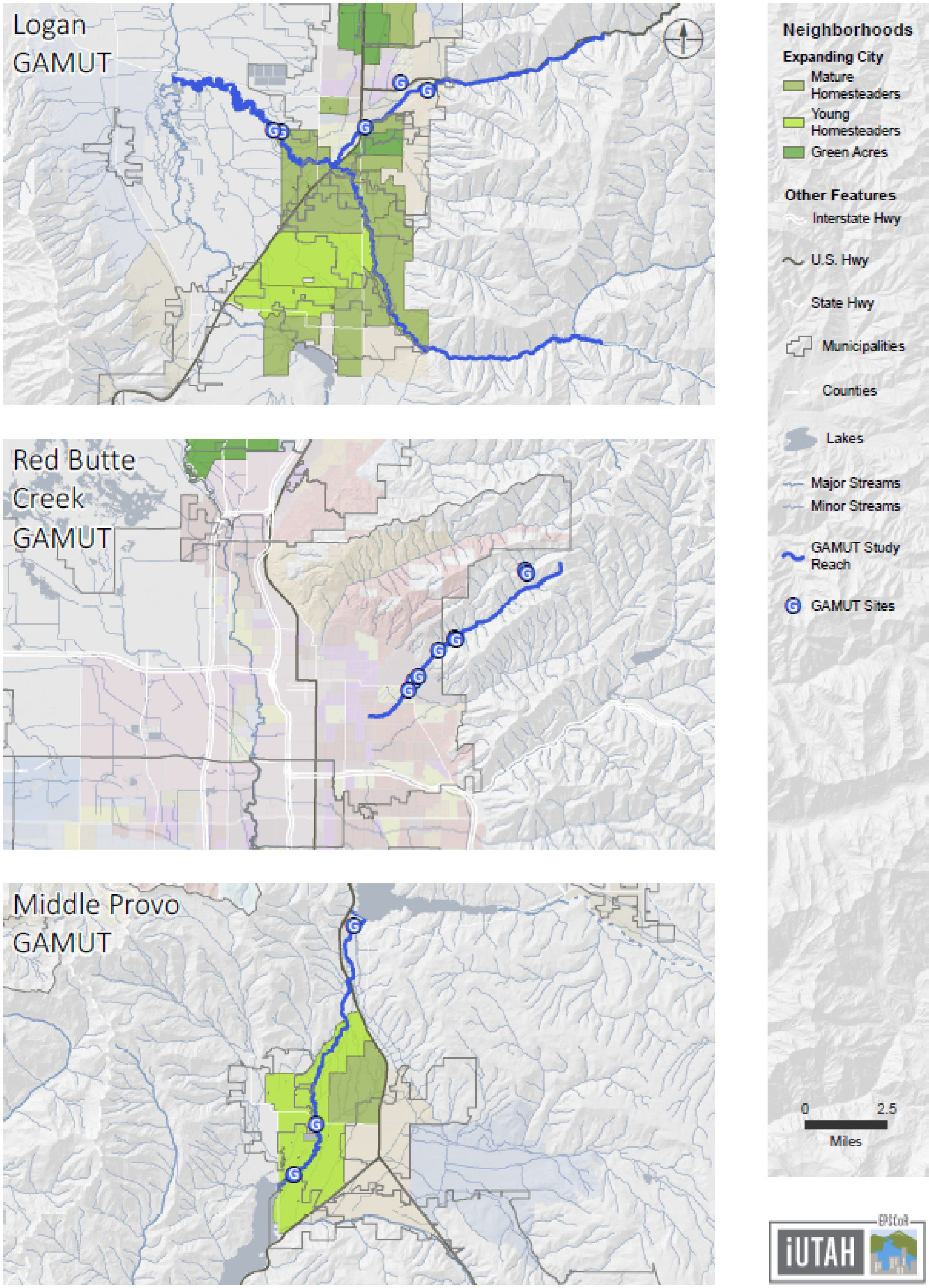
Urban Typology: The Expanding City



Urban Typology: Expanding City



Urban Typology: Expanding City



CLUSTER GROUP 2: NEW SUBURBAN

The New Suburban cluster group of neighborhood types are notable for very high scores on the hoising mix-suburban factor (which reflects a family-household, single-family home dominated residential pattern), newly built houses, very young populations, and relatively small lot sizes (Figure 8). Within this cluster group there are three distinctive neighborhood types. The largest (n=124) are the "Starter Suburbs" that are the most 'classic' exemplar of this type of place. A second neighborhood type, "Away from It All Suburbs" are among the newest developments, tend to be located farther from the urban core, have slightly higher than average elevation, and are among the most suburban and residential-dominated of all the neighborhood types. They are distinctive in this cluster for their relatively low score on the 'greenness factor' – reflecting a relatively lower proportion of green vegetation and trees than the other two types. The third neighborhood type in this category is the 'Suburban Elite' – a group with the highest SES score of any of our neighborhood types, but located at slightly lower than average elevations.

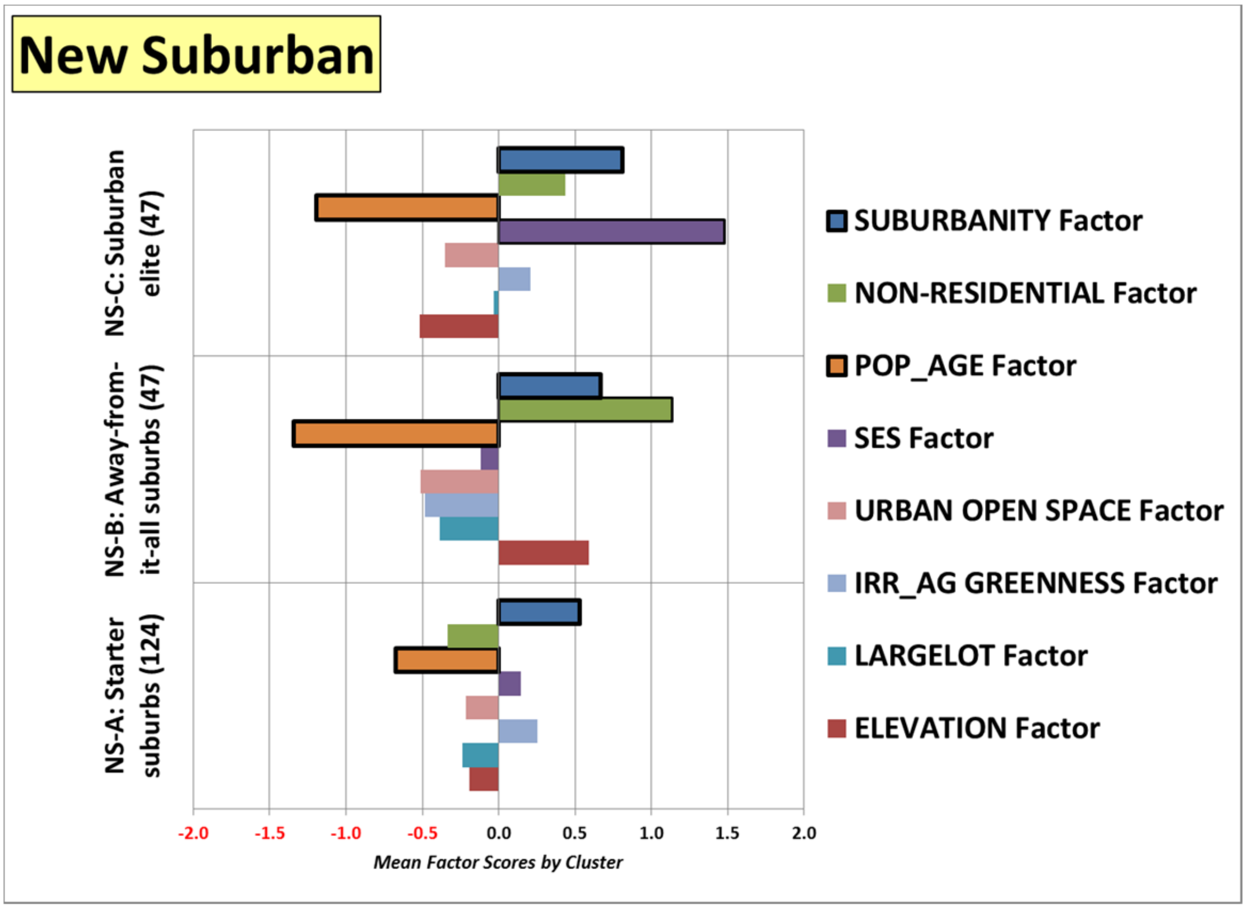
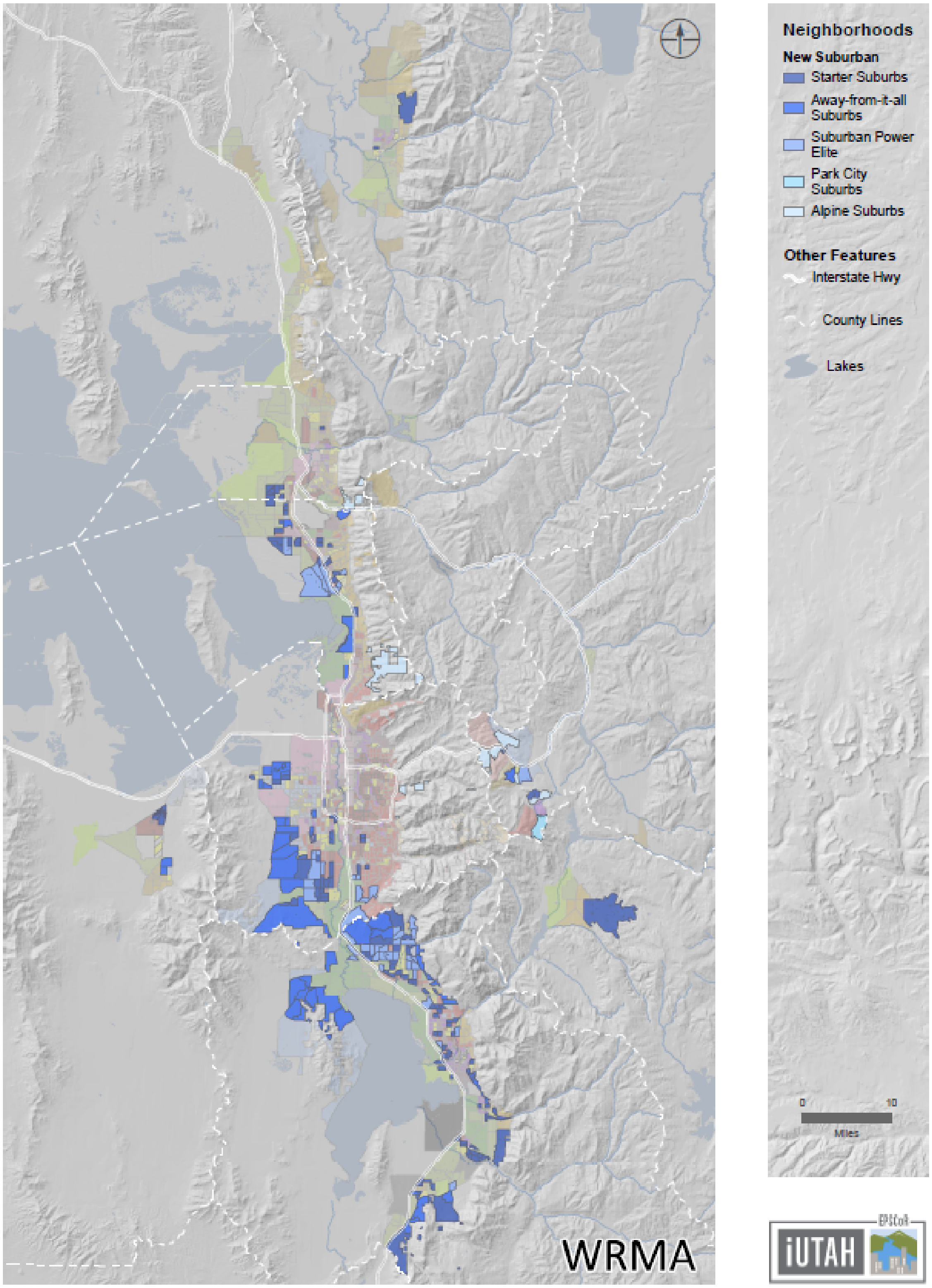


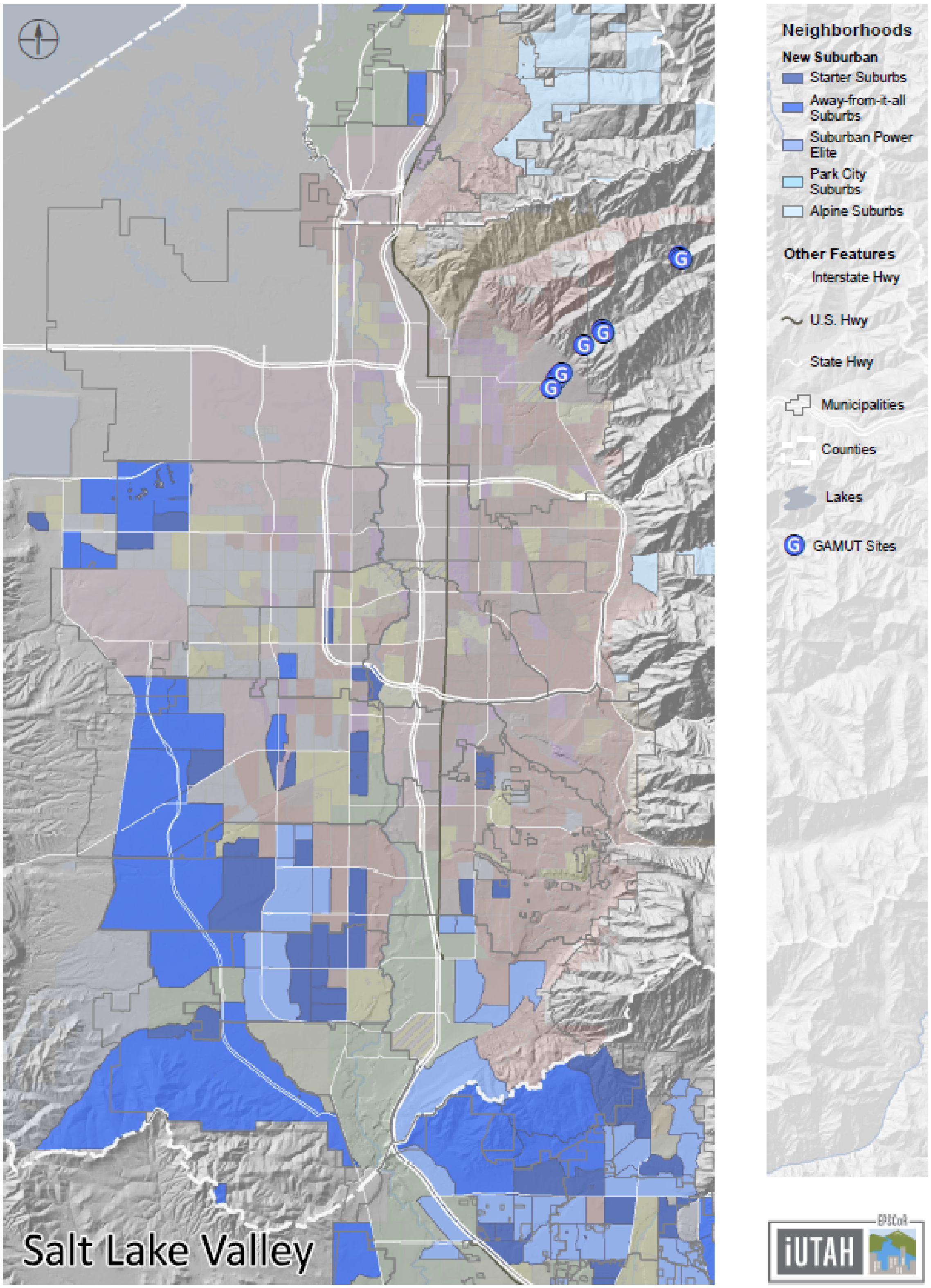
Figure 8: Mean Factor Scores for Neighborhood Types within the New Suburban major cluster group.

Maps of the distribution of census block groups in this cluster group for the WRMA, Salt Lake Valley, and iUTAH GAMUT areas are illustrated in Figures X-Y.

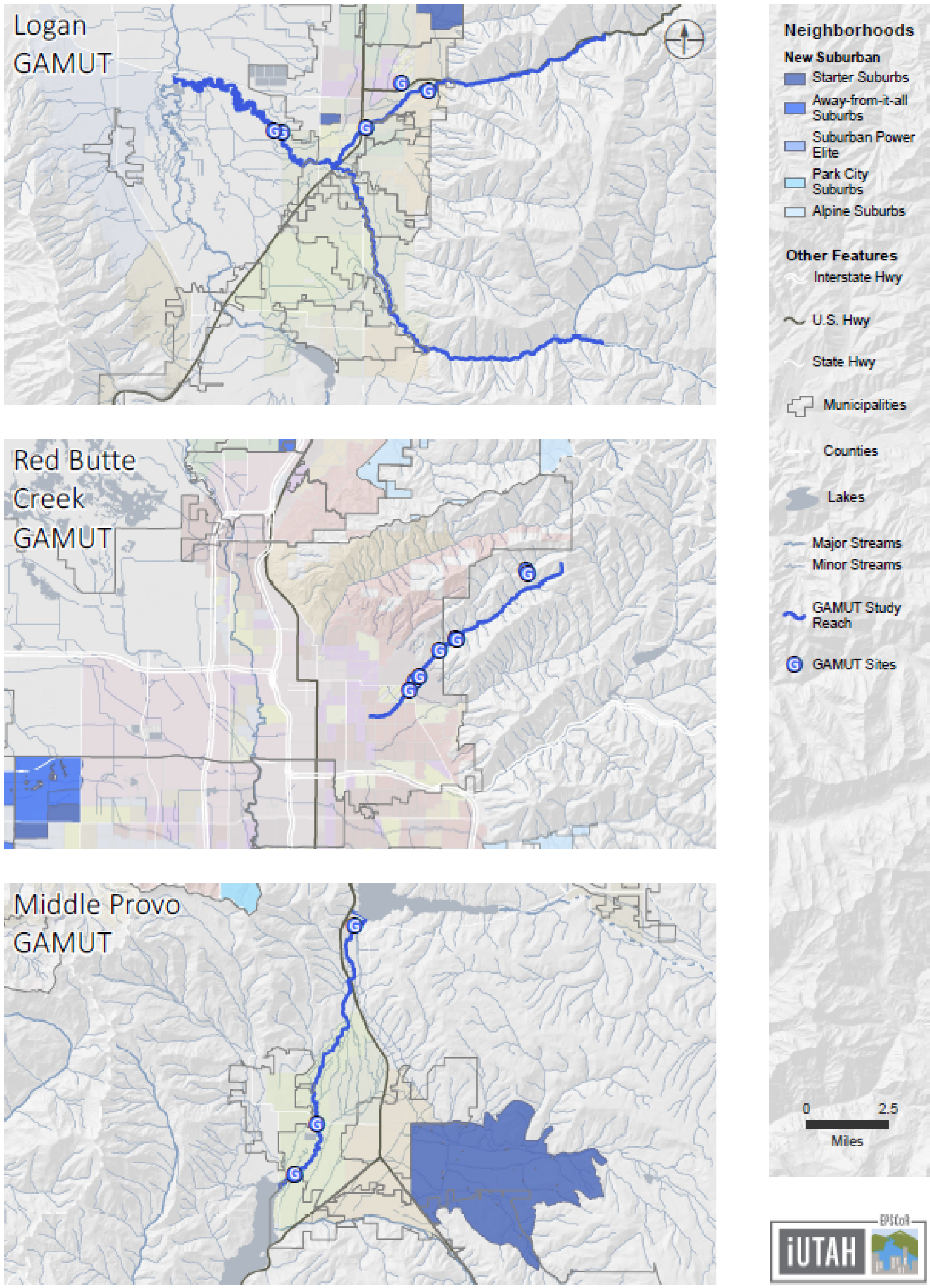
Urban Typology: New Suburban



Urban Typology: New Suburban



Urban Typology: New Suburban



CLUSTER GROUP 3: SUBURBAN WORKING CLASS

The Suburban Working Class cluster group has just one significant neighborhood type, Working Class Suburban (n=99) that is noteworthy for having a family household, single-family detached housing type, young population and housing stock, predominant residential land use, notably low levels of 'greenness' in its land cover, and moderate to low SES status (Figure X). When viewed on a map (Figures Y1-Y4), these types tend to be located …

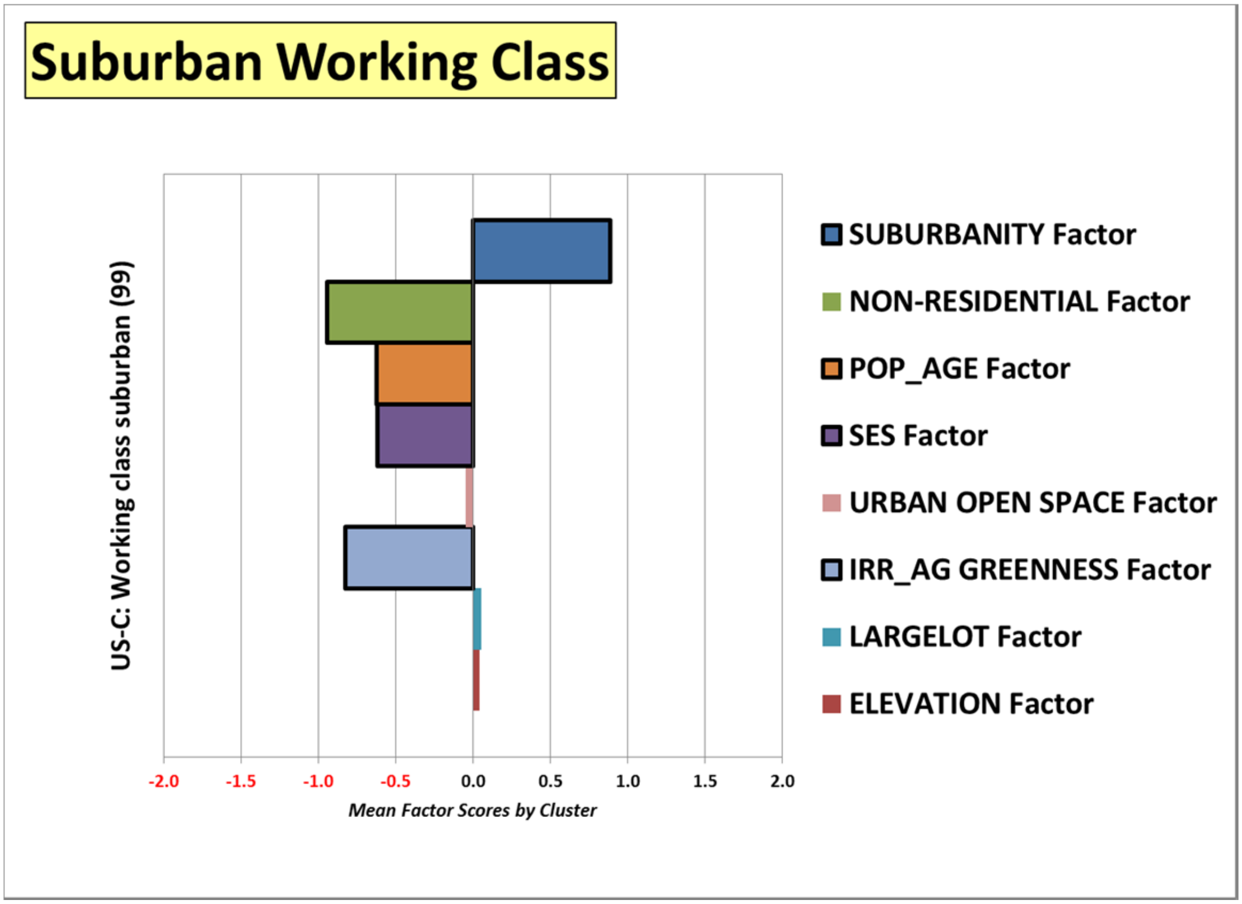
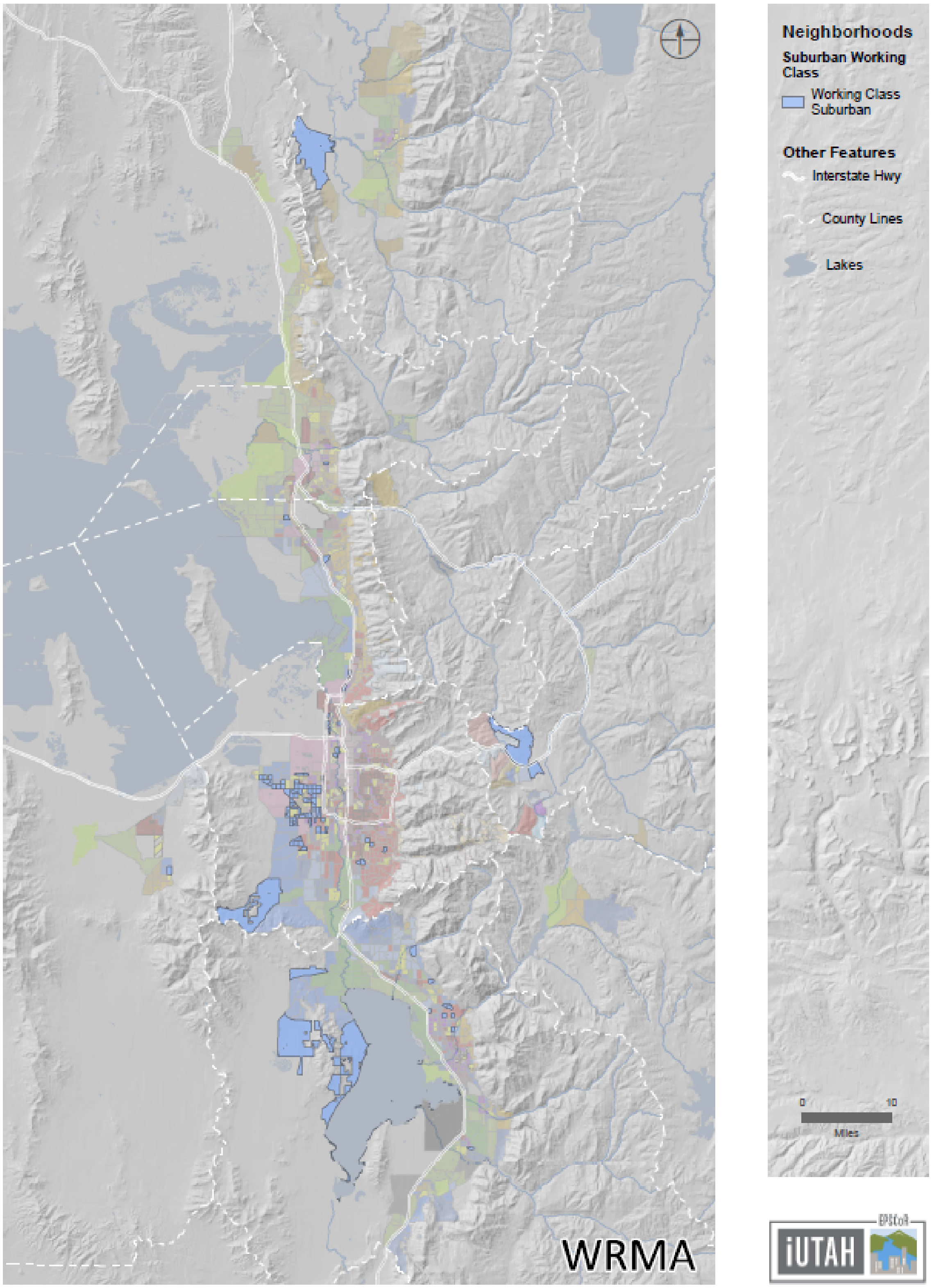


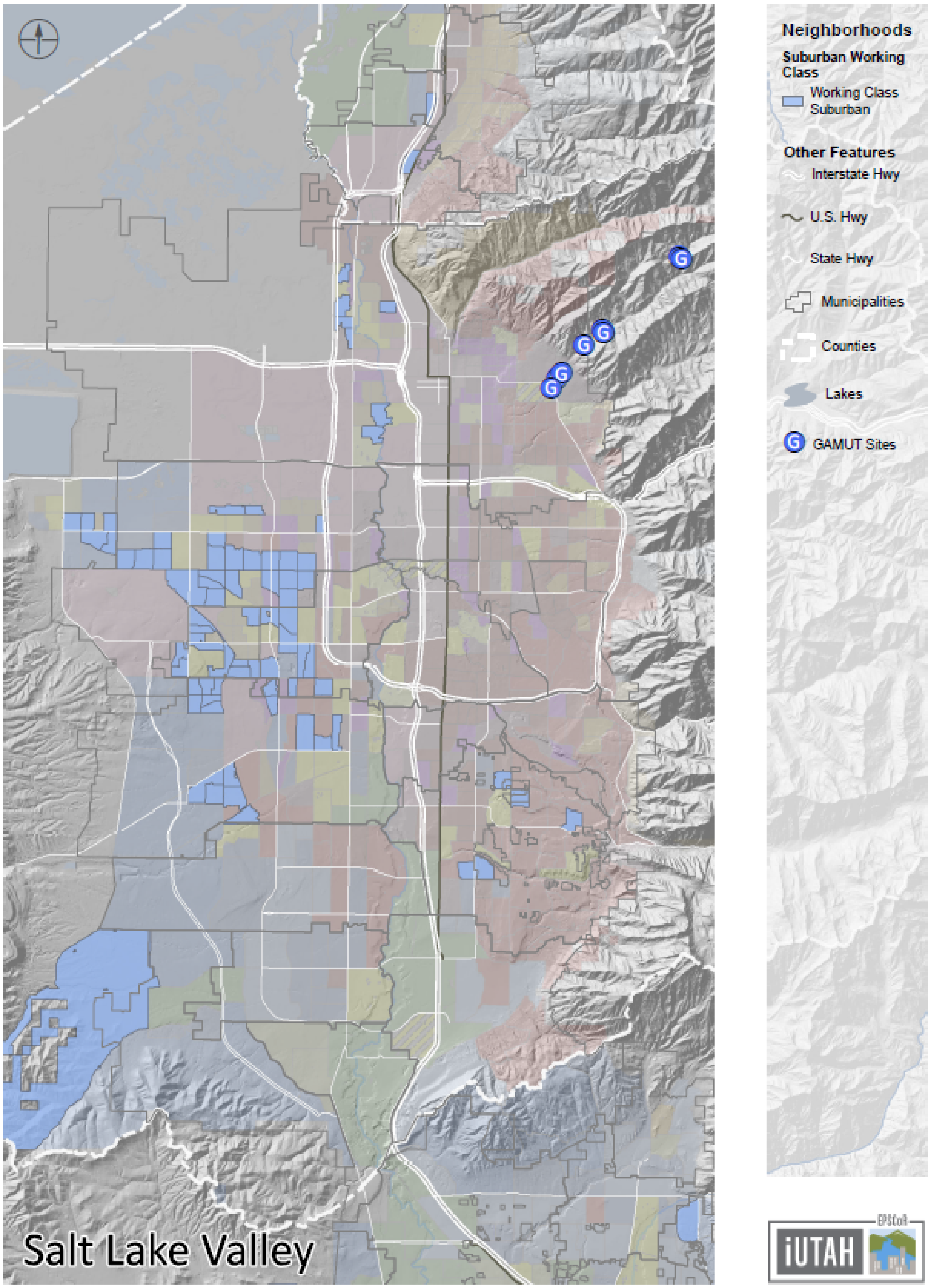
Figure 9: Mean Factor Scores for Neighborhood Types within the Suburban Working Class major cluster group.

Maps of the distribution of census block groups in this cluster group for the WRMA, Salt Lake Valley, and iUTAH GAMUT areas are illustrated in Figures X-Y.

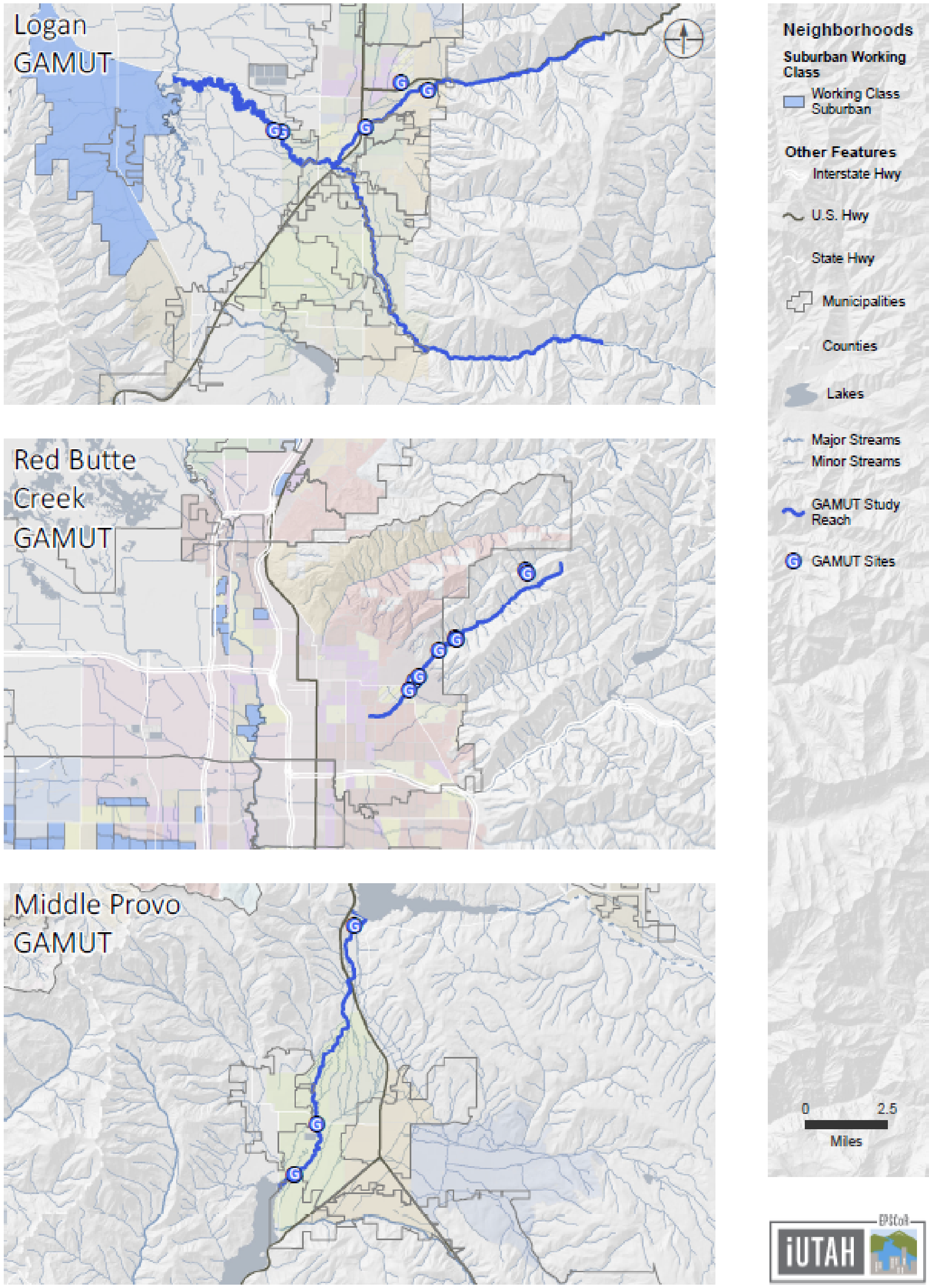
Urban Typology: Suburban Working Class



Urban Typology: Suburban Working Class



Urban Typology: Suburban Working Class



CLUSTER GROUP 4: THE MODERATE MIDDLE

The Moderate Middle cluster group of neighborhood types are all defined by having a predominance of residential land use, suburban style homes, family households, relatively older housing stock and populations, and relatively higher elevations (Figure 10). When viewed on a map (Figures Y1-Y3), these neighborhoods represent areas along the benches that have relatively average income and SES status. Within this group, the "Middle-Class with a View" neighborhood subtype (n=106) is notable for somewhat older neighborhoods in higher elevation locations with 'average' income and housing values. The other major subgroup ("Working Class Traditional"; n=112) is distinctive for significantly lower SES status and slightly lower scores on the suburban factor.

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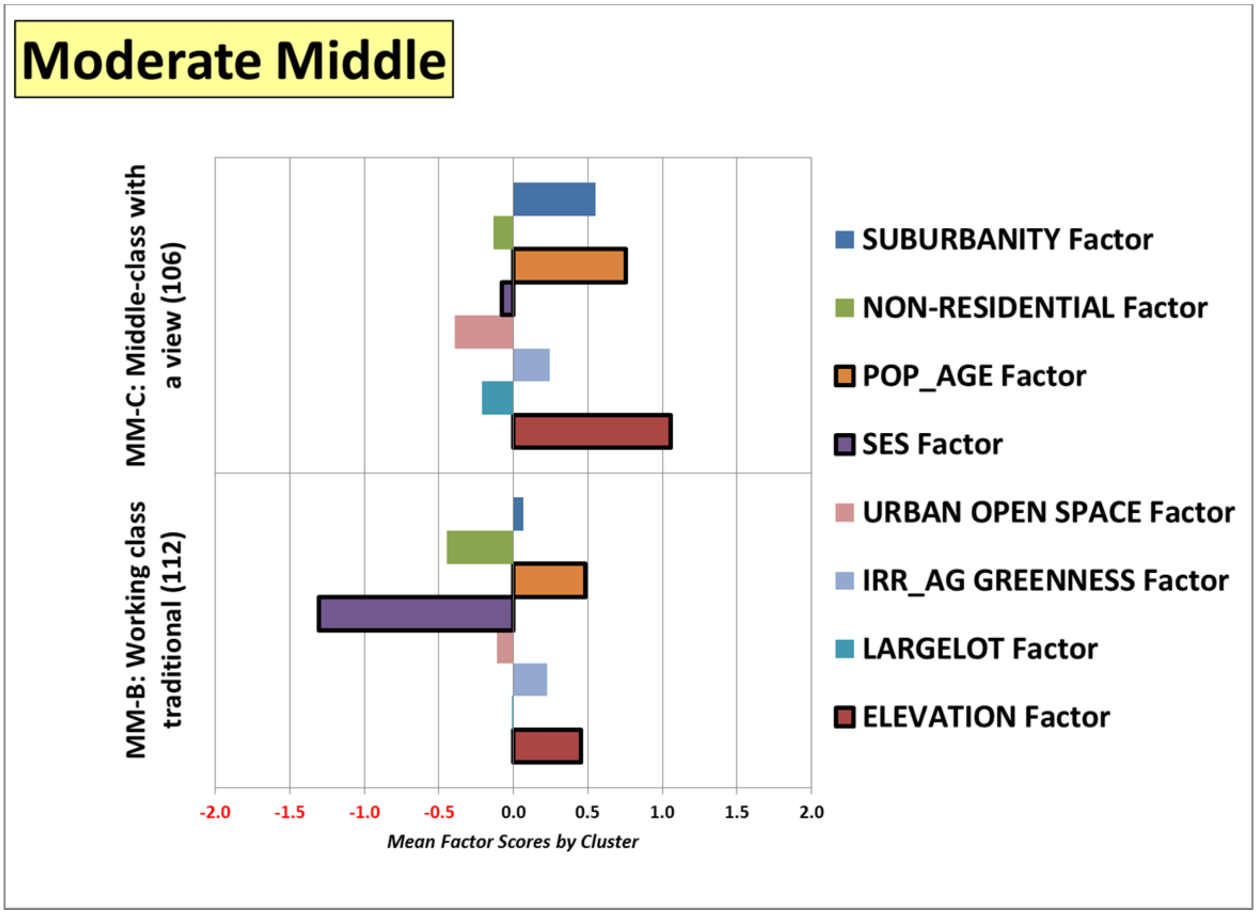
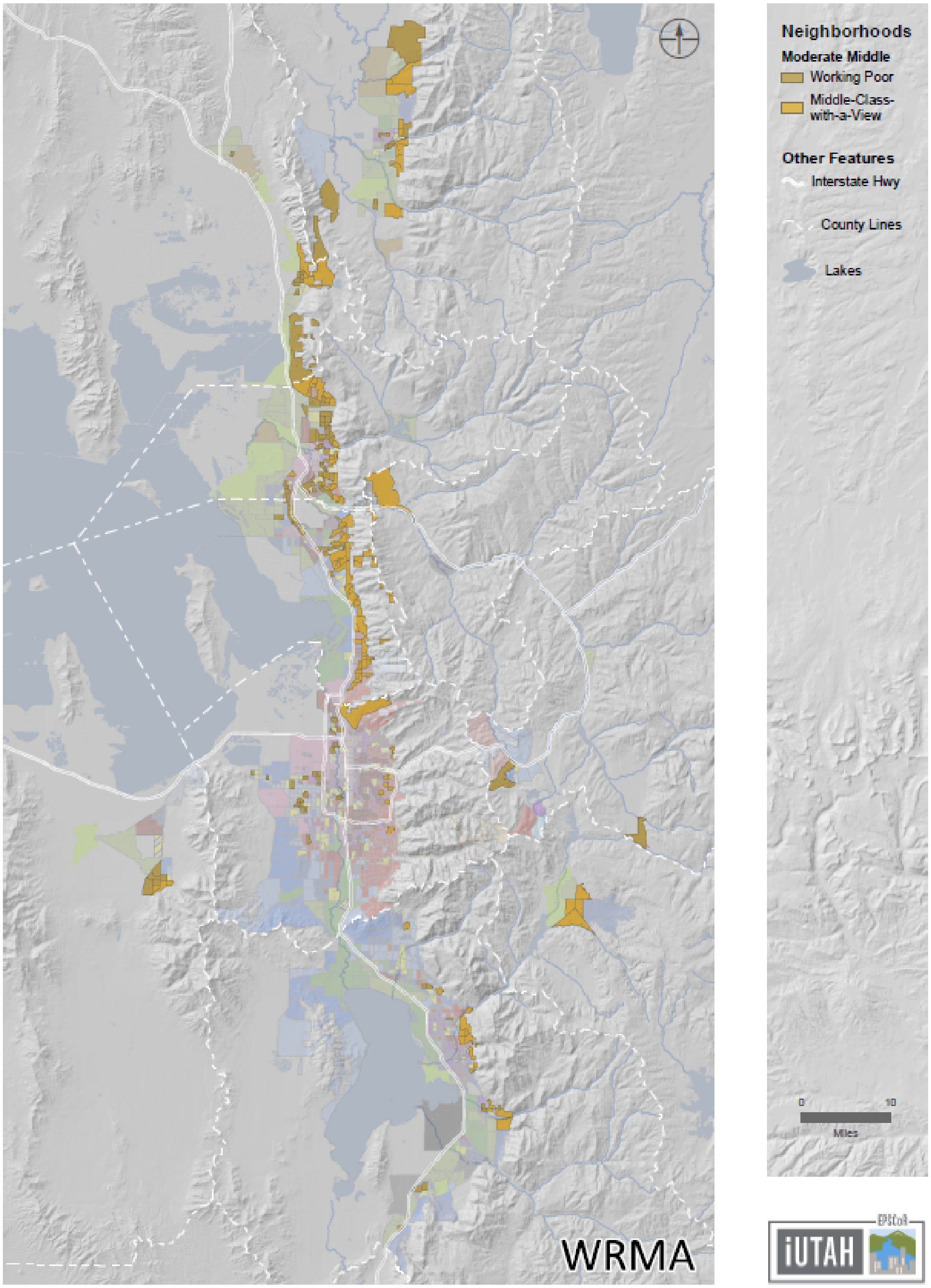


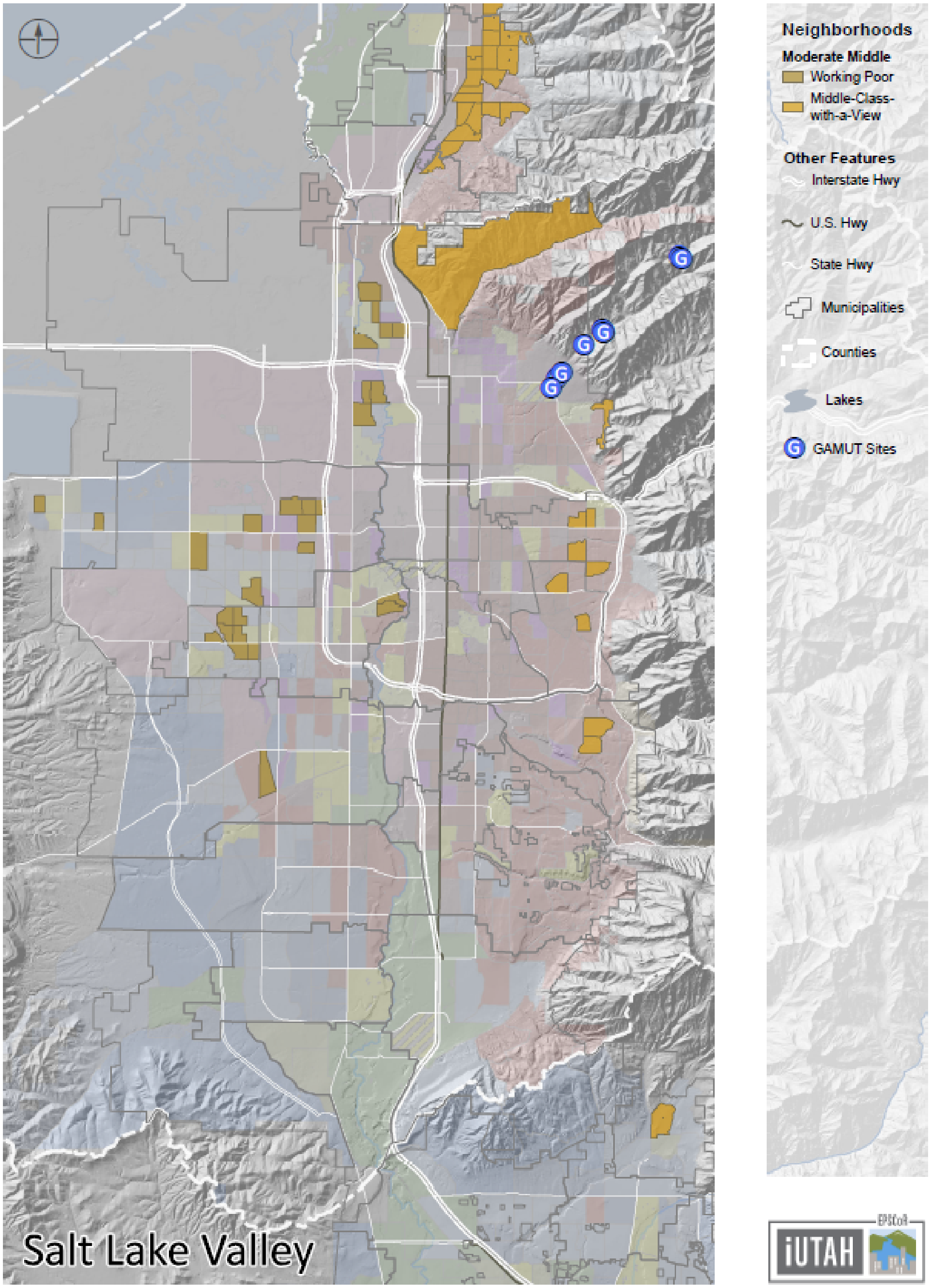
Figure10: Mean Factor Scores for Neighborhood Types within the Moderate Middle major cluster group

Maps of the distribution of census block groups in this cluster group for the WRMA, Salt Lake Valley, and iUTAH GAMUT areas are illustrated in Figures X-Y.

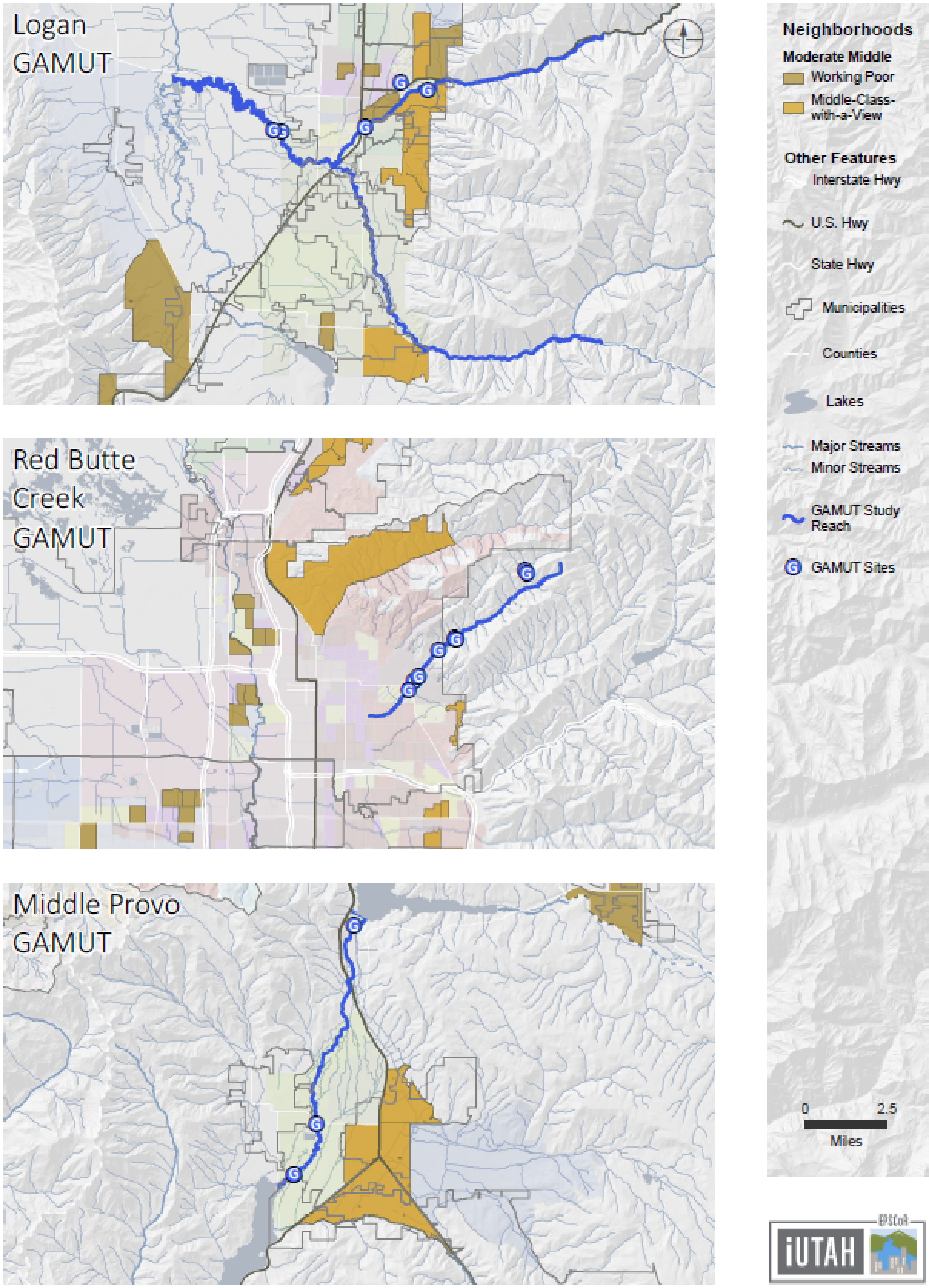
Urban Typology: Moderate Middle



Urban Typology: Moderate Middle



Urban Typology: Moderate Middle



CLUSTER GROUP 5: TRADITIONAL RESIDENTIAL CORE

The Traditional Residential Core cluster group of neighborhood types (as a group) are all characterized mostly by the older age of the housing stock, relatively small lot sizes and generally lower elevation settings. Generally speaking these represent some of the originally developed neighborhoods in Utah's urban areas. One important neighborhood type in this cluster (Traditional Upper Crust'; n=131) is notable for having unusually high SES status, a more suburban type of housing stock (perhaps because more parcels have been redeveloped), and somewhat lower levels of 'green' land cover. The other neighborhood type in this group (Original Residential) has among the oldest housing stock in the region and has a much less suburban pattern of housing and household types.

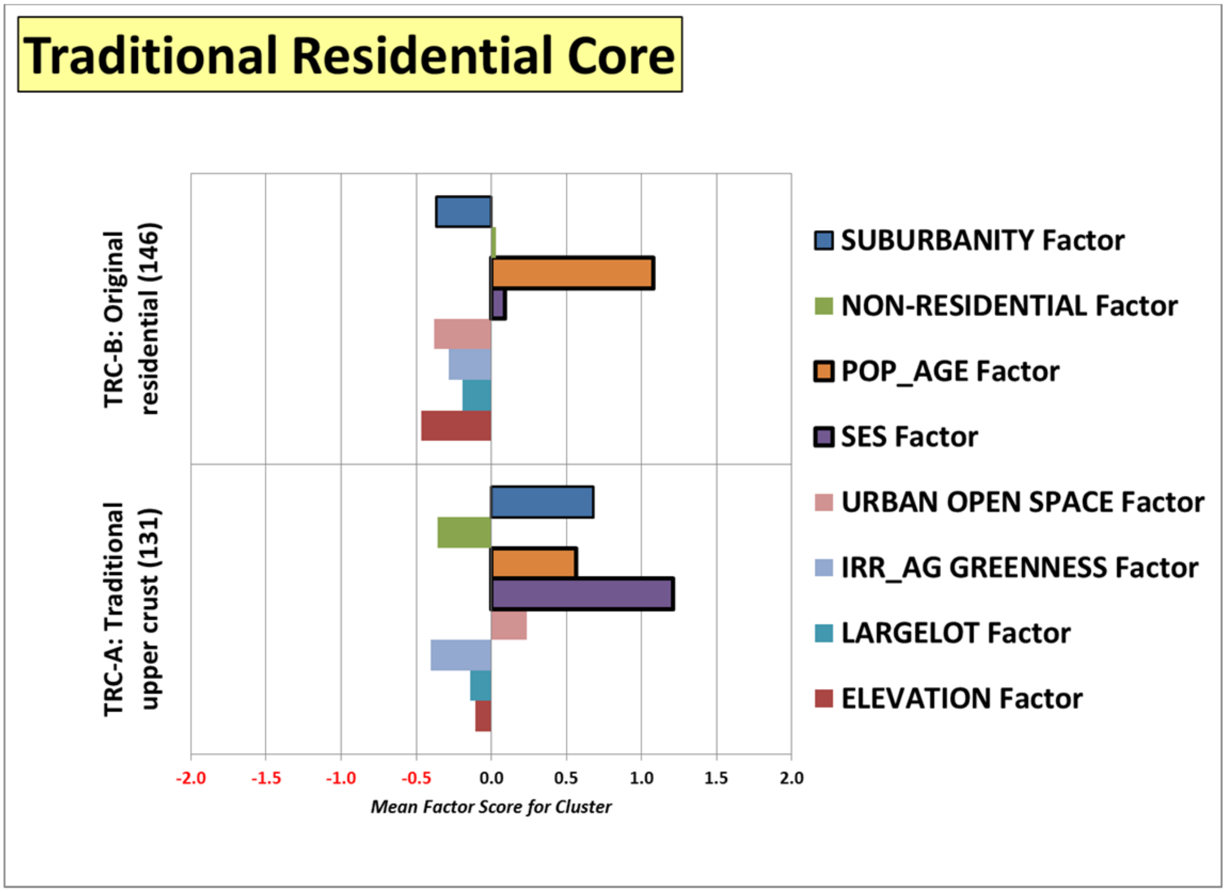
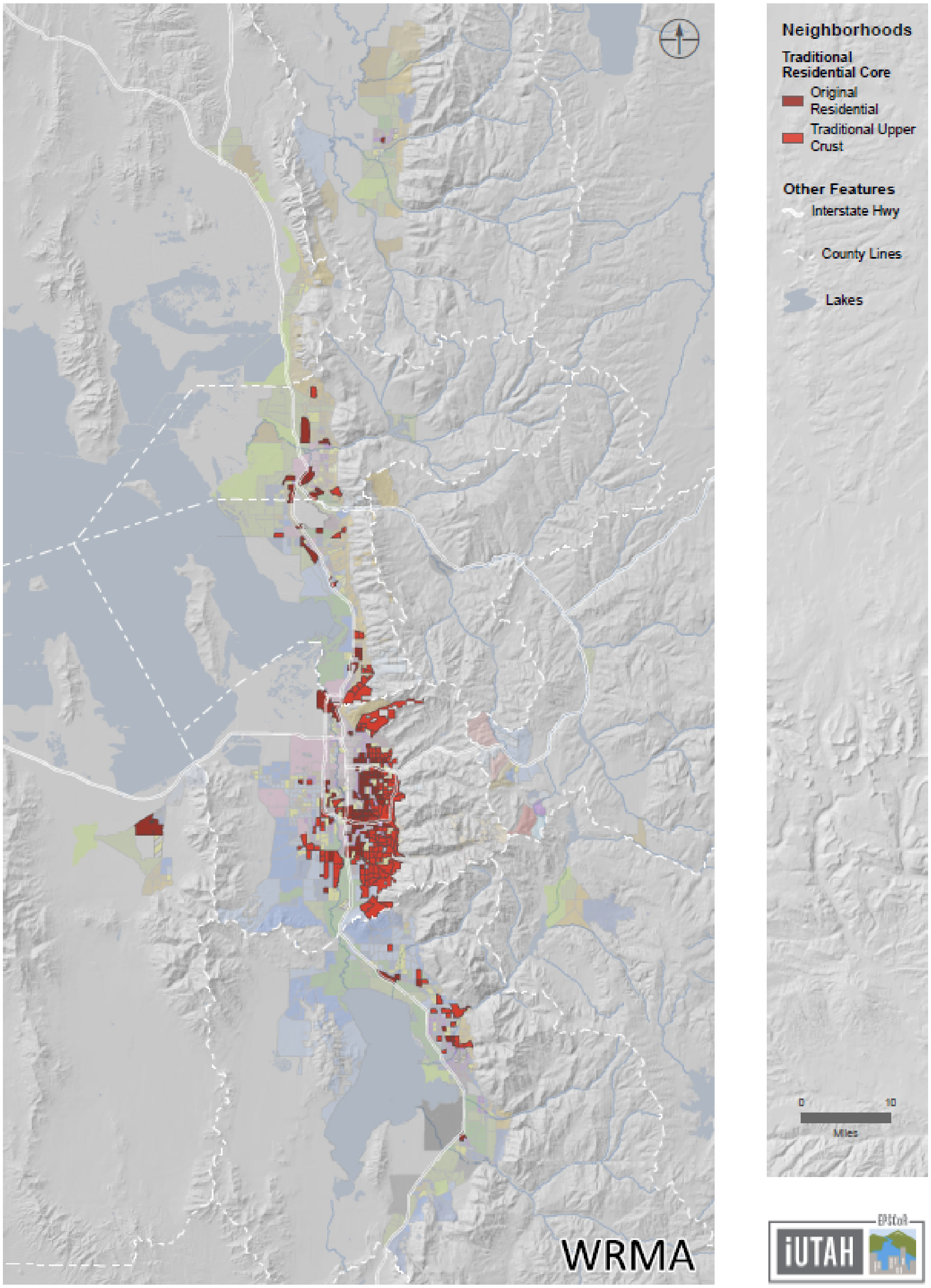


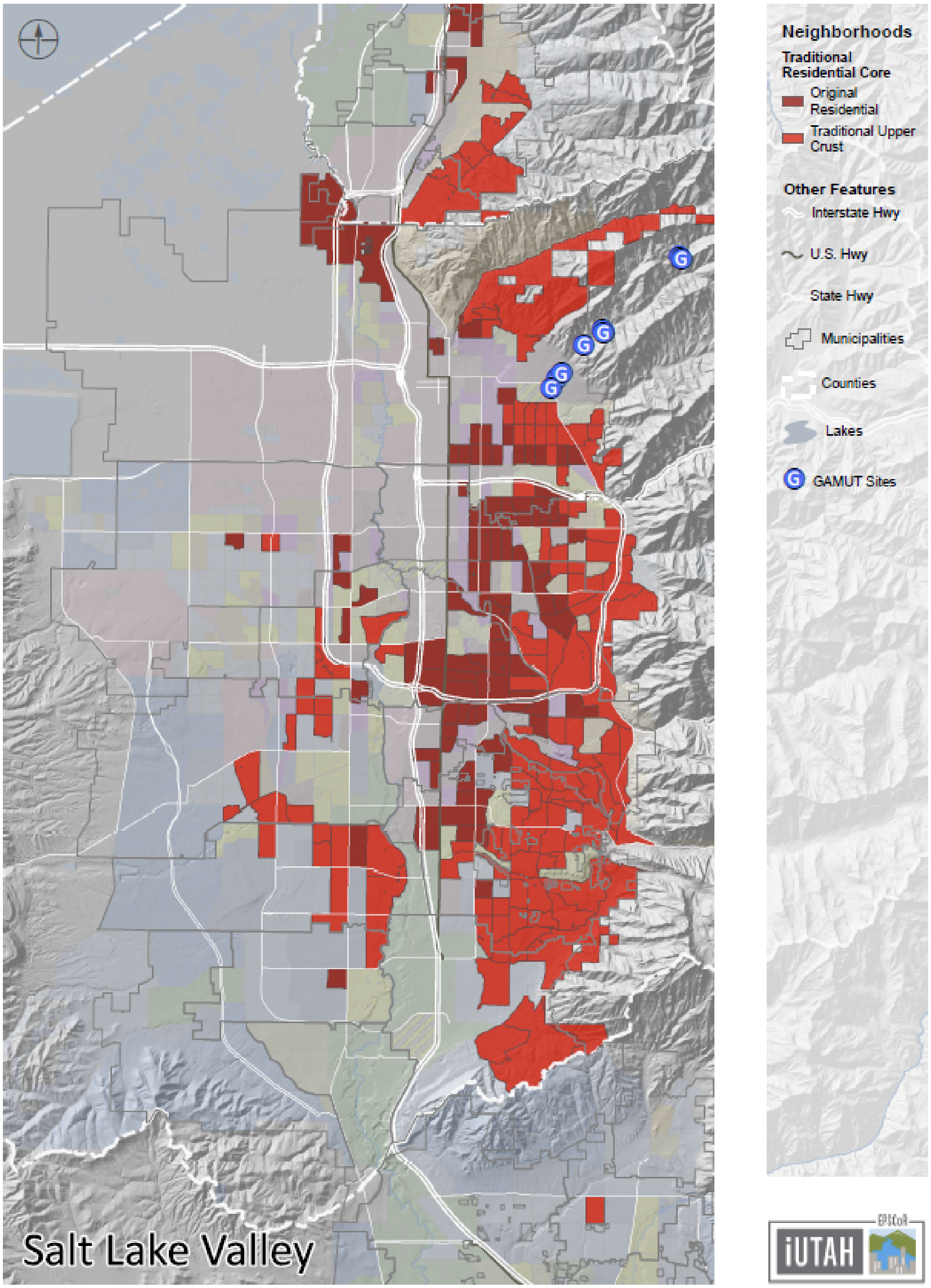
Figure 11: Mean Factor Scores for Neighborhood Types within the Traditional Residential Core major cluster group.

Maps of the distribution of census block groups in this cluster group for the WRMA, Salt Lake Valley, and iUTAH GAMUT areas are illustrated in Figures X-Y.

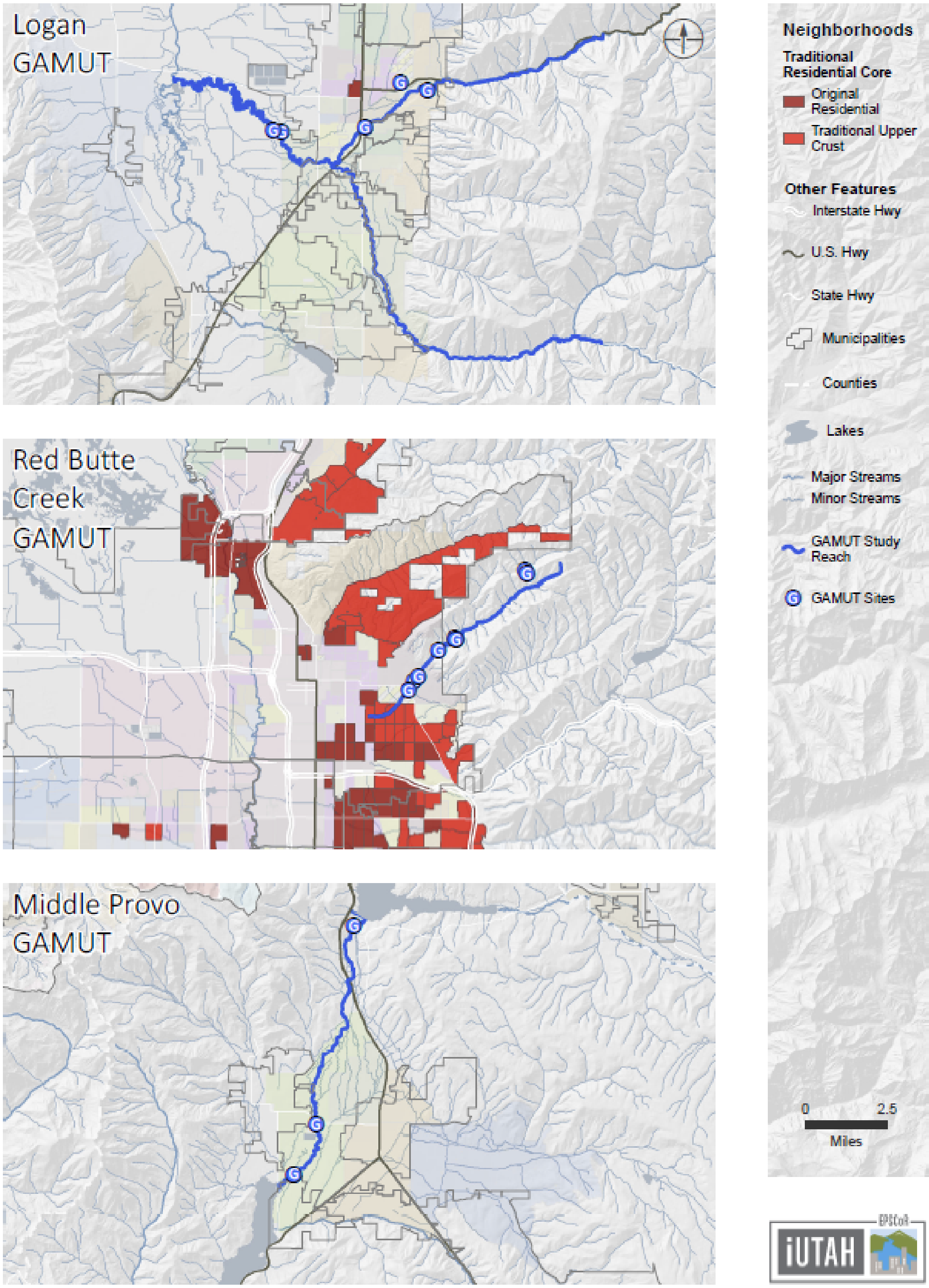
Urban Typology: Traditional Residential Core



Urban Typology: Traditional Residential Core



Urban Typology: Traditional Residential Core



CLUSTER GROUP 6: PARKSIDE RESIDENTIAL

The Parkside Residential cluster group of neighborhood types are quite clearly distinctive for being home to a significant urban park or open space. These green spaces include official parks, but also golf courses, church and school grounds, and other institutional spaces that maintain large lawns and open areas. Neighborhoods in this cluster group are not geographically concentrated, but rather scattered across most urban areas. The two main subgroups in this category are distinguished by the degree of suburban housing pattern: Neighborhood Park neighborhoods (n=70) are surrounded by newer homes in more suburban patterns, while City Park neighborhoods (n=12) tend to be characterized by older houses and diverse housing types.

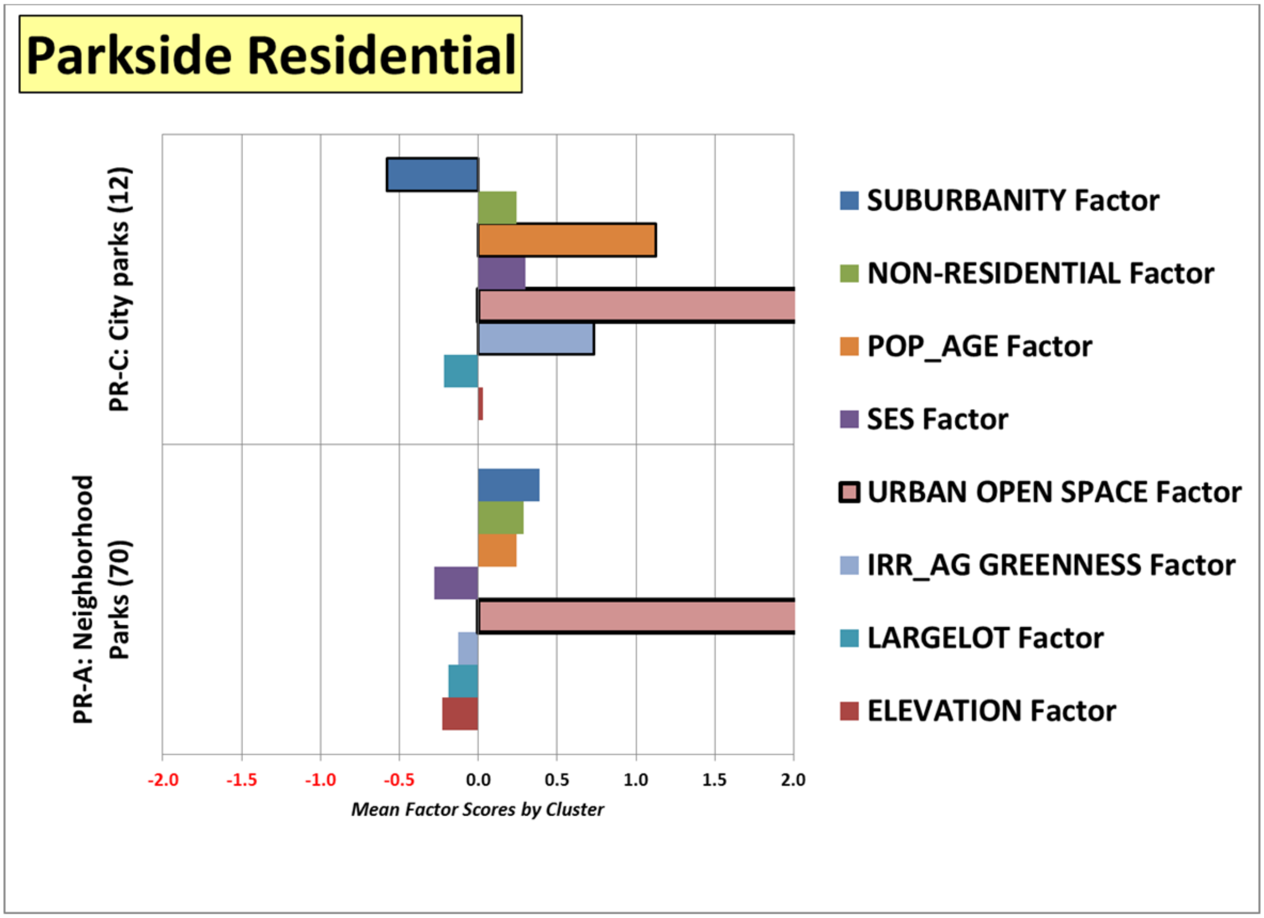
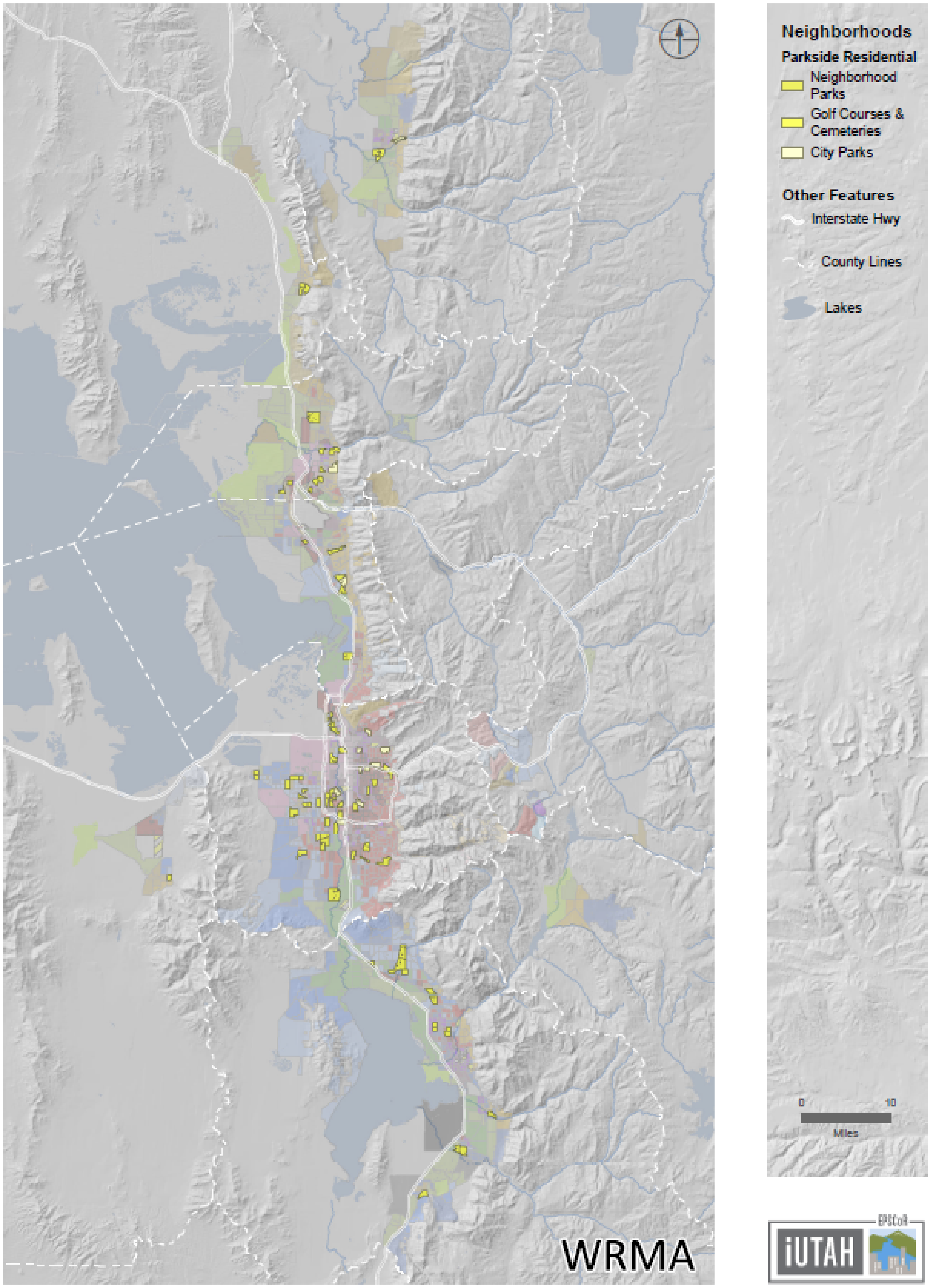


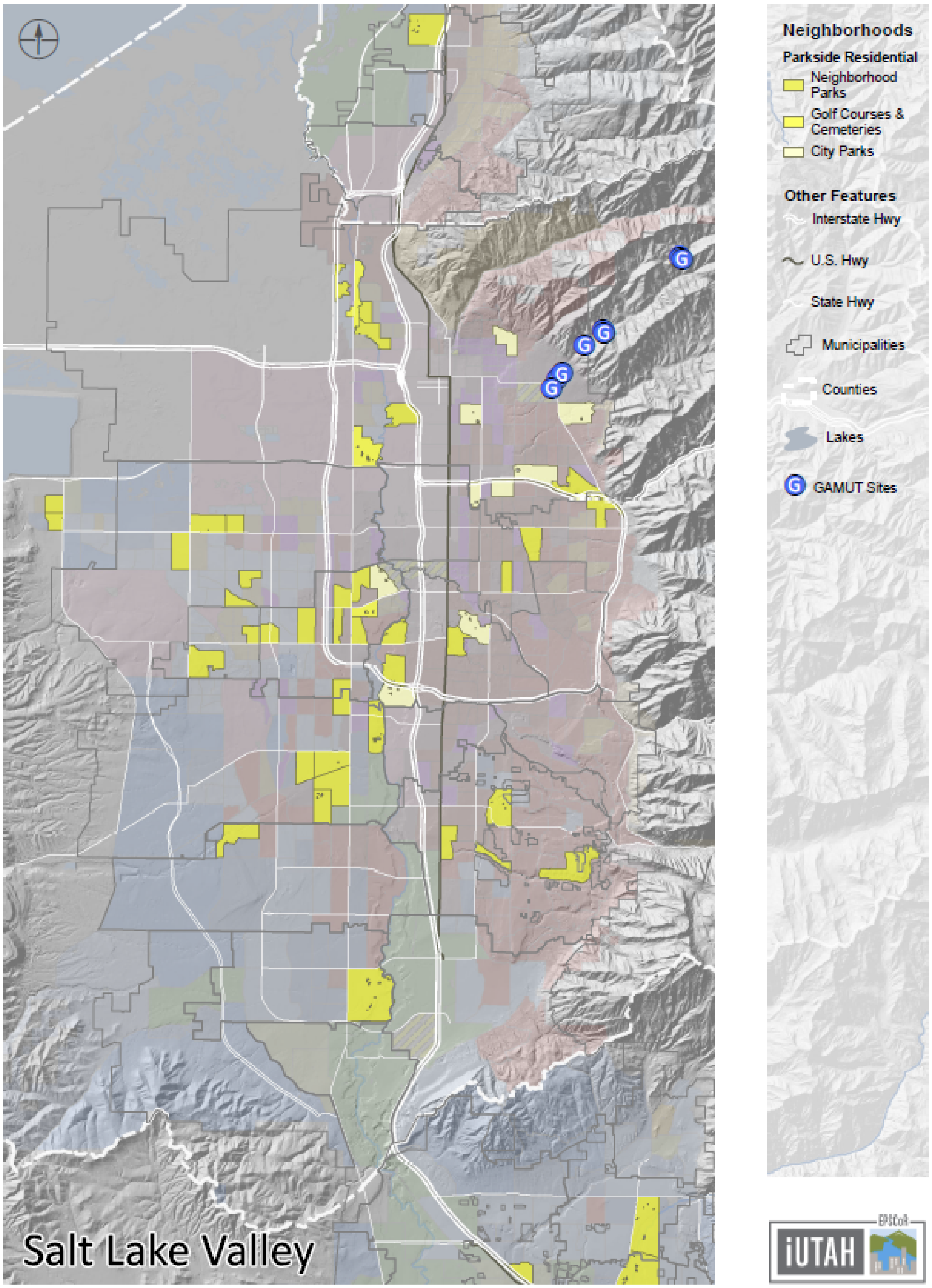
Figure 12: Mean Factor Scores for Neighborhood Types within the Parkside Residential major cluster group.

Maps of the distribution of census block groups in this cluster group for the WRMA, Salt Lake Valley, and iUTAH GAMUT areas are illustrated in Figures X-Y.

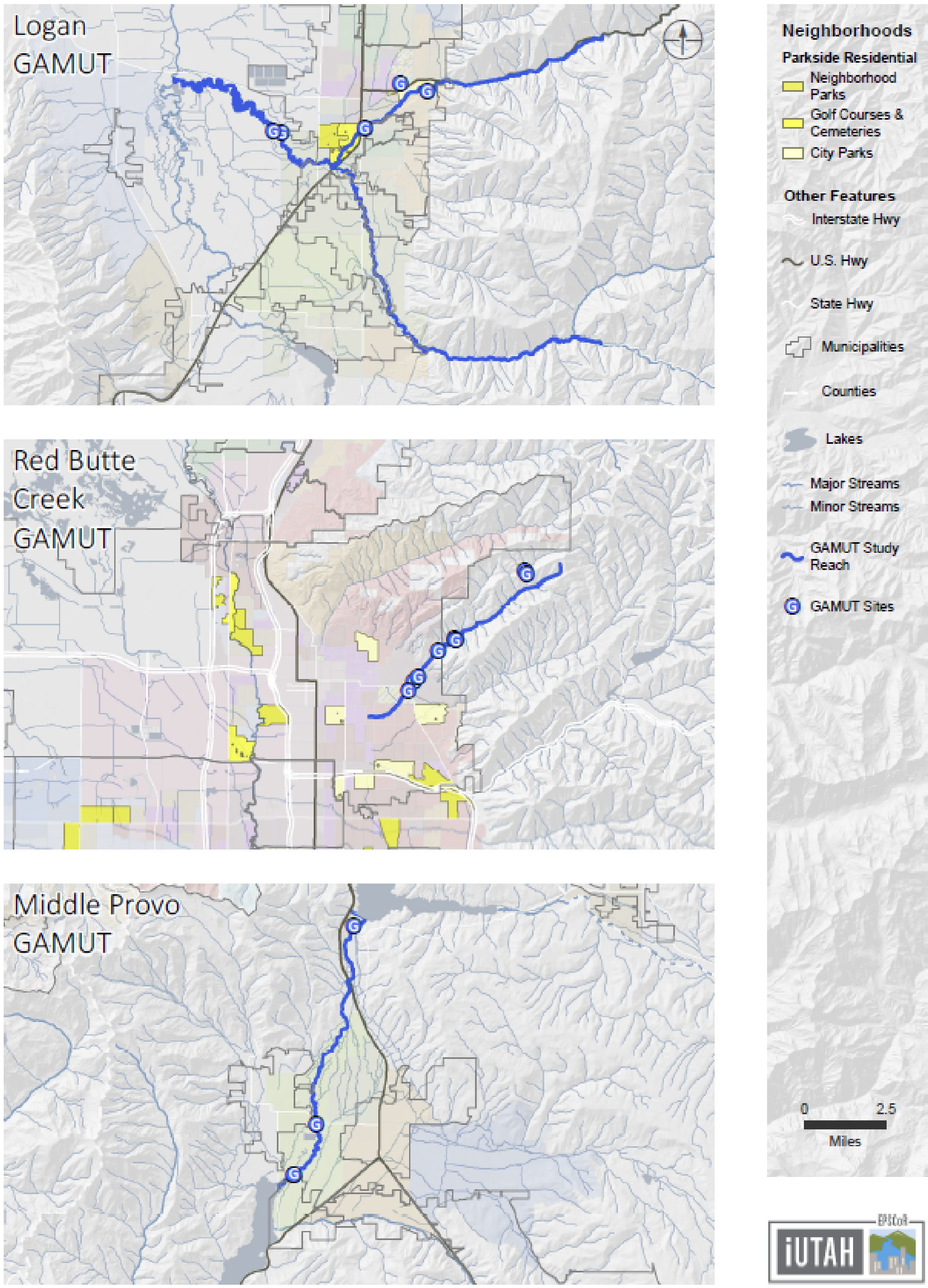
Urban Typology: Parkside Residential



Urban Typology: Parkside Residential



Urban Typology: Parkside Residential



CLUSTER GROUP 7: MIXED URBAN RESIDENTIAL

The Mixed Urban Residential cluster group of neighborhood types are notable for being dominated by residential land use, but of a decidedly non-suburban character. Neighborhoods in this group have relatively few family households, diverse housing options, and a young population. Mixed Urban Residential neighborhoods are also scattered across much of the WRMA, with few large aggregations of this type in any one area. The two main neighborhood types in this group are distinguished by their SES status, with Working Class Mixed (n=70) tending to have relatively low income and SES status, while the Wasatch Bohemians are one of the wealthier and less racially mixed neighborhood types.

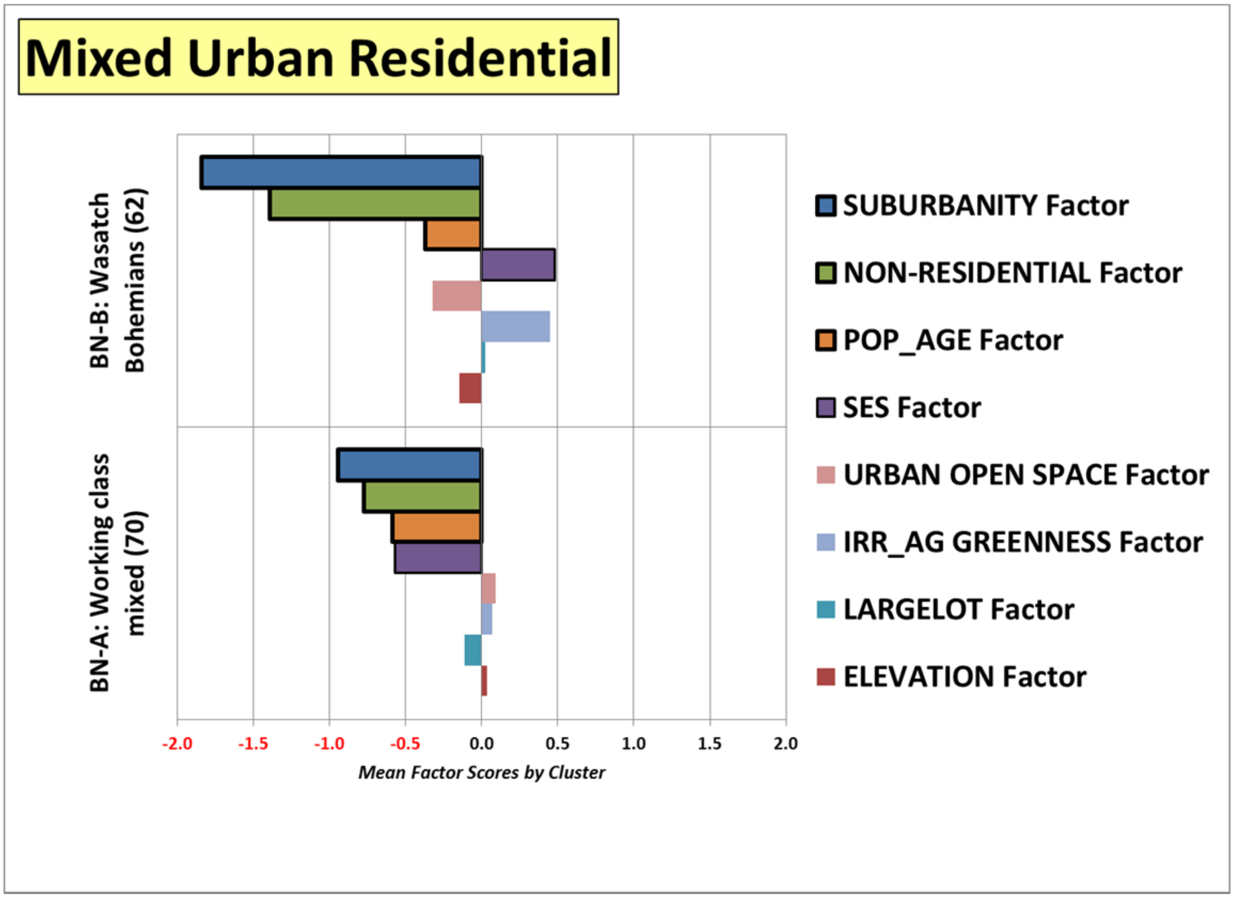
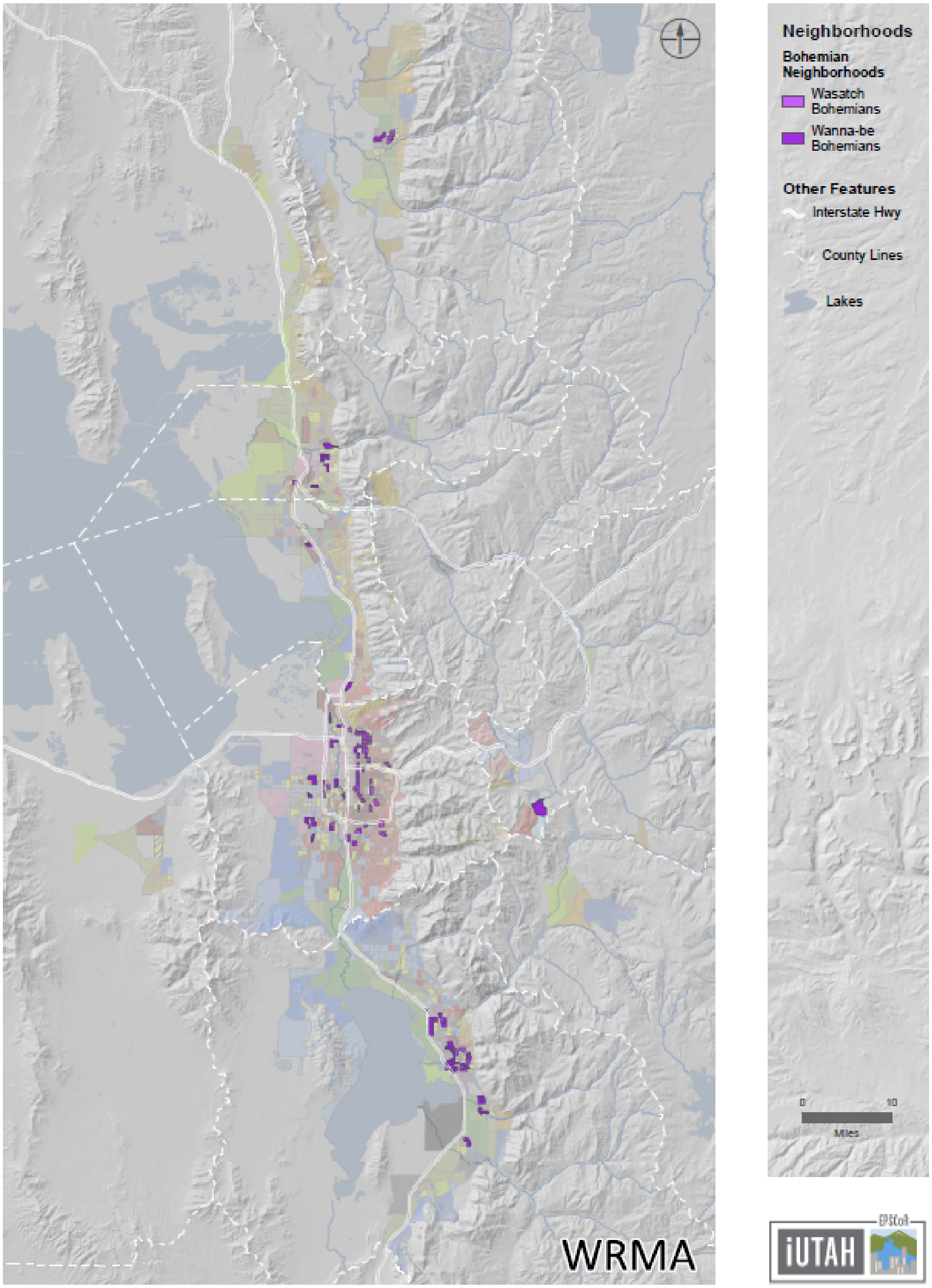


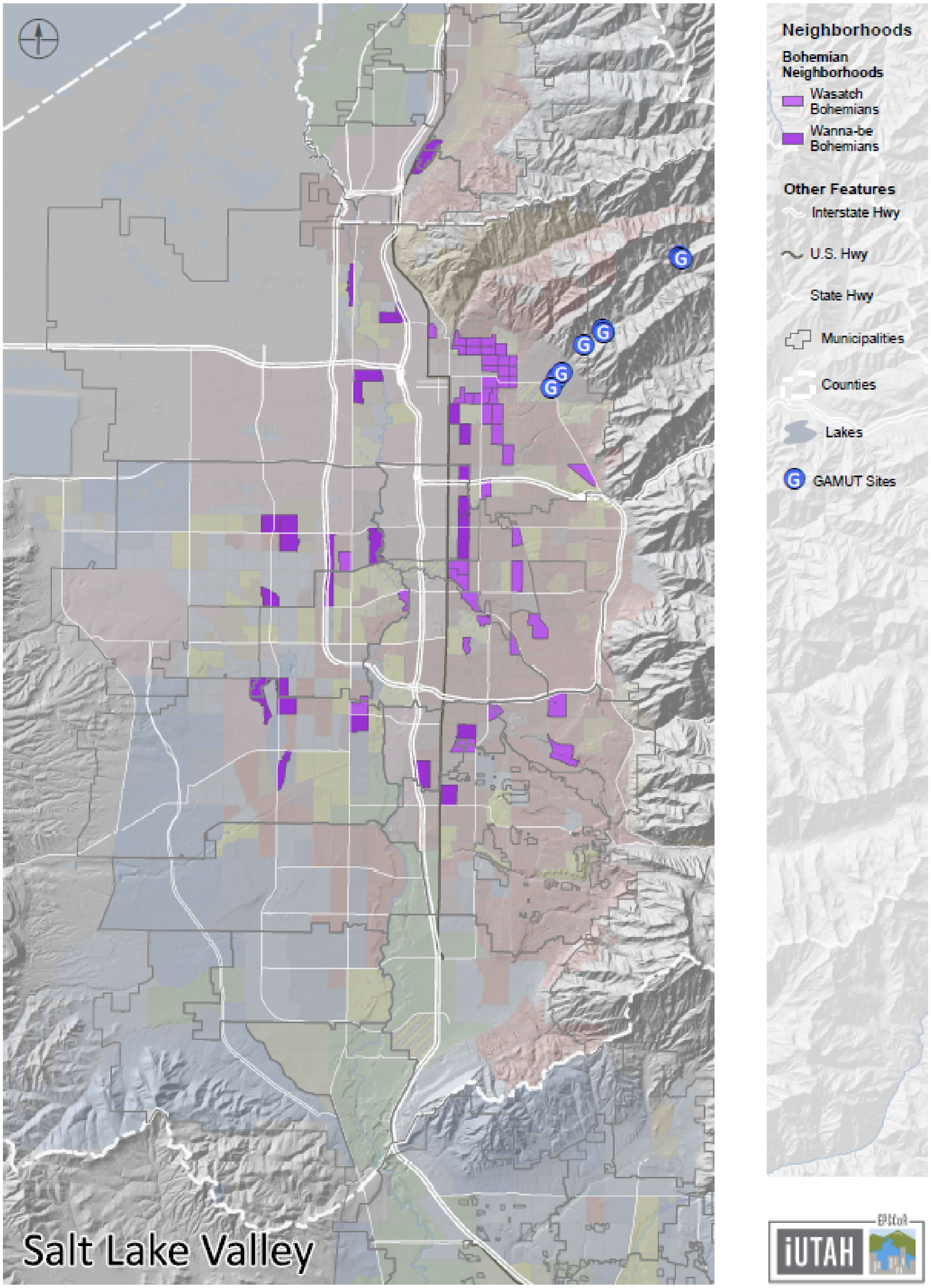
Figure 13: Mean Factor Scores for Neighborhood Types within the Mixed Urban Residential major cluster group.

Maps of the distribution of census block groups in this cluster group for the WRMA, Salt Lake Valley, and iUTAH GAMUT areas are illustrated in Figures X-Y.

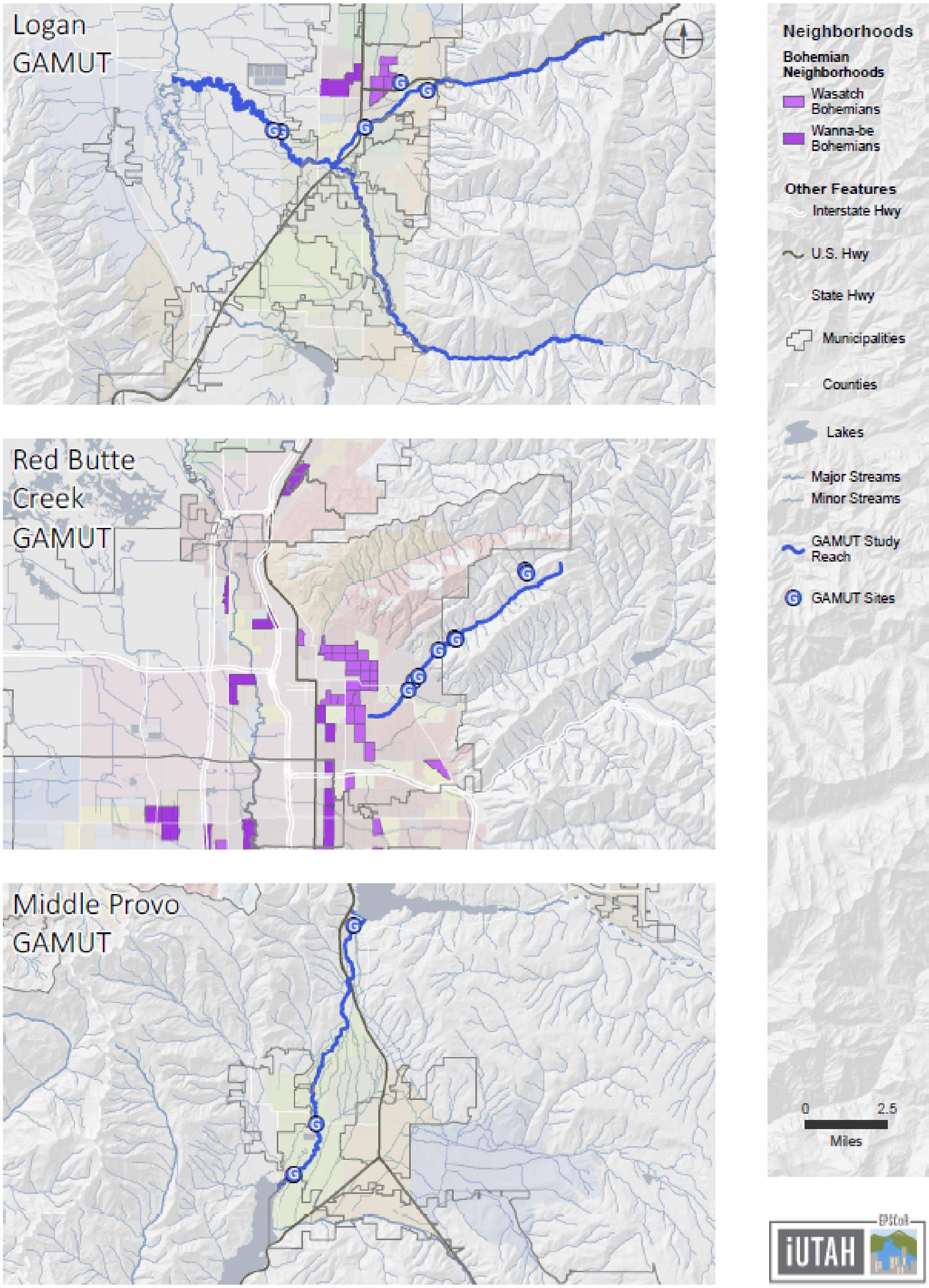
Urban Typology: Bohemian Neighborhoods



Urban Typology: Bohemian Neighborhoods



Urban Typology: Bohemian Neighborhoods



CLUSTER GROUP 8: THE URBAN SCENE

The Urban Scene cluster group of neighborhood types are defined by their location in the urban core of WRMA cities, with a high level of land use diversity, large amounts of commercial-industrial land use, mixed housing types, and relatively low levels of green landcover.

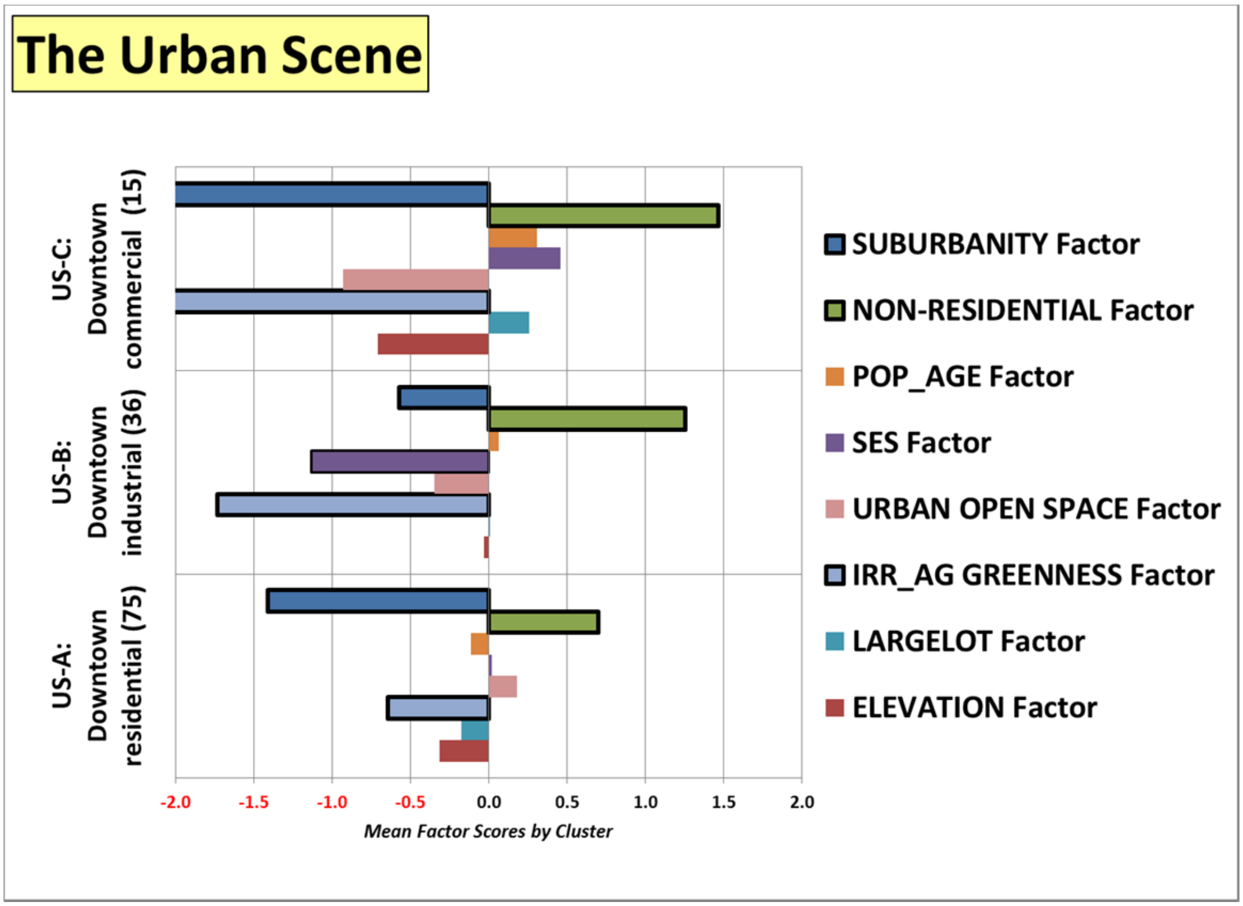
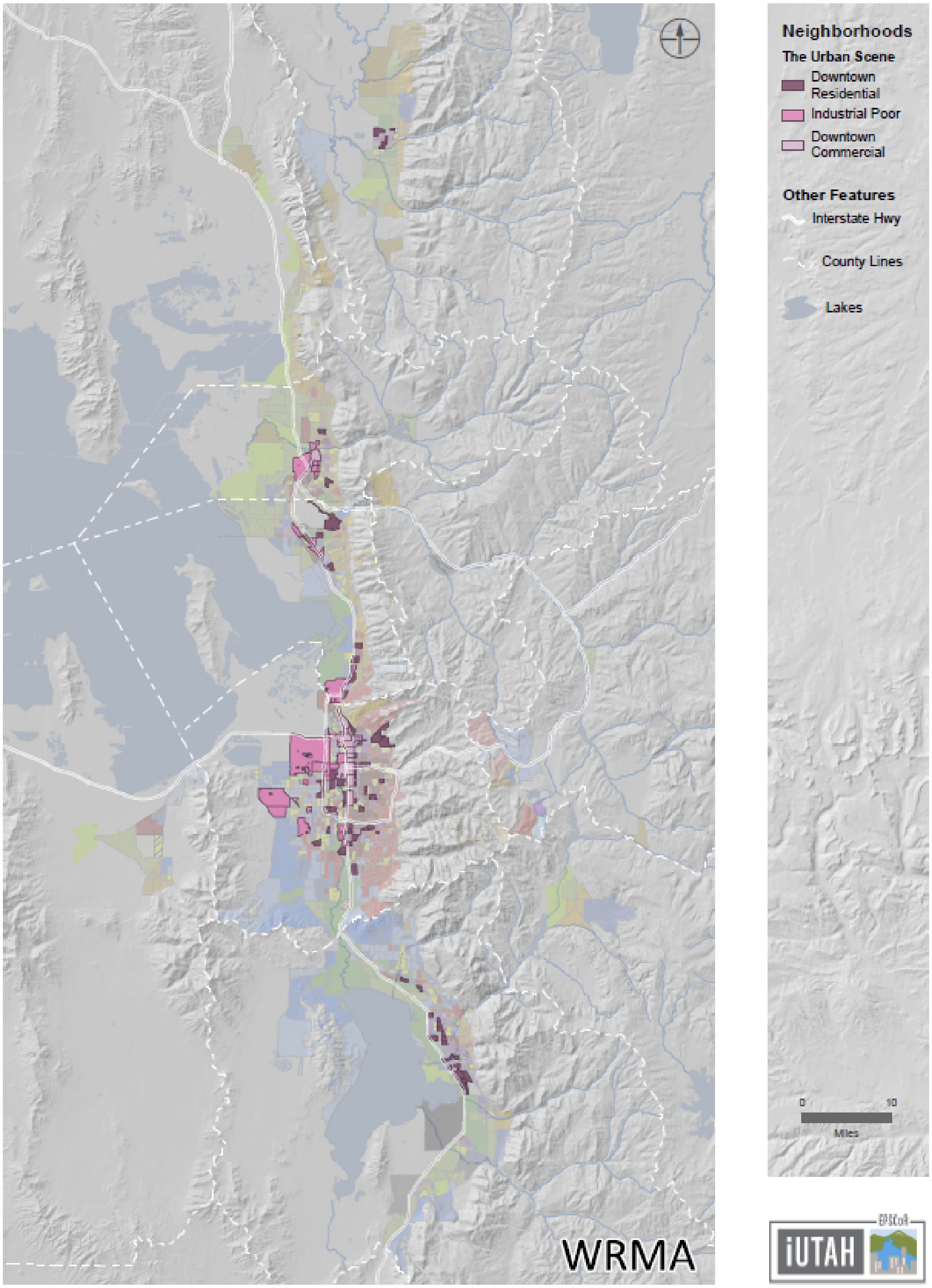


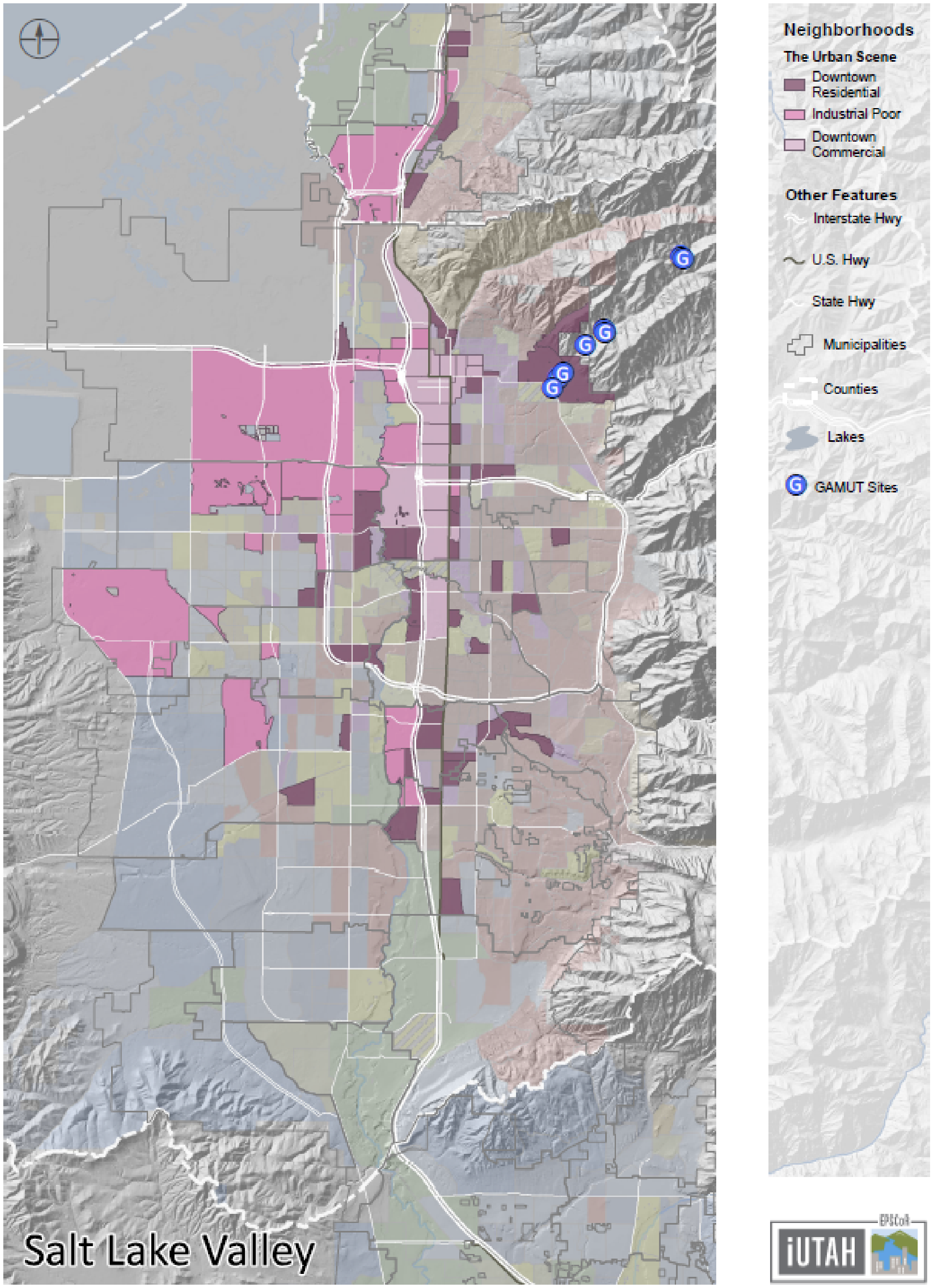
Figure 14: Mean Factor Scores for Neighborhood Types within the Urban Scene major cluster group.

Maps of the distribution of census block groups in this cluster group for the WRMA, Salt Lake Valley, and iUTAH GAMUT areas are illustrated in Figures X-Y.

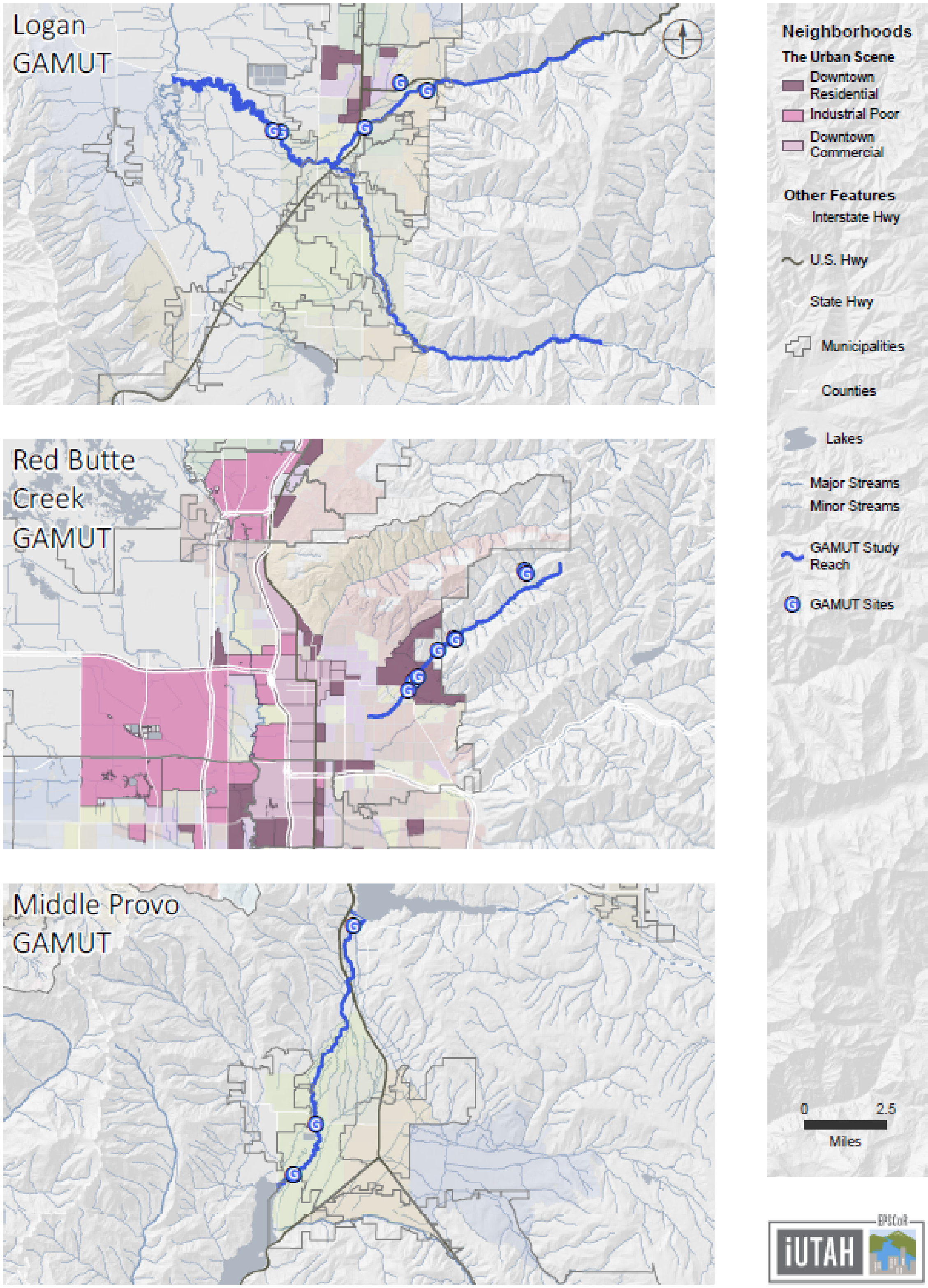
Urban Typology: The Urban Scene



Urban Typology: The Urban Scene



Urban Typology: The Urban Scene



Discussion and Conclusions

In this paper, we developed a neighborhood typology based on characteristics of socio-ecohydrologic measures. Neighborhoods were defined as census block groups (CBGs) because the U.S. Census designates CBGs as approximate neighborhoods, and data availability was sufficient at the CBG level. To guide our research, we asked which variables represented meaningful and measurable expressions of the diverse ways humans occupy landscapes? We collected 48 variables (Table X) that represented land cover, land use, the built environment, household structure, socioeconomic status, water infrastructure, policy, and climate characteristics the neighborhoods. We used these variables to conduct a factor analysis to identify variables that were closely correlated to each other. This analysis resulted in eight factors: housing mix-suburban, elevation, land use mix-non-residential, socioeconomic status (SES), lower density, population age, irrigated agriculture/greenness, urban parks/open space, and mobile homes. A neighborhood's factor scores described the character of the neighborhood. For example, neighborhoods that scored high on the land use mix-suburban factor had a high percentage of housing units that were detached single family homes, and had a high percentage of housing units that were family households.

We then asked if a typology can be developed that would reflect distinct measurable attributes that link urban characteristics and water system outcomes. While we successfully developed a typology to group similar neighborhoods together, and to separate dissimilar neighborhoods, our question remains unanswered. The typology is based on a hierarchical cluster analysis of all CBGs based on their eight factor. We identified eight distinctive clusters and 22 individual subcluster types. Each type was labelled based on our interpretation of the factor scores (Table X) and the results indicate that the major clusters represents between 6-21% of the population and 2-27% of the land area in the urban WRMA. However, we have not yet examined the links between our typology classification and water system outcomes.

Our third research question also remains unanswered. We asked if the statistically produced typology fits with local understandings of neighborhood boundaries. Throughout the process the authors used intuition and expert judgment to ensure that the typology classifications were reflecting with their perceptions of familiar neighborhoods. However, no effort was made to test whether the neighborhood classification fit with the public's perceptions of neighborhood boundaries and characteristics. This remains as a future task.

However, we can conclude that we identified statistically distinct clusters of urban neighborhoods. For example, our mature homesteaders cluster differs significantly from our downtown commercial cluster in regard to the suburban factor. Other statistically significant differences between typology groups exist for each of the factor scores. Our use of hierarchical cluster analysis ensured that our clusters were similar within clusters and different as possible between clusters. This strategy has been employed by other researchers seeking to identify similar and dissimilar neighborhoods (Shay and Khattak 2007).

The neighborhood typology now provides a formal basis for future research. As mentioned earlier, the work reported here will be a fundamental building block of a larger NSF-funded project that will install and implement human and research infrastructure. This typology can guide the selection of neighborhoods for future research. For example, researchers can select neighborhoods examine differences in hydrological outcomes. Do the “Working Class Traditional neighborhoods” use less water than the “Working Class Mixed” neighborhoods? Does stormwater runoff differ between “suburban elite” and “starter suburbs”? Questions like these can now be answered by researchers, and this typology provides justification for a formal basis for selecting different neighborhoods.

Our research is methodologically similar to other research that developed a typology for neighborhoods (Chow 1998; Shay and Khattak 2007), but is the first to develop a neighborhood typology based on land cover, land use, built environment, housing, and demographic characteristics that likely have hydrologic outcomes. Almost all of the variables that we collected for our analysis can be easily obtained across the U.S., and this methodology can be replicated in other metropolitan regions.

We note the following limitations to our study. First, this is a cross-sectional research design and therefore our typology cannot establish causality between neighborhood characteristics and water system outcomes. The typology can establish correlation or relationships, but causality will remain elusive in the absence of experimentation. Secondly, this typology is not externally valid. Our typology types are appropriate for the WRMA, and likely not appropriate for other metropolitan regions. The methodology we used can be employed in other regions in order to tailor the typology to a specific region. The more replications of this work, the more the external validity will improve. Third, our selection of CBGs as a unit of analysis may artificial bias the boundaries of “true” neighborhoods. For example, the boundaries of a neighborhood from a resident’s perspective may not align with the boundaries designated by the Census Bureau. Defining neighborhood boundaries has challenged researchers for years (Hawley and Duncan 1957), and we addressed this challenge by employing an accepted methodology (Chow 1998; Shay and Khattak 2007) while working within data availability constraints.

Over time, we will use the typology to explore the impacts of urban form on this suite of hydrologic outcomes and the ecosystem services that are driven by flows and fluxes of water in the urban landscape. Future work will examine residential water use outcomes between neighborhood types. Researchers will administer questionnaires will be based on the typology, to examine if water attitudes, perceptions and values differ between neighborhood types. This typology will also guide the physical implementation of biophysical research instruments. In sum, this typology will help provide a framework for establishing a water sustainability research network in this region.

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